Barrier Failure and Well Integrity Failure – Just What is a Well Failure & How Often Do They Occur? (Focus is on Groundwater)

George E. King
What Does it Take for a Producing Well To Pollute?

1. A “leak path” must be established through all the barriers in a multi-barrier system
2. The pressure at the point of the leak must be greater inside the well than outside (or an operational U-tube).
3. The viscosity of the escaping fluid must be low enough to pass through the leak path.
Barrier Failure or Well Integrity Failure

- **Single Barrier Failure => No Leak Path? => No Well Integrity Failure**
- **Unless All Barriers Fail, A Leak Cannot Not Happen**

Wells are Designed with Multiple Barriers. Number of Barriers Depends on the Hazard Level.

<table>
<thead>
<tr>
<th>ZONE</th>
<th>Hazard to Ground Water If Well Integrity Is Lost</th>
<th>Typical Number of Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above Surface</td>
<td>Low</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Fresh Water</td>
<td>Low to Moderate</td>
<td>2 to 4</td>
</tr>
<tr>
<td>Mid Depth</td>
<td>Very Low</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Deep</td>
<td>Lowest</td>
<td>1</td>
</tr>
</tbody>
</table>
How Much Cement is Needed for Isolation?
Every inch of cement is NOT required to be perfect.

Quality of cement is more important than the volume.

Isolation can only be measured with a pressure test.

Bond logs are not always best tool

- ~10% channels missed.
- Instances of false negatives.

Over 10,000 psi can be held with less than 50 ft of cement, but 200 to 300 ft is routinely used.

Source, Amoco, circa 1990's.

SPE 166142, Barrier vs. Well Failure, King
But Where You Put Cement is Even More Important

[Diagram showing different layers of the earth with pressure values and the importance of where cement is placed for gas problems vs. no gas problems.]
But Where You Put Cement is Even More Important
The Potential For Pollution is Reduced by Application of Technology.

ERA of Well Construction is More Important Than Age of the Well.

<table>
<thead>
<tr>
<th>Time Era</th>
<th>Operation Norms - Level of Technology</th>
<th>Era Potential For Pollution</th>
</tr>
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<tbody>
<tr>
<td>1830 to 1916</td>
<td>Cable Tool drilling, no cement, wells vented</td>
<td>High</td>
</tr>
<tr>
<td>1916 to 1970</td>
<td>Cementing isolation steadily improving.</td>
<td>Moderate</td>
</tr>
<tr>
<td>1930’s</td>
<td>Rotary drilling replace cable tool, BOPs</td>
<td>Moderate &amp; Lower</td>
</tr>
<tr>
<td>1952</td>
<td>Fracs reduce # wells. Better pipe &amp; cement</td>
<td>Lower from Frac aspects</td>
</tr>
<tr>
<td>1960</td>
<td>Gas tight couplings and joint make up</td>
<td>Moderate</td>
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<tr>
<td>1970</td>
<td>Cement improving, Horizontal Wells introduced</td>
<td>Lower</td>
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<tr>
<td>1988</td>
<td>Multi-frac, horizontal wells, pad drilling reducing environmental land footprint 90%</td>
<td>Lower</td>
</tr>
<tr>
<td>2005</td>
<td>Well integrity assessment, premium couplings, adding barriers &amp; cementing full strings.</td>
<td>Lower after 2008 to 2010 (STRONGER Reg Review)</td>
</tr>
<tr>
<td>2008</td>
<td>Chemical toxicity &amp; endocrine disruptors sharply reduced. Real time well integrity needs studied - early warning &amp; avoidance.</td>
<td>Lowest yet, most states caught up with design and inspection requirements.</td>
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<td>Area / Number of Wells</td>
<td>Number of construction failures</td>
<td>Barrier Fail Freq. Range (containment)</td>
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<td>Ohio / 64,830</td>
<td>74 fail initial cement test. 39 failed in production.</td>
<td>1983-2007 0.035% in 34,000 wells 0.1% in older wells – worst case.</td>
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<td>TX / 253,090</td>
<td>10 fail initial cement test. 56 failed in production.</td>
<td>0.02% all wells.</td>
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<tr>
<td>TX / 16,000 horizontal multi-frac</td>
<td>No reported failures – added barrier</td>
<td>No failure reported</td>
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<td>MT / 671</td>
<td>Salt creep crush casing</td>
<td>5.5%</td>
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<tr>
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<td>Total vent flow data</td>
<td>No separation data available</td>
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Barrier and Integrity Failures: >330,000 US wells
Focus is on groundwater pollution potential

Things That Keep Real Integrity Failures Very Low
1. Pressure inside oil wells lower than outside hydrostatic of water table (at leak point).
2. Modern wells are built with multiple barriers.
3. Cement reinforces and protects the casing. Newer cement design better.
4. Regulations are tighter now than 3 years ago.
5. Multi-Fractured horizontal wells replace 5 to 10 vertical wells in shale. Less pollution potential with fewer water table penetrations.

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<th>Number of construction failures</th>
<th>Barrier Fail Freq. Range (containment)</th>
<th>Well Integrity Failure Range (containment lost)</th>
<th>Leaks to GW by sampling</th>
<th>Data Sources</th>
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<td>74 fail initial cement test. 39 failed in production.</td>
<td>1983-2007 0.035% in 34,000 wells 0.1% in older wells – worst case.</td>
<td>0.06% for all wells 0.03% in older wells – worst case.</td>
<td>Detailed not available</td>
<td>Kell, 2011</td>
</tr>
<tr>
<td>TX / 253,090</td>
<td>10 fail initial cement test. 56 failed in production.</td>
<td>0.02% all wells.</td>
<td>0.02% (older wells to 0.004% for newer wells (vertical)</td>
<td>0.005% to 0.01% for producers 0.03% to 0.07% for injectors</td>
<td>Kell, 2011</td>
</tr>
<tr>
<td>TX / 16,000 horizontal multi-frac</td>
<td>No reported failures – added barrier</td>
<td>No failure reported</td>
<td>No failure data or pollution reports</td>
<td>No well associated pollution</td>
<td>Kell, 2011</td>
</tr>
<tr>
<td>MT / 671</td>
<td>Salt creep crush casing</td>
<td>5.5%</td>
<td>Unknown</td>
<td>None reported</td>
<td>Clegg, 1971</td>
</tr>
<tr>
<td>Alberta / 316,000</td>
<td>Total vent flow data</td>
<td>No separation data available</td>
<td>4.6% taken as worst case.</td>
<td>No data – mostly gas escape</td>
<td>Watson &amp; Bachu, 2009</td>
</tr>
</tbody>
</table>
So – What are Actual Groundwater Pollutants?

- UST – Gas & Diesel
- Septic Systems
- Landfills
- Spills
- Fertilizer
- Large Industrial Facilities
- Hazardous Waste Sites
- Animal Feedlots
- Pesticides
- Surface Impoundments
- Storage Tanks – surface
- Urban Runoff
- Salt Water Intrusion
- Mine Drainage
- Agriculture Chem. Facilities
- Pipelines & Sewer
- Shallow Inj. Wells
- Salt Storage & Road Salting
- Land application of Waste
- Irrigation Practices

EPA, 2000

Oil and Gas Wells Didn’t Make the List.
What are Groundwater Pollutants Today & Where do Oil & Gas Wells Rank?

Used Texas as a Study Case.

Over a million penetrations through the 29 major & minor aquifers in Texas.

Texas is #2 in total Groundwater withdrawals with ~ 80% going to Agriculture & Municipalities.

If the water was really polluted by O&G wells, we’d see it quickly in Municipal & Ag.
Last 12 years of Pollution Reports in Texas – Top 20 Listed - TCEQ & TGPC Database

- Gasoline (from Underground Petroleum Storage Tank)
- SVOC & VOC
- Chlorinated Solvents
- TPH (Total Petro. Hydro. Non-TRC Control
- Chloronated Mixed Materials
- Unknown
- Toxic Metals (Sb, As, Pb, Hg, Cr, Zn, etc.)
- Waste Oil
- MTBE
- Pesticides & Herbicides
- Nitrate & Nitrile
- PCB
- PAH
- Barium
- Crude Oil (transport)
- Radioactive
- Brominated & other Halogenated

Number of New Reports Per Year

2000
2006
2011

SPE 166142, Barrier vs. Well Failure, King
Legacy issues with surface pads (tanks, compressors, truck terminals, gas plants) !!!

Producin[g Wells are less than 1% of total for most years.
Failure Factors Recognized:

- **Type of Well**
- **Maintenance Culture**
- **Era of Construction**
- **Geographical Location**
- **Age of Well**
- **Design & Construction**
- **Usage Change**

Full Details in SPE 166142
## Proven Another Way - % of Produced Fluids Leaked

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of Wells</th>
<th>Type of Wells</th>
<th>Barrier Failure Freq. Range (w/ containment)</th>
<th>Integrity Failure (leak path – in or out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Gulf of Mexico</td>
<td>11,498</td>
<td>Platform based wells</td>
<td>30% overall first annulus SCP 50% of cases. 90% of strings w/ SCP have less than 1000 psi. 10% are more serious form of SCP (Wojtanowicz, 2012)</td>
<td>0.00005% to 0.0003% of prod oil spilled 1980 thru 2009.</td>
</tr>
<tr>
<td></td>
<td>(3542 active)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US Gulf of Mexico</td>
<td>4,099</td>
<td>Shoe test failures required repair</td>
<td>12% to 18% require cement repair to continue drilling</td>
<td>0 (all repaired before resuming drilling)</td>
</tr>
<tr>
<td>Norway</td>
<td>406</td>
<td>offshore</td>
<td>18%</td>
<td>0</td>
</tr>
<tr>
<td>GOM/Trinidad</td>
<td>2,120</td>
<td>Sand Control</td>
<td>0.5 to 1%</td>
<td>0% subterranean ~0.0001% via surface erosion potential</td>
</tr>
<tr>
<td>Matagorda Island 623</td>
<td>17</td>
<td>Compaction failures; casing shear &amp; sand fail</td>
<td>80% to 100% - the high number is due to high pressure and formation compaction.</td>
<td>Wells routinely shut-in and repaired prior to restart.</td>
</tr>
<tr>
<td>Sumatera</td>
<td>175</td>
<td>without maintenance</td>
<td>43%</td>
<td>1 to 4%</td>
</tr>
</tbody>
</table>

SPE 166142, Barrier vs. Well Failure, King
Gas migration >>200+ yrs. old, highly regional, many causes, 1000’s of seeps.

Common Factors in Gas Migration

Problems in methane migration control include lack of water well construction standards and water quality checks when drilled.

SPE 166142, Barrier vs. Well Failure, King
Methane Seepage from Soils

Oil & Gas Seeps are indicators of oil & gas beneath the surface

Many natural seep flows diminished as wells were drilled & produced.

Total: 4.3 Million Wells

Well Density in US & Canada

Source: IHS / HPDI

Areas of possible micro and macro seeps of methane to the surface

Source: Kevenvolden 2005, Etiope & Klusman, 2002
Comparing Spills and Seeps

Various sources – data in SPE 166142
Problems?

• Transport spills – same frequency as other chemical transport options (rail, barge, truck).

• Technology eras define the leak rates.
  – Well leaks dropped steadily from 1916 to year 2000.

• Leakage rates of modern wells often less than 0.00005% of volumes produced.

• Safest is horizontal, multi-fractured well.
  – Replaces 5 to 10 vertical wells
  – Can reduce development footprint by >90%
  – Over 1 million fracs from horizontal wells.
Some Conclusions

1. Risk of GW pollution from producing well is low.
2. Barrier failure rates and well failure rates vary widely.
3. Failure of wells of a specific time era are artifacts of that era; not reflective of wells completed today.
4. Methane gas migration from deep drilling often not connected to O&G production – check the design! Check for natural seeps.
5. Improperly plugged old wells & water wells may be conduits for methane migration.

See SPE 133456, 152596 and 166142 for more information
All available on www.OnePetro.org