Well Integrity – Basics, Prevention, Monitoring, Red Flags & Repair Options

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DOE Well Integrity Briefing
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Sources of US Total Energy Supply

- Fossil Energy is 82% of supply

- Oil: produced & imported, 36%
  - US Produced Oil
    - About 80% of US oil wells require fracturing
    - All other states: 14%
    - Alaska, Calif., OK & N.M.: 21%
    - North Dakota: 12%
    - Offshore (mostly GOM): 17%
    - Texas: 36%
- Natural Gas: 26%
- Coal: 20%
- Renewables: 9%
- Nuclear: 8%
- Deep mine coal: 30%
- Strip/open pit mine coal: 70%

Data sources: DOE, EIA
Energy Sources with Ground Disturbance Impacts or Dependencies

93% of US total energy supply is dependent on ground penetration and/or substantial subsurface stability.

- Coal: 20%
- Natural Gas: 26%
- Wind Energy: 0.9% of total energy needed
- Biofuels: 1.9% of total energy needed
- Wood: 2% of total energy needed
- Hydroelectric Power: 3.2% of total energy needed
- Nuclear: 8%
- Solar: 0.2%
- Geothermal: 0.2%
- Waste burning: 0.5%
- Marginal wells: 16%
  - Shale (oil) wells: 29%
  - Conventional wells: 55%
- About 80% of US oil wells require fracturing
- About 75% of US gas wells require fracturing

Data sources: DOE, EIA
Risk exists in every action.

What is operationally safe?

Occurrence & impact create a threat level that we can understand & accept or reject based on what we believe: hopefully on assessment of facts.

SPE 166142, Barrier vs. Well Failure, King
Basics of Well Integrity

• NORSOK Definition:
  – “Application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well”.

• Maximum challenge in stimulation?
• Maximum challenge in production?
• Plug & Abandonment – Life?
Status of the Well Integrity Issue

• How many wells leak?
• Where, why and what?
• How much do they pollute?
• What is special about leaking wells?
• What are the pathways? – route of spills?
  – 15.2 million US residential water wells (integrity?)
  – 1 million Class V injection wells (?)
  – Old wells in Northeast (no location & no records)
## Review of Well Studies: >650,000 wells

(Sources of data in SPE 166142)

<table>
<thead>
<tr>
<th>Area</th>
<th># Wells</th>
<th>Type Wells</th>
<th>Barrier Failure Freq. Range (w/contain)</th>
<th>Well Integ Freq. w/ leak path</th>
<th>Leaks to GW by sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH</td>
<td>64,830</td>
<td>D&amp;C shoe test fail (74)* Take worst case - Prod. 39</td>
<td>0.035% in (34,000 wells 1983-2007), 0.1% old wells worst</td>
<td>~0.06% (total)</td>
<td></td>
</tr>
<tr>
<td>TX</td>
<td>253,090</td>
<td>D&amp;C Failures, shoe test fail* (10) **Prod (56) fail assumed</td>
<td>0.02%</td>
<td>0.02% old era wells, 0.004% new era wells</td>
<td>0.005% to 0.01% producers 0.03% - 0.07% injector</td>
</tr>
<tr>
<td>Texas</td>
<td>16,000</td>
<td>Horizontal Multi-frac wells</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mn Cedar Creek</td>
<td>671</td>
<td>Vertical</td>
<td>5.5%</td>
<td>Unk</td>
<td></td>
</tr>
<tr>
<td>Alberta</td>
<td>316,000</td>
<td>All well types used in the study.</td>
<td>(4.6%) – unk if active leaks or single barrier fail.</td>
<td>(4.6%) – unk if active leaks or single barrier fail.</td>
<td></td>
</tr>
</tbody>
</table>

*Sources of data in SPE 166142*
## Sustained Casing Pressure

<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 with first annulus SCP of 50% of cases. 90% of strings w/ SCP have less than 1000 psi. 10% are more serious form of SCP (Wojtanowicz, 2012)</td>
<td>0.01% to 0.05% of wells leaked - 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 during drilling*</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>
Well Study Review >650,000 wells

Failure Factors Recognized:
- Type of Well
- Maintenance Culture
- Era of Construction
- Geographical Location
- Age of Well
- Specifics of Design & Construction
- Usage Change

Single barrier compromised by tubing leaks.

SPE 166142, Barrier vs. Well Failure, King
Background Context – 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.

*Image showing well density and areas of possible seeps in the United States and Canada.*
Other Context - Comparing Spills and Seeps

History –
• Drake’s 1859 well hit flowing oil at 69.5 ft.

• Hart’s 1821 Shale gas well found flowing gas at 28 ft.

• Water, Oil & Gas commonly cohabitate shallow formations in oil producing areas.
Prevention of Well Integrity Problems

• Initial planning and creating effective barriers - goal of first well construction effort - lowest cost opportunity for problem prevention.
• Adding/modifying barriers later is expensive.
• Fracturing and acidizing – What is required in well construction?
  – A place for temporary barriers.
  – Barriers that stand up to cyclic pressure.
Well Barrier Failure vs. Well Integrity Failure

- Barriers are containment elements - Can individually isolate design loads. **If one barrier fails, the next barrier accepts the load.**
- Multiple, nested barriers = redundant barrier system. **No Leak Path**
- Well integrity failure = if all barriers fail in series = leak path is formed

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Number</th>
<th>Press</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casing + Cmnt</td>
<td>2 to 7</td>
<td>Very High</td>
<td>Very High</td>
</tr>
<tr>
<td>Hanger + Seal</td>
<td>2 to 4</td>
<td>High</td>
<td>High –replace easy.</td>
</tr>
<tr>
<td>Pipe body</td>
<td>1 to 3</td>
<td>High</td>
<td>Very High w/ corros. maintenance</td>
</tr>
<tr>
<td>Packer, Plug</td>
<td>1 to 2</td>
<td>Mod.</td>
<td>Mod.</td>
</tr>
<tr>
<td>Safety Valve</td>
<td>1</td>
<td>Mod. to High</td>
<td>Mod.</td>
</tr>
<tr>
<td>Valves, Spools in Prod. Tree</td>
<td>4 to 20+, tandem?</td>
<td>Mod. to High</td>
<td>Mod- easy repair</td>
</tr>
</tbody>
</table>
Cement Every Annulus to Surface? May **NOT** be the best plan.

**Full Annulus Cementing?**

- Most full cement columns require a two-stage cement job – requires perforating or DV tool – may decrease well integrity.
- Careful positioning of cement top in inner annulus allows monitoring of pressure build-up or monitoring type of fluid flow if leaks are seen.
- Repair options increase when open annulus exists including down-squeezes & inner pipe removal.
- Placing end of casing in strong, low permeability formations increases isolation success.
- Placing salt water and fresh water zones behind different casing strings nearly eliminates potential for salt water intrusions behind the pipe.

*Note: local conditions can dictate fewer casing strings.*
Example Completion & P&A

The Completion Enables Successful P&A

SPE 170949 – Environmental Risk P&A - George King & Randy Valencia
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.
The Best “Tool” for Evaluating Cement Quality is the Pump Chart

<table>
<thead>
<tr>
<th></th>
<th>Filling surface equipment w/ fresh water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pressure test – two leaks in surface connection &amp; a successful test</td>
</tr>
<tr>
<td>2</td>
<td>Pump spacer to separate mud from cement</td>
</tr>
<tr>
<td>3</td>
<td>Constant density spacer between mud in the well and cement</td>
</tr>
<tr>
<td>4</td>
<td>Shut down to drop bottom plug &amp; switch to on-the-fly cement</td>
</tr>
<tr>
<td>5</td>
<td>Pumping cement – within density guidelines, but barely.</td>
</tr>
<tr>
<td>6</td>
<td>Cement free-fall – heavy cement pushes mud faster than vol. inj.</td>
</tr>
<tr>
<td>7</td>
<td>Cement density variance – was a special tail-in slurry used?</td>
</tr>
<tr>
<td>8</td>
<td>Shut-down to flush surface lines and drop the solid top plug.</td>
</tr>
<tr>
<td>9</td>
<td>Bottom plug lands, diaphragm ruptures &amp; cement into annulus.</td>
</tr>
<tr>
<td>10</td>
<td>Free-fall make up – more flow in than out - pressures equalizing</td>
</tr>
<tr>
<td>11</td>
<td>Cement lift pressure too low – check return volumes and timing.</td>
</tr>
<tr>
<td>12</td>
<td>Top plug “bumps” (lands in the shoe track) – placement complete.</td>
</tr>
<tr>
<td>13</td>
<td>Hold back pressure on casing if float valve fails. (not in this case).</td>
</tr>
</tbody>
</table>

![Pump Chart Diagram]
Cement Evaluation Tool – Value & Limits

Amplitude

1. Transit Time
2. Gamma Ray Log
3. Collar Locator
4. Amplitude
5. Variable Density Log

• Issues:
  • Cement must develop strength before CBL is useful (>72 hours)
  • CBL will not predict or confirm pressure isolation.
  • Properly run CBL – 90% reliable in finding channels of >10% total annular space
  • Many wells show effective isolation, even when CBL shows only 30% to 75% of bond as “good”.
  • CBL utility is determining cement presence & info on bonding across zone of investigation.
  • “Fast” formation may act like free pipe when bonding is good.
  • Cement sheaths less than ½ “ to ¾” may look unbonded even when seal is good.
  • Gas bubbles decrease signal. Void spaces increase amplitude.
  • Pipe thickness changes cause amplitude shift
  • Tool eccentricing & microannuli reduce amplitude
Conclusions from actual tests, trials & case studies is the only risk from deep well (>2000 ft) hydraulic fracturing is:

- Low risk in transport & produced water storage
- Very low risk in well construction.
- Virtually no risk in fracturing.

Monitoring Well Integrity

• The Era of construction is the first indicator of the stability of well integrity. => couplings & cement
• Is a base line set and a trend line maintained?
• Simple, regular monitoring can be inexpensive.
• Are the working limits of the asset known and strictly observed?
• Monitoring is more effective when a company has a “culture of proper maintenance”.
• Are wells P&A’d when practical value is gone? (does shut-in have a required end point?)
## Well Failures & Improvements in Development Eras

<table>
<thead>
<tr>
<th>Time Era</th>
<th>Operation Norms</th>
<th>Era Potential For Pollution</th>
</tr>
</thead>
<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>
</tr>
<tr>
<td>1970</td>
<td>Cement improving, Horizontal Wells introduced</td>
<td>Lower</td>
</tr>
<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>
</tr>
</tbody>
</table>

When evaluating well integrity, **ALWAYS** look at era of construction.

SPE 166142, Barrier vs. Well Failure, King
What are Groundwater Pollutants Today & where do oil & Gas Wells Fit in this Picture?

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.
Red Flags – Looking Into the Future

• There are very few well integrity failures that do not show signs of their approach.

• Major issues
  – Corrosion possibly creates more damage than all other failures combined.

• To predict future problems – look at the past.
  – What era of technology was the well built in?
  – What level of maintenance has the asset received?
  – Who is responsible?
Repairs

• Sequence of Outcomes:
  – Safety impact
  – Contamination impact
  – Containment issues
  – Remediation potential
  – Retribution and punishment

• Repair – methods – success
  – Convention squeeze (cement & sealer)
  – Pipe removal
  – Better initial design/application
Gas migration >>200+ yrs. Old - highly regional - many causes - 1000’s of seeps.

SPE 166142, Barrier vs. Well Failure, King
Conclusions

1. Risk of GW pollution from producing well is low.
2. Barrier failure rates and well failure rates vary widely.
3. Barriers may fail without creating a pollution pathway.
4. Failure of wells of a specific time era are artifacts of that era; not reflective of wells completed today.
5. The nation’s 15 million residential water wells may be conduits for methane migration.
Society of Petroleum Engineers

Well Integrity Symposium

- 3 potential training courses (June 1)
  - General integrity overview
  - Integrity inspection points
  - Well integrity for stimulations in new & old Wells

- 2 day symposium (June 2 & 3)