A Wellbore Integrity Study: Conventional and Unconventional Wells in Pennsylvania, 2000-2012

A. R. Ingraffea
M. T. Wells
Cornell University
R. Santoro, S. Shonkoff
Physicians, Scientists, and Engineers for Healthy Energy, Inc.

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Outline of Presentation

• Created database of inspection and violation records for over 41,000 gas and oil wells drilled in Pennsylvania since 2000

• Mined the data to identify all wells with wellbore integrity problems

• Statistically analyzed results: Cox Proportional Hazard Model

• First preliminary results presented here
“There are at least three possible mechanisms for fluid migration into the shallow drinking-water aquifers that could help explain the increased methane concentrations we observed near gas wells...A second mechanism is leaky gas-well casings...Such leaks could occur at hundreds of meters underground, with methane passing laterally and vertically through fracture systems.”

From Osborn et al. PNAS, 2011
What a “Leaky” Well Can Look Like at the Wellhead: Bubbling in the Cellar

This could be result of **cement** failure, or **casing** failure. How common are such failures in PA?
Industry well integrity outlook

- Industry will drill more wells in next decade then have been drilled in last 100 years
- Global well population is +/- 1.8 million, of which +/- 35% has sustained casing pressure
- Public awareness and concern of zonal isolation requirements is increasing (USA/Australia/Europe)
- Geothermal wells and CO2 sequestration wells are on the increase
- Subsidence is a risk in some depleting reservoirs
  Life cycle extension of aging assets is becoming a pre-requisite of legislators
- Zonal isolation challenges and assurance does need push in technology
- Abandonment of legacy wells is becoming more of a focus
- Industry collaboration is an inevitable pre-requisite on all topics
SCP=Sustained Casing Pressure. Also called sustained annular pressure, in one or more of the casing annuli.

- About 5% of wells fail soon
- More fail with age
- Most fail by maturity

Wells with SCP by age. Statistics from the United States Mineral Management Service (MMS) show the percentage of wells with SCP for wells in the outer continental shelf (OCS) area of the Gulf of Mexico, grouped by age of the wells. These data do not include wells in state waters or land locations.

Brufatto et al., *Oilfield Review*, Schlumberger, Autumn, 2003
Industry-Reported Data On Loss of Wellbore Integrity: Onshore Wells

Watson and Bachu, SPE 106817, 2009.
Leaky Well Industry Statistics

From George E King Consulting Inc.: http://gekengineering.com/id6.html
Gas leaks from shale wells rare
• Created database of inspection and violation records for over 41,000 gas and oil wells drilled in Pennsylvania since 2000
• Mined the data to identify all wells with wellbore integrity problems
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The Well Database

• The database is based on spud reports from the PADEP Office of Oil and Gas Management web page.

• Conventional and unconventional gas, oil, combined gas and oil, and coalbed methane wells spudded from 01 Jan 2000 to 31 Dec 2012: 41,381 wells

• All available compliance reports over the same time period. Reports provide data on inspection category (i.e. site, client, or facility), inspection type (e.g. administrative review, drilling, routine), inspection date, violations issued, and comments noted by the PADEP inspection staff regarding the inspection and/or violation(s) issued.

• 8,703 wells show no record of inspection; 5,223 wells with erroneous spud or inspection dates: all removed from further study

• Resulting modeled statewide dataset contains 27,455 wells and 75,505 inspections.
• Created database of inspection and violation records for over 41,000 gas and oil wells drilled in Pennsylvania since 2000
• **Mined the data** to identify all wells with wellbore integrity problems
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Integrity Problem Indicators
Search Procedure: Three Passes

• Filter database for entries in “Violation Code” or “Violation Comment” fields in inspection reports

• Filter both the “Inspection Comment” and “Violation Comment” fields for most common keywords associated with failure of primary cement/casing or common remediation measures

• Keyword filter results then human-read thoroughly to confirm an indication of impaired well integrity
### PA DEP Chapter 78 Violation Codes Used in Filter

<table>
<thead>
<tr>
<th>Violation Code (#)</th>
<th>Violation Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>78.83GRNDWTR (76)</td>
<td>Improper casing to protect fresh groundwater</td>
</tr>
<tr>
<td>78.83COALCSG (12)</td>
<td>Improper coal protective casing and cementing procedures</td>
</tr>
<tr>
<td>78.81D1 (1)</td>
<td>Failure to maintain control of anticipated gas storage reservoir pressures while drilling through reservoir or protective area</td>
</tr>
<tr>
<td>207B (11)</td>
<td>Failure to case and cement to prevent migrations into fresh groundwater</td>
</tr>
<tr>
<td>78.85 (1)</td>
<td>Inadequate, insufficient, and/or improperly installed cement</td>
</tr>
<tr>
<td>78.86 (101)</td>
<td>Failure to report defective, insufficient, or improperly cemented casing w/in 24 hours or submit plan to correct w/in 30 days</td>
</tr>
<tr>
<td>78.81D2 (4)</td>
<td>Failure to case and cement properly through storage reservoir or storage horizon</td>
</tr>
<tr>
<td>78.73A (21)</td>
<td>Operator shall prevent gas and other fluids from lower formations from entering fresh groundwater.</td>
</tr>
<tr>
<td>78.73B (81)</td>
<td>Excessive casing seat pressure</td>
</tr>
<tr>
<td>78.84 (2)</td>
<td>Insufficient casing strength, thickness, and installation equipment</td>
</tr>
<tr>
<td>209CASING (1)</td>
<td>Using inadequate casing</td>
</tr>
<tr>
<td>210NCPLUG (1)</td>
<td>Inadequate plugging of non-coal well above zones having borne gas, oil, or water</td>
</tr>
<tr>
<td>78.83A (2)</td>
<td>Diameter of bore hole not 1 inch greater than casing/casing collar diameter</td>
</tr>
<tr>
<td>210INADPLUG (1)</td>
<td>Leaking plug or failure to stop vertical flow of fluids</td>
</tr>
<tr>
<td>79.12 (2)</td>
<td>Inadequate casing/cementing in conservation well</td>
</tr>
<tr>
<td>78.82 (1)</td>
<td>Remove conductor pipe</td>
</tr>
</tbody>
</table>

(Source: PADEP (2013a))
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
<th>Keywords/phrasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Squeeze</td>
<td>Remedial cementing operation performed to repair poor primary cement jobs, repair damaged casing or liner, or isolate perforations. Any squeeze job, not related to plugging activities, is assumed to be indicator of loss of containment</td>
<td>“squeeze”, “squeeze*”, “eeze”, “perf and patch”, “perf”</td>
</tr>
<tr>
<td>Top Job</td>
<td>Remedial cementing operation used to bring cement up to surface in the event of a cement drop following primary cementing. Documented top jobs are assumed to be an indicator of loss of primary cement integrity.</td>
<td>“top job”, “topped off”, “cement drop*”, “cement fall”, “cement not to surface”</td>
</tr>
<tr>
<td>Annular Gas</td>
<td>Gas/methane detected within an annulus, whether in an annular vent or otherwise, indicates a loss of subsurface integrity. Combustible gas or lower explosive limit (LEL) readings off of vents or annuli and indications of gas detected from annular vents are assumed to indicate loss of containment.</td>
<td>“LEL”, “comb*”, “annular gas”, “annular vent”</td>
</tr>
<tr>
<td>SCP</td>
<td>Sustained Casing Pressure</td>
<td>“bubbling”, “bubbl*”, “bleed”, “bled down”</td>
</tr>
<tr>
<td>Other</td>
<td>Additional phrasing relevant to primary cement job failure or casing corrosion was also searched and assessed according to inspection history and the other information contained within each inspection’s comments.</td>
<td>“remediation”, “recement”, “cement fail*”, “casing fail*”, “casing patch”, “Improper casing”, “improper cement”, “gas migration”, “gas leak*”</td>
</tr>
</tbody>
</table>

* Indicates a wildcard search
# Wells With Indicators, Statewide

| Spud Year | Conventional Wells | | | | Unconventional Wells | | | | | | Statewide Total | | | |
|-----------|---------------------|-----|-----|-----|-------------------|-----|-----|----------------------|-----|-----|-------------------|-----|-----|
|           | Indicator | Inspected | % | | Indicator | Inspected | % | | Indicator | Inspected | % | | | |
| 2000      | 5        | 1389      | 0.40% | | 0        | 0        | 0 | | 5        | 1389      | 0.4% | | | | |
| 2001      | 10       | 1827      | 0.50% | | 0        | 0        | 0 | | 10       | 1827      | 0.5% | | | | |
| 2002      | 10       | 1564      | 0.60% | | 0        | 1        | 0 | | 10       | 1565      | 0.6% | | | | |
| 2003      | 17       | 1940      | 0.90% | | 0        | 4        | 0 | | 17       | 1944      | 0.9% | | | | |
| 2004      | 14       | 2308      | 0.60% | | 0        | 2        | 0 | | 14       | 2310      | 0.6% | | | | |
| 2005      | 22       | 2949      | 0.70% | | 0        | 6        | 0 | | 22       | 2955      | 0.7% | | | | |
| 2006      | 42       | 3307      | 1.30% | | 3        | 23       | 13.0% | | 45       | 3330      | 1.4% | | | | |
| 2007      | 28       | 3461      | 0.80% | | 2        | 83       | 2.40% | | 30       | 3544      | 0.8% | | | | |
| 2008      | 34       | 3337      | 1.00% | | 15       | 304      | 4.90% | | 49       | 3641      | 1.3% | | | | |
| 2009      | 17       | 1620      | 1.00% | | 56       | 749      | 7.50% | | 73       | 2369      | 3.1% | | | | |
| 2010      | 16       | 1345      | 1.20% | | 148      | 1532     | 9.70% | | 164      | 2877      | 5.7% | | | | |
| 2011      | 48       | 1055      | 4.50% | | 107      | 1862     | 5.70% | | 155      | 2917      | 5.3% | | | | |
| 2012      | 17       | 813       | 2.10% | | 24       | 1197     | 2.00% | | 41       | 2010      | 2.0% | | | | |
| **SUM**   | **280**  | **26915** | **1.0%** | | **355**  | **5763** | **6.2%** | | **635**  | **32678** | **1.9%** | | | | |
• Created database of inspection and violation records for over 41,000 gas and oil wells drilled in Pennsylvania since 2000

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• **Statistically analyzed results: Cox Proportional Hazard Model**

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Well Failure Rate Analysis

- **Cox Proportional Hazard Model to model well failure (hazard) rate**
- A multivariate regression technique to model the instantaneous risk of observing an event at time $t$ given that an observed case has survived to time $t$, as a function of predictive covariates.
- Well type (i.e. unconventional or conventional) and inspection counts (i.e. the number of times a well is inspected during the analysis time) are used as covariates.
- Spud year cut-off (pre- and post-2009) and geographic (i.e. county) strata are run in separate analyses.
- Inter-annual Wilcoxon statistics used to assess whether any groups of well spuds were statistically significantly different in terms of their predicted failure risk.
- **Risk of cement/casing problems for wells with incomplete inspection histories can be estimated from the behavior of wells with more complete histories.**
Comparison of Hazard Estimates for Pre- and Post-2009 Spudded Wells: Statewide Data

These plots predict, based on the cumulative histories of inspections and assuming that the risk of any one well is proportional to that in other wells, that at a given analysis time a well in a particular stratum has the indicated chance of exhibiting loss of zonal isolation.

Please Note: This chart blacked out at this time because of pending publication.
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Unconventional wells show a 58% (95%CI [47.3%, 67.2%]) higher risk of experiencing structural integrity issues relative to conventional wells.

Please Note: This chart blacked out at this time because of pending publication.
Comparison of Northeast to Non-Northeast Counties: All Wells

Bradford, Cameron, Clinton, Lycoming, Potter, Sullivan, Susquehanna, Tioga, Wayne, and Wyoming = Northeast

Please Note: This chart blacked out at this time because of pending publication
Comparison of Conventional to Unconventional Wells: Northeast Counties

Please Note: This chart blacked out at this time because of pending publication
Comparison of Northeast Counties, Pre- and Post-2009 Spuds

Please Note: This chart blacked out at this time because of pending publication
Observations and Conclusions

According to the PADEP data, at least 1.9% of 2000-2012 spudded oil and gas production wells are showing indications of structural integrity loss. However, this superficial indication comes with important caveats:

- **Publically available records indicate that the majority of older, active wells are no longer being inspected.** The actual number of pre-2009 spudded wells with leak indications is likely much larger than what is reported here.

- **The number of events reported here is dependent on the comments and violations noted in the state compliance reports.** A large proportion of the inspections without violations noted do not include inspection comments, and therefore no means of assessing the structural integrity of wells inspected. Without additional information from inspector’s comments, we must assume that the wells associated with these inspections have never experienced a cement/casing event.
Observations and Conclusions

- PADEP records indicate that of the more than 41,000 oil and gas production wells spudded over the past 13 years, **24% of conventional and 4% of unconventional well spuds have not received facility-level inspections (8,703 wells in total), or do not have inspections reported in the PADEP database.** Such inspections are not accounted for in this analysis.

- **Northeastern counties make up just 11% of the total wells spudded but 54.7% of the state’s unconventional wells and 88.8% of the indications of cement/casing events in unconventional wells.** Total structural integrity events in the northeast Pennsylvania region are 266, or approximately 52% of events statewide. **Predicted cumulative risk for all wells (unconventional and conventional) in the northeastern region is 11.6 (95% CI [9.28, 14.60]) times greater than that of wells drilled in the rest of the state.** The log-rank test for this regional difference is extremely significant (p< 0.0001).
Observations and Conclusions

The Cox Proportional Hazard predictive process predicts that:

1. At least \( \text{XX\%}^* \) of all oil and gas wells drilled statewide since 2009 will experience loss of zonal isolation.
2. At least \( \text{XX\%}^* \) of unconventional wells drilled in Northeast counties since 2009 will experience loss of zonal isolation.
3. Post-2009 unconventional wells in the Northeast counties will experience loss of zonal isolation at a higher rate than pre-2009 wells.

*Please note: This data blacked out because of pending publication
Thank You
Backup Slides for Discussion and Q&A
Abandoned Gas/Oil Wells in PA

Photos Courtesy of Laurie Barr: http://www.cardcreek.com/Other/Duke-Center-Wells/28890531_sxPNGz#l=2454762524
Industry/DEC Performance in New York: Plugging Abandoned Wells

Table 3. Summary of Plugged and Unplugged Abandoned Oil and Gas Wells

<table>
<thead>
<tr>
<th>Year</th>
<th>1994&lt;sup&gt;a&lt;/sup&gt;</th>
<th>2009&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total projects</td>
<td>61,000</td>
<td>75,000</td>
</tr>
<tr>
<td>Active wells</td>
<td>12,857</td>
<td>10,982</td>
</tr>
<tr>
<td>Abandoned wells, plugged</td>
<td>13,070</td>
<td>15,748</td>
</tr>
<tr>
<td>Abandoned wells, unplugged</td>
<td>35,000</td>
<td>48,000</td>
</tr>
<tr>
<td><strong>Total abandoned wells</strong></td>
<td><strong>48,000</strong></td>
<td><strong>64,000</strong></td>
</tr>
<tr>
<td><strong>Percentage plugged</strong></td>
<td><strong>27</strong></td>
<td><strong>25</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup>Data from STRONGER review [4] and Plugged Wells Survey [3].
<sup>b</sup>Data from 2009 DMN annual report [6], Plugged Wells Survey [3], and Table 1.

Bishop, HISTORICAL ANALYSIS OF OIL AND GAS WELL PLUGGING IN NEW YORK: IS THE REGULATORY SYSTEM WORKING?, *NEW SOLUTIONS*, 23(1) 103-116, 2013
Gas Zones Above Marcellus/Utica
John H. Williams and Dennis W. Risser, USGS
EPA Workshop, April, 2013

Kesselring No. 1
Chemung County, New York
“Methane was detected in 82% of drinking water samples, with average concentrations six times higher for homes <1 km from natural gas wells”

Vengosh et al. Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas Extraction. *PNAS 2013 110 (28)*