Wellbore Leakage Potential in CO₂ Storage or EOR

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Theresa Watson
T.L. Watson & Associates Inc.
theresa.watson@tlwatson.com

Dr. Stefan Bachu
Energy Resources Conservation Board
Stefan.Bachu@gov.ab.ca
Introduction

- Wellbore Leakage
- Shallow Leakage
- Tool Development
- Deep Leakage
- Case Studies
- Risk Analysis
Wellbore Leakage

- Wellbore leakage is separated into two distinct areas of the wellbore

- Shallow leakage generally due to poor cementing practices

- Deep leakage generally due to stimulation or perforating

- Only deep leakage is generally associated with CO$_2$

- CO$_2$ leakage in the shallow areas are due to secondary events
Example of Cement and Casing Quality in a Well in the Haynes Field, Alberta
Shallow Leakage

- Surface Casing Vent Flow
- Gas Migration
- Casing Failure
Factor with Significant Impact on Shallow Well Leakage

- Well Type (Open Hole or Cased Hole)
- Regulatory Change
- Spud Date (Historical Impacts)
- Geographic Area
- Wellbore Deviation
- Cement Top
- Cased Hole Abandonment Method
Tool Development

- **Data gathering**
  - ERCB well data
    - Depths, sizes, location, type, dates, H$_2$S/CO$_2$ levels, SCVF/GM, CF, etc.
  - Alberta Environment
    - Groundwater depth
    - Water well location

- **Database creation**
  - All data for Alberta dumped into SQL database
  - Data manipulated to calculate various fields such as; required cement top, proximity to water wells, well density, exposure to H$_2$S

- **User interface**
  - Choose a smaller subset (Spawned Database) to work with
  - Set the values to be assigned to various factors

- **Output Analysis**
  - Small database created in Access to allow for easy analysis or special manipulation of the data.
<table>
<thead>
<tr>
<th>Criteria No</th>
<th>Test Field</th>
<th>Search Criteria</th>
<th>Target Field</th>
<th>True Value</th>
<th>Default Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AbStartDate</td>
<td>BETWEEN #01/01/1995# AND #12/31/1999#</td>
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<td>5</td>
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<tr>
<td>2</td>
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<td>AbStartDate</td>
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<td>1</td>
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<td>&gt;= 244.5</td>
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<td>7</td>
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<tr>
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<td>1</td>
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<tr>
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<td>AbWithResep</td>
<td>3</td>
<td>1</td>
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<td>12</td>
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</tbody>
</table>
Factors Used in Shallow Analysis

<table>
<thead>
<tr>
<th>Factor</th>
<th>Criterion</th>
<th>Meets Criterion Value</th>
<th>Default Value</th>
</tr>
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<tbody>
<tr>
<td>Spud Date</td>
<td>1965-1990</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Abandonment Date</td>
<td>&lt;1995</td>
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<td>1</td>
</tr>
<tr>
<td>Surface Casing Size</td>
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<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Well Type</td>
<td>Cased</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Geographic Location</td>
<td>Special Test Area</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Well Total Depth</td>
<td>&gt;2500 m</td>
<td>1.5</td>
<td>1</td>
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<tr>
<td>Well Deviation</td>
<td>1.2-1.8</td>
<td>1.5</td>
<td>1</td>
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<tr>
<td>Cement to Surface</td>
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<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Cement to Surface</td>
<td>Unknown</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Additional Plug</td>
<td>No</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Additional Plug</td>
<td>Unknown</td>
<td>1.5</td>
<td>1</td>
</tr>
</tbody>
</table>
Deep Leakage

- To adjacent zones
- To groundwater
- To atmosphere
Deep Leakage

Figure 1 Deep Saline Aquifer Storage: No wellbores

Figure 2 Deep Saline Aquifer Storage

Figure 3 Depleted Hydrocarbon Reservoir
Deep Leakage Factors

- Stimulation
- Perforated intervals
- Abandonment mode
- Cement type
Stimulation and Perforating

Potential to create pathways in wellbore cement during perforating, acidizing or fracturing.

High pressure fracturing may also affect zonal isolation near the wellbore within the reservoir itself.

Multiple perforated intervals may increase the potential for cement sheath damage as well as provide leak pathways within the wellbore for zone to zone communication.

Photograph courtesy of Halliburton Energy Services
Zonal Abandonment

- Cement plug set across perforations.
- Cement squeeze with retainer to perforations.
- Bridge plug capped with 8 meters of cement.
Zonal Abandonment Failure

- Casing
- Cement
- Rock
- Cement Cap

Bridge plug with nitrile sealing element between cast iron slips.

Infiltrating CO₂
Cement Type

One year degradation of neat class H cement

Data and photograph courtesy Barbara Kutchko, DOE
# Deep Leakage Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Criterion</th>
<th>Meets Criterion Value</th>
<th>Default Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture count</td>
<td>=1</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Fracture count</td>
<td>&gt;1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Acid count</td>
<td>=1</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>Acid count</td>
<td>=2</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>Acid count</td>
<td>&gt;2</td>
<td>1.5</td>
<td>1</td>
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<tr>
<td>Perforations</td>
<td>count&gt;1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Abandonment type</td>
<td>Bridge Plug</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Abandonment type</td>
<td>Not abandoned</td>
<td>2</td>
<td>1</td>
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</tbody>
</table>

**Cement types and values.**

<table>
<thead>
<tr>
<th>Cement Type</th>
<th>Assigned Value</th>
<th>Description</th>
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<tbody>
<tr>
<td>1:1 POZ MIX</td>
<td>1</td>
<td>Cement and fly ash</td>
</tr>
<tr>
<td>1:1:# POZ</td>
<td>3</td>
<td>Cement, fly ash and various quantities of bentonite</td>
</tr>
<tr>
<td>BLACKGOLD</td>
<td>1</td>
<td>Unknown</td>
</tr>
<tr>
<td>CAP (NEAT)</td>
<td>1</td>
<td>Cap pumped on top of foam cement, not applicable.</td>
</tr>
<tr>
<td>CLASS X NEAT</td>
<td>1</td>
<td>Various neat cements</td>
</tr>
<tr>
<td>FILL ECP</td>
<td>1</td>
<td>Cement to fill annular packer, not applicable</td>
</tr>
<tr>
<td>FOAMED</td>
<td>1</td>
<td>Cement foamed with nitrogen</td>
</tr>
<tr>
<td>G + # PC SALT</td>
<td>1</td>
<td>Cement with various percent salt additive</td>
</tr>
<tr>
<td>G + # PC SAND</td>
<td>1</td>
<td>Cement with various percent silica sand additive</td>
</tr>
<tr>
<td>GPSL/GPCEM/THX</td>
<td>3</td>
<td>Gypsum and gel additives</td>
</tr>
<tr>
<td>LIGHT WEIGHT</td>
<td>3</td>
<td>Assumed gel additive to reduce density</td>
</tr>
<tr>
<td>SELF STRESS</td>
<td>3</td>
<td>No cement, hole allowed to slough in on casing</td>
</tr>
<tr>
<td>SLAG</td>
<td>1</td>
<td>Blast furnace slag, reduces cement porosity</td>
</tr>
<tr>
<td>SLOTTED LINER</td>
<td>3</td>
<td>No cement</td>
</tr>
<tr>
<td>SLURRY 6D</td>
<td>1</td>
<td>Unknown</td>
</tr>
<tr>
<td>TAPERED CASING</td>
<td>3</td>
<td>No cement</td>
</tr>
<tr>
<td>TH CEM/CEM FNDU</td>
<td>1</td>
<td>Thermal cement, usually sand or silica additive</td>
</tr>
<tr>
<td>UNCEM CSG/LINER</td>
<td>3</td>
<td>No cement</td>
</tr>
</tbody>
</table>
Scores

<table>
<thead>
<tr>
<th>Shallow leak potential.</th>
<th>Deep leak potential.</th>
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<tbody>
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<td><strong>Shallow Leak Potential (SLP)</strong></td>
<td><strong>Deep Leak Potential (DLP)</strong></td>
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<tr>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>&lt;2</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>2-6</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>6-10</td>
</tr>
<tr>
<td>Extreme</td>
<td>Extreme</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

SLP = v(spud date) X v(aban date) X v(SC size) X v(well type) X v(location) X v(TD) X v(dev) X v(cement top) X v(additional plugs)

DLS= v(fracture count) X v(acid count) X v(perforated interval count) X v(aban type) X v(cement type)
Case Studies

Field data and results summary.

<table>
<thead>
<tr>
<th></th>
<th>Pembina</th>
<th>Zama</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cased wells</td>
<td>9860</td>
<td>607</td>
</tr>
<tr>
<td>Number of wells drilled and abandoned</td>
<td>1050</td>
<td>106</td>
</tr>
<tr>
<td>% of wells with cement data</td>
<td>40%</td>
<td>64%</td>
</tr>
<tr>
<td>% of wells with high DLP cement score</td>
<td>28%</td>
<td>20%</td>
</tr>
<tr>
<td>% of wells fractured</td>
<td>75%</td>
<td>2%</td>
</tr>
<tr>
<td>% of wells acidized</td>
<td>47%</td>
<td>80%</td>
</tr>
<tr>
<td>% of wells abandoned</td>
<td>12%</td>
<td>13%</td>
</tr>
<tr>
<td>% of wells with multiple completions</td>
<td>11%</td>
<td>55%</td>
</tr>
<tr>
<td>% of wells with extreme DLP</td>
<td>14%</td>
<td>28%</td>
</tr>
<tr>
<td>% of wells with extreme SLP</td>
<td>7%</td>
<td>18%</td>
</tr>
<tr>
<td>% of wells with extreme SLP and DLP</td>
<td>1.6%</td>
<td>4.3%</td>
</tr>
</tbody>
</table>
Zama Deep Leakage Potential

The graph shows the distribution of wells with different DLP scores. The x-axis represents the DLP score, while the y-axis shows the number of wells with a specific DLP score. The bars indicate the number of wells in each score category: Low, Medium, High, and Extreme.
Zama Shallow Leakage Potential

Number of Wells with SLP Score

SLP Score

Low
Medium
High
Extreme
Pembina Deep Leakage Potential

Number of Wells with DLP Score

DLP Score

0 5 10 15 20 25 30+

Low Medium High Extreme

Energy Resources Conservation Board
Pembina Shallow Leakage Potential

![Graph showing the number of wells with different SLP scores]

- **Low**
- **Medium**
- **High**
- **Extreme**

![Map highlighting areas with different SLP scores]
Potential Risk

- Groundwater exposure
- Proximity to groundwater well
- Proximity to other oil and gas wells
- Toxic gas release
- Encroaching population
Increase in Water Wells Associated with Population Increase

An increase in the number of water wells increases the likelihood that gas, due to migration through shallow zones, can accumulate in buildings.
Deep Leakage to Surface and Groundwater in Central Alberta
Increasing Wellbores

It is estimated that there will be 959,000 wells in the province by 2056 compared to 343,000 in 2006.
Wellbore Strike by Farming Equipment
Toxic Gas Release

• The program calculates which wells penetrate horizons that contain $\text{H}_2\text{S}$. 
• This information can be used in conjunction with the potential for leakage to determine the risk to a population in the event of a leak from the well.
Urban Encroachment

Population growth by expanding urban centres
Population Growth

Population is expected to increase from 3,000,000 to almost 6,000,00 people by 2056. This growth will take place in the large urban centres such as Calgary, Edmonton, Red Deer etc.
Wellbore Strike during Development
Conclusions

• The development of this tool provides the ability to evaluate large numbers of wells on a first pass look.
• Will enable operators/regulators to zoom in on wells or areas with high potential for leakage.
• Can be used to determine risk, not only due to CO$_2$ but also other toxic gas releases.
• More work needs to be done to verify the factors that contribute to deep well leakage.