Performance Analysis of Engineered Liner Systems used to Store Saline Fluids in the Canadian O&G Industry: Physical and Environmental Influences

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Recent Study completed by Higher Ground Consulting entitled: “Performance Analysis of Engineered Liner Systems Used to Store Saline Fluids in the Canadian Oil and Gas Industry: Physical and Environmental Influences” By Rich MacDonald, Wes Ferris and Amanda Klimchuk (August 2016)

Study Commissioned by:
- Petroleum Technology Alliance Canada (PTAC) under the Alberta Upstream Petroleum Research Fund (AUPRF)
- BC Oil and Gas Research and Innovation Society (BC OGRIS) and
- Technical Champion Progress Energy.
Topic of Discussion

- Instigated by recent high profile pond failures in Shale Gas Regions

- Industry coming together and trying to assess:
  - are we, as industry, missing something here?
  - More specifically... is there something unique to these facilities that is contributing to these failures from a liner material selection stand-point or maybe a construction, operational, environmental or chemical standpoint?

- Study intended to bridge knowledge gaps between owners, operators, engineers, manufacturers and researchers
Cost Impacts - 30,000 m³ Pond Illustration

• Summary of relative costs associated with a theoretical 30,000 m³ pond in Western Canada
• Includes capital civil costs only, excludes owners costs, impacts to operations, and damage to relationships with the public and regulators associated with a pond failure
• Costs are for relative comparison purposes only, not intended for project estimating

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Pond Construction</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>Decommissioning Costs for Minor Liner Repairs</td>
<td>$100,000</td>
</tr>
<tr>
<td>Pond Repairs and/or Minor to Moderate Rehabilitation</td>
<td>$100,000 to $2,000,000</td>
</tr>
<tr>
<td>Pond Reconstruction (Major)</td>
<td>$4,600,000</td>
</tr>
<tr>
<td>Environmental Remediation</td>
<td>$50,000 to &gt;$1,250,000</td>
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Scope of Study

- Regulatory Framework in Western Canada
- Investigate the performance of engineered liner systems used in the storage of saline fluids
- Investigate the impacts of the following:
  - Liner Material Selection
  - Construction Techniques
  - Environmental Conditions
  - Operational Techniques
Study Methodology

- Literature review - journal articles, government symposiums and publications, white papers
- Interviews with Regulators - AER and OGC
- Interviews with O&G Operators - Shell, ConocoPhillips, Progress, etc
- Interviews with liner suppliers and installers - like Layfield Plastics, and Engineered Containment Inc (ECI)
- Interviews with specialists and academic researchers such as Dr. Kerry Rowe at Queens University and Material Testing Lab Sageous (CTT)
- Case Studies on 4 pond failures in Western Canadian O&G
Regulatory Framework for Saline Storage in BC for O&G

*Generally speaking ... the term “Saline” refers to water >4,000 mg/L TDS but this varies by jurisdiction*

- **Management of Saline Fluids for Hydraulic Fracturing Guideline, Version 1.1 (OGC 2016)** - The OGC has recently developed and issued a detailed guideline for how to site, design, construct and operate saline ponds, includes:
  - Cover both “temporary” and “permanent” and
  - Covers both below ground storage (i.e. ponds) and above ground storage (i.e. AWSS aka “C-rings”)
  - Liner Requirements
  - Requirement of Professional Engineer for design and construction oversight
  - a geotechnical investigation
  - it must include a double lined system complete with a leak detection system, waterfowl mitigation, a sub-drain system, and site fencing.

- **Monitoring Requirements**
- **Leakage Allowances**
- **Saline Water Storage Ponds ARE NOT dams in BC and are not subject to Dam regs....**
Regulatory Framework for Saline Water Storage in AB for O&G

- In Alberta,...regulations are not so simple...
- For “Temporary” Storage of Saline Fluids (3 months - 1 year):
  - Directive 055—Addendum: Interim Requirements for Aboveground Synthetically-Lined Wall Storage Systems (AWSS’s), Updates to Liner Requirements, and Optional Diking Requirements for Single-Walled Aboveground Storage Tanks
- For “Permanent” Storage (>1 year) of saline fluids, you need to consider a number of documents and regulations, including:
  - New Oilfield Waste Management Application Requirements Checklist
  - Alberta Dam and Canal Safety Regulations (1999) (if you meet the criteria of a dam i.e. >2.5m high berm and >30,000 m³)
  - Alberta Water Act
  - Guideline for Alberta Brine Storage Reservoirs (March 1978)
- AER has initiated work on Regulatory Tool for Storage of Re-used and Recycled Fluids (ie. Saline Water)
Several geosynthetic materials are used in pond construction and operation:

- Geotextiles (filter and protection)
- Geonet (fluid transport)
- Geocomposite (combination of geonet bonded to 1 or 2 layers of geotextile)
- Geomembrane (fluid containment, also referred to as “liner” or “plastic”)

![Diagram of pond construction materials](image)
Liner Types

- Multiple liner types were assessed as part of this study:
  - Medium Density Polyethylene (MDPE) and High Density Polyethylene (HDPE) liners
  - Linear Low Density Polyethylene (LLDPE)
  - Polyurea (PUR) - spray applied
  - Polypropylene (PP)
  - Bituminous Geomembranes (BGM)
  - Geosynthetic Clay Liner (GCL)

- Review of the most common liners used (HDPE, LLDPE)
Liner Materials - High Density Polyethylene (HDPE)

Pros:
• Readily available
• Long design life
• Quality of welding is good
• Excellent chemical resistance and toughness

Cons:
• Semi-crystalline (low ductility)
• More rigid and installation can be difficult
• Lower resistance to stress cracking
Liner Materials - Linear Low Density Polyethylene (LLDPE)

Pros:
• Readily available
• More flexible, can elongate and deform better than HDPE
• Quality of welding is good

Cons:
• Higher flexibility but still plastic deformation
• Lower chemical resistance
Other Liners

Other liners were evaluated however omitted from this presentation due to various reasons:

- **Poly Urea - Spray applied**
  - Very flexible and durable but costly

- **Geosynthetic Clay Liner (GCL)**
  - Regulations do not currently allow for use as primary or secondary containment
  - Has self-healing benefit

- **Polypropylene (PP)**
  - Limited by chemical resistance and lack of research regarding saline pond applications, no clear advantage over HDPE or LLDPE

- **Bituminous Geomembranes (BGM)**
  - Limited availability, cost prohibitive, lack of studies / history in saline water storage applications

Option to combine liner types in liner system e.g. primary HDPE (for chemical resistance) and secondary LLDPE (for ductility)
What does this all mean?

- There is no such thing as the “best” liner
- There is only the most applicable liner for your application considering:
  - Material being stored - chemistry, temperature, etc
  - Subgrade conditions
  - Environmental conditions - UV, ambient temp, etc
  - Design life
- You want to carefully evaluate these various factors when determining liner selection
But containment is not just the liner...

- Peggs (2013) describes the durability of your containment system to be a function of:
  - Internal factors (i.e. The “liner”):
    - The stress crack resistance of the resin used
    - The ability of the manufacturer to produce a consistent homogenous material with a minimum number of internal and surface flaws and with effective antioxidant additives
    - Shear and peel stress resistance at overheated seams
  - External factors (i.e. everything outside of the “liner”):
    - Knowledge of the designer selecting and specifying the most appropriate liner material for the application
    - Subgrade quality - i.e. The smoothness and uniformity of the subgrade.
    - The quality of the installation - lack of excessive wrinkles, intimate contact with sub grade, minimal seams, penetrations (preferably none), extrusion welding and minimal sheet stress on slopes
    - Appropriate Construction QA
    - Minimizing damage from on-going operations
But what is a Liner Failure anyway? Don’t all liners leak?

- No liner is truly “impermeable” but leakage can be managed to an acceptable level of risk with the right design, operation and monitoring.

- We defined failure as leakage through the primary liner above the Action Leakage Rate (ALR), which is about two holes per hectare each with a diameter of 2 mm (Giroud et al, 1992).

- We need to think about the entire containment system as a whole, not just the liner material.
Modes Liner Failure - when liner fails, how does it fail?

- **Modes of liner failure:**
  - **Physical/ Mechanical Damage** - subgrade settlement, punctures from dropped tools/ equipment, tension (i.e not enough slack) etc
  - **Welding deficiencies** - The strength of the weld depends on temp of the material, heating time, degree of mixing in the melt flow and absence of impurities (such as moisture) as welding involves locally heating. **Workmanship is important!**
  - **Stress Cracking** - a brittle cracking phenomenon that occurs at stress lower than the short-term yield strength of the material.
  - **Chemical Degradation** - surfactants and propants may create issues for liner. Immersion testing seems to indicate it is generally not an issue for most frac water but each chemical is different.
  - **Thermal Degradation** - above 60C could be an issue
  - **UV Degradation** - less of an issue for most liners in our latitudes
Environmental Stress Cracking

- Stress Cracking often occurs at the heat effected zone
- Heat effected zone is not tested in typical air channel testing of wedge welds
- Study indicates this phenomenon may be exacerbated by cold temps
Environmental Stress Cracking

Heat Effected Zone

Typical Hot Wedge Double Track Fusion Weld

Not to scale
The Importance of Construction QA

- Forget et al. (2005) looked at more than 89 projects and determined that projects using a rigorous CQA program had very low leak densities (an average of 4 leaks per hectare).

- For ponds constructed without CQA program, an average leak density of 22 leaks per hectare was calculated!
Root Causes of Liner Failures based on findings:

- Siting that does not identify or avoid geotechnical hazards such as shallow bedrock, high permeable soils, groundwater, or unstable slopes
- Inadequate Engineering design - eg. converted borrow pits
- Inadequate groundwater control - creating liner floatation
- Inadequate moisture control and compaction of earthworks during construction
- Inappropriate selection of liner material
- deficiencies of workmanship in the field seaming process - often related to cold weather conditions
- Insufficient on-site QA/QC during construction
- Physical damage to liners cause by equipment and human traffic prior to commission or during operation
Pre-commissioning Leak Detection Surveys
..the last line of defence

- Pre-Commissioning Quality Assurance → test completed on liner-in-place

- Typical Options include:
  - Spark testing
  - Electrical Leak Location Surveys
  - Acoustic Leak Surveys
  - Pre-installed geomembrane monitoring systems
Spark Testing

- conductive liner is used and spark is used to test installed membrane for defects. Use charged wand to scan liner and look for defect in liner.

Pros:
- Material and equipment readily available
- Technology has been used for last 20 years and well established

Cons:
- Liner is 20% more expensive
- Additional welding
- Weather impacts effectiveness of spark test
- Only one liner layer can be tested at one time
- Higher carbon black, therefore more brittle, therefore more susceptible to stress cracking
Electrical Leak Location Surveys

Electrical Leak Location Surveys - one electrode placed in water above liner and one below. Charge is applied and current will flow if there is a leak.

- **Pros:**
  - Accurate and consistent at finding leaks
  - Established technology
  - Relatively low cost
  - Can be used on any liner poly material

- **Cons:**
  - You need to fill pond with water!
  - Only test where you fill water to
  - Only test upper-most membrane
  - Weather impacts effectiveness

Source: Layfield - Leak Location Overview Presentation, 2016
Vacuum Acoustic Leak Surveys

Vacuum Acoustic Leak Surveys - vacuum is placed on liner interstitial space and sound signature of air being pulled through defect can be detected.

- **Pros:**
  - Relatively low cost
  - Can be used on any liner material
  - No water is needed
  - Can detect leaks in primary and secondary liners!

- **Cons:**
  - Cannot have any water above liner or in interstitial space
  - Need to weld the entire perimeter of the liners together

Source: Layfield - Leak Location Overview Presentation, 2016
Pre-Installed Leak Monitoring Systems

Pre-installed Geomembrane Monitoring Systems - install a grid based sensors in interstitial space to actively monitor potential leakage during operations

- **Pros:**
  - Can alert pond during operations of a leak and determine it’s location
  - Can be tied into SCADA and alert send out alarm via cell phone
  - Has been used successfully on Class 1 Landfills

- **Cons:**
  - High capital costs
  - Minimal vendors - specialized
  - One system required for each line layer
Conclusions and Wrap-up

Risks of Liner failure can be mitigated by:

- Allowing adequate schedule and budget for site selection and geotechnical investigations
- Having a detailed pond design, completed by engineers experienced in the design, construction and operation of lined containment ponds
- Properly selecting the materials, products and components of the liner system
- Avoiding winter construction
- Implementing a QA/QC program that includes appropriately qualified contractors and an experienced QA team
- Including pre-commissioning leak detection surveys
- Developing and following appropriate operating and monitoring procedures

*An Ounce of Prevention is worth a pond of Cure!*
Acknowledgements

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- BC Oil and Gas Commission (BCOGC)
- Alberta Energy Regulator (AER)
- British Columbia Oil and Gas Commission (OGC)
- Shell Canada Limited
- Canbriam Energy Inc.
- Tourmaline Oil Corp.
- ConocoPhillips
- Encana Corporation
- Engineered Containment Inc
- Layfield Environmental Containment
- Dr. Kerry Rowe, Queens University
- Sageous at CTT Group
- Trireme Consulting Inc.
Higher Ground Consulting

- HGC was formed in 2013 with a focus on Civil/ Geotech Engineering space and changing the EPC status quo
- HGC’s mantra... “Reducing Risk and Increasing Trust with Earth, Waste and Water Projects in the O&G Industry”
- Expertise and Services:
  - Containment Structures - Lined Ponds, Landfills, Freshwater Ponds, Dams/ Reservoirs
  - Dam Assessments
  - Water Storage Licencing
  - Drainage and Stormwater management
  - Site Investigation - Geotech, Hydrogeological and Environmental
  - Capital Cost Estimating
  - Detailed Engineering and Procurement support
  - On-Site QA/QC

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Questions?

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