Barrier systems advances and challenges for protecting the environment from contamination

R. Kerry Rowe OC

Barrington Batchelor Distinguished University Professor and
Canada Research Chair in Geotechnical and Geoenvironmental Engineering

The GeoEngineering Centre at Queen's-RMC

Queen's University
Kingston
Canada
www.geoeng.ca

20:00 [25:00]

1

For a barrier system to protect the environment from contamination, the liner design

must address three challenges. It must:

1. limit leakage (fluid escape) to an acceptable level.
2. have a service life > design life. Remember: after it is built it is hard to change its service life.
3. be suitable for the environment in which it must function and accommodate changes in that environment for its design life.

2

Topics in This Talk

Service life of HDPE

A framework for selection of a GMB

Estimating Service Life of GMBs

Topics in Next Talk

Factors in selection of the type of geomembrane

Bituminous geomembranes and HDPE

LLDPE and HDPE

The many faces of HDPE

3

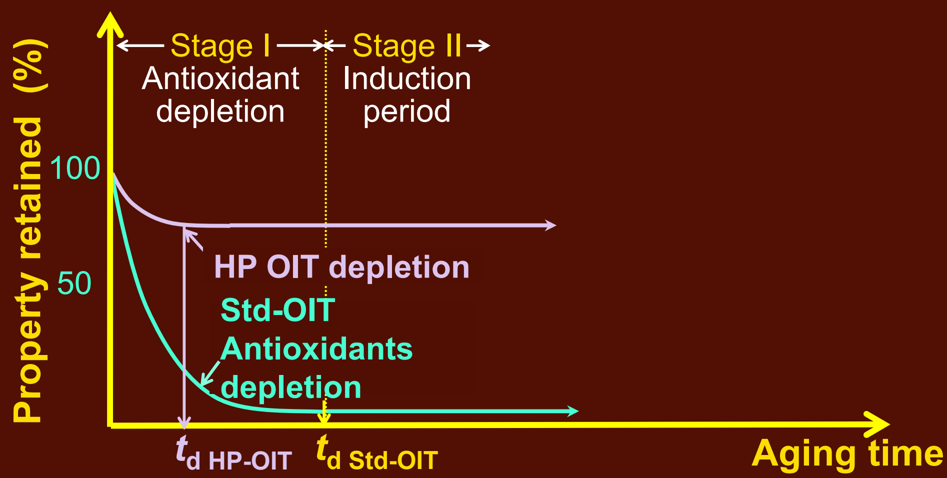
What is in a high density polyethylene (HDPE) geomembrane (GMB)

Usually:

- medium density polyethylene resin (~96-97%)
- antioxidant and stabilizer package (0.5-1%) (several chemical groups)
- additives (2-3%) carbon black and special chemicals

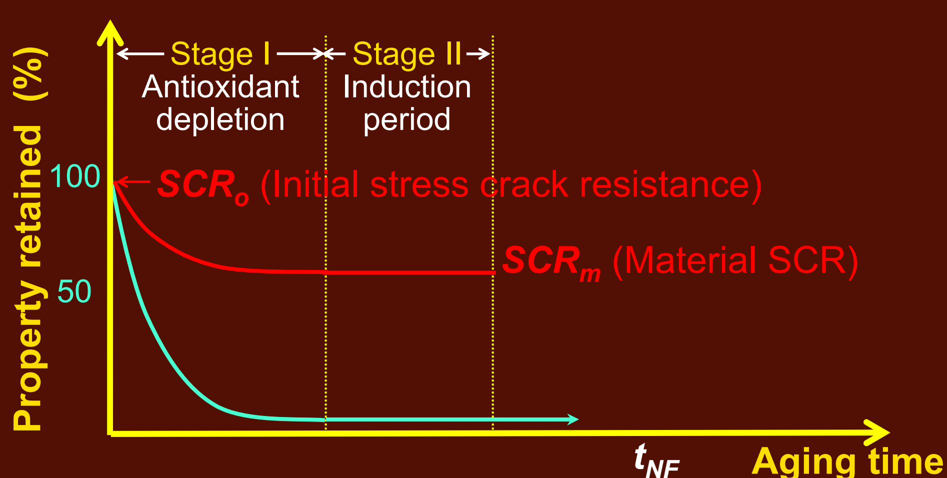
4

Stages in the life of a geomembrane Thermo-oxidative degradation



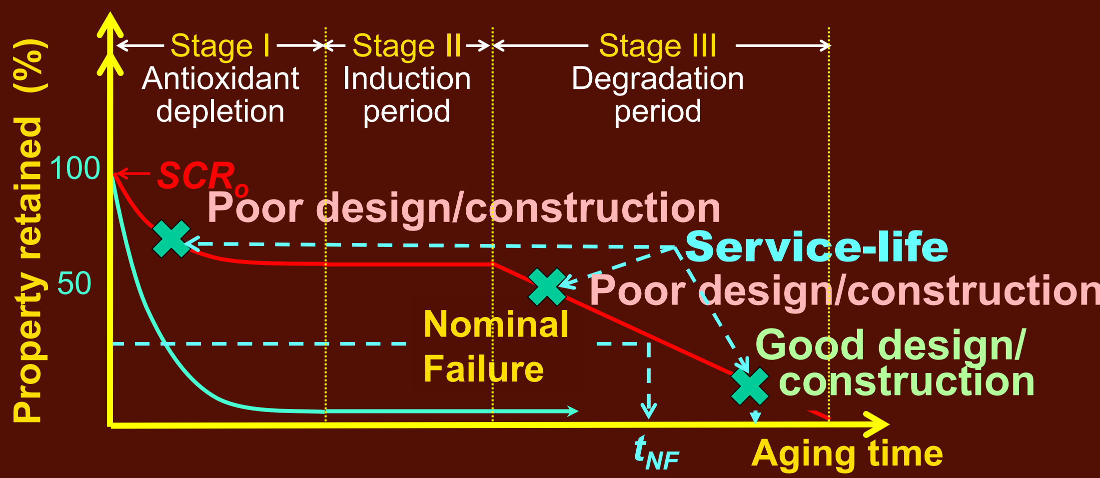
5

Stages in the life of a geomembrane Degradation in Stress Crack Resistance



6

Stages in the life of a geomembrane Degradation in Stress Crack Resistance



7

What is end of life (service-life) for a geomembrane (GMB)?

When it no longer serves its original design function: i.e., when it has sufficient number/size of holes (ruptures) to allow excessive fluid loss

61 holes in 0.6m dia.
2.2 million holes/ha

Ewais et al. (2014)

8

The Questions

- How can the current (2023) knowledge of geomembrane (GMB) performance be used for selecting a GMB for a specific project?
- How do GMBs products with different characteristics interact with different incubation media.
- If we do not have the privilege of testing candidate GMB for 5 or 10 years before deployment in the field then:
  - What is the best geomembrane (GMB) for my application?

  and
  - Will the geomembrane last for the design life of the facility?

9

Topics in This Talk

Service life of HDPE

A framework for selection of GMB

Estimating Service Life of GMBs

Topics in This Talk

Factors in selection of the type of geomembrane

Bituminous geomembranes and HDPE

LLDPE and HDPE

The many faces of HDPE

10

A framework for selection of GMB

- A framework for selecting a GMB for challenging design requirements based on testing in a reasonable time period (Rowe et al. 2020)

  - Need to select a preferred GMB from candidates

  - Need some confidence that the GMB will:
    1. Meet required design-life (e.g., 20 years in a pond, 550 years for LLW, or 2000 years for tailings), and
    2. Have the durability to resist the site-specific exposure conditions (high or low pH; surfactants)

11

1-Design Specification to ensure liner longevity

Establish

- The nature of the material above and below the geomembrane
- Chemistry of mining fluid to be contained
- Likely operating temperature, and
- Desired service life

To guide the choice of candidate GMBs

12

2-Select the Candidate GMBs

- Advising manufacturers of the design requirements and exposure conditions and seeking their proposed candidate GMBs.
- Selecting multiple candidate GMBs for testing. For example:
- 5 GMBs from 3 manufacturers
- 25 GMBs from 5 manufacturers are selected for testing.

13

3- Select your leachate

What do you know about chemistry of fluid in contact with the mine waste?

- pH – is important
- total dissolved solids (TDS)
- surfactants, foaming or anti-foaming agents, flocculants etc, ? these can be significant
- primary constituents
- trace metals?
- any health and safety issues?

Note water is not always benign:

- Reverse osmosis water
- Chlorinated water

May be as aggressive or more aggressive than your mining fluid

14

4-Evaluation of the Candidate GMBs

A-Index Properties

Characteristic reflected	Property	Specification	Candidate GMBs				
		GRI-GM13 (2021)	xTB	xTD**	zTA	yTA**	yTB
Antioxidant & stabilizer package	Std-OIT (min)	100	285	220	185	165	165
	HP-OIT (min)	400	960	705	1920	800	915
Resin	SCR_o (hr)	500	1630	805	665	1500	350

** Conductive

Rowe et al. (2020)

15

4-Evaluation of the Candidate GMBs

But we still need to answer 2 Questions:

1. Are they all satisfactory for the design life?
2. Which is/are best?

The initial index properties really do not help much in answering these questions:

16

4-Evaluation of the Candidate GMBs

B-Performance Tests

Need to immerse candidate GMBs in:

- **Solution(s) representative of expected exposure conditions (chemical)** over a range of temperatures (85, 75, 65 and 55^{o}C; 40^{o}C good for long-term studies)
- **Reference solution:** allows performance comparison with GMBs having a much longer history of exposure (e.g., MSW L3, High or low pH mining solution)
- **Reference GMB:** allows performance comparison with GMBs having a much longer history of exposure

17

Immersion testing?

Immersion in leachate @ different temperatures: exposure - both sides

Jar with specimens

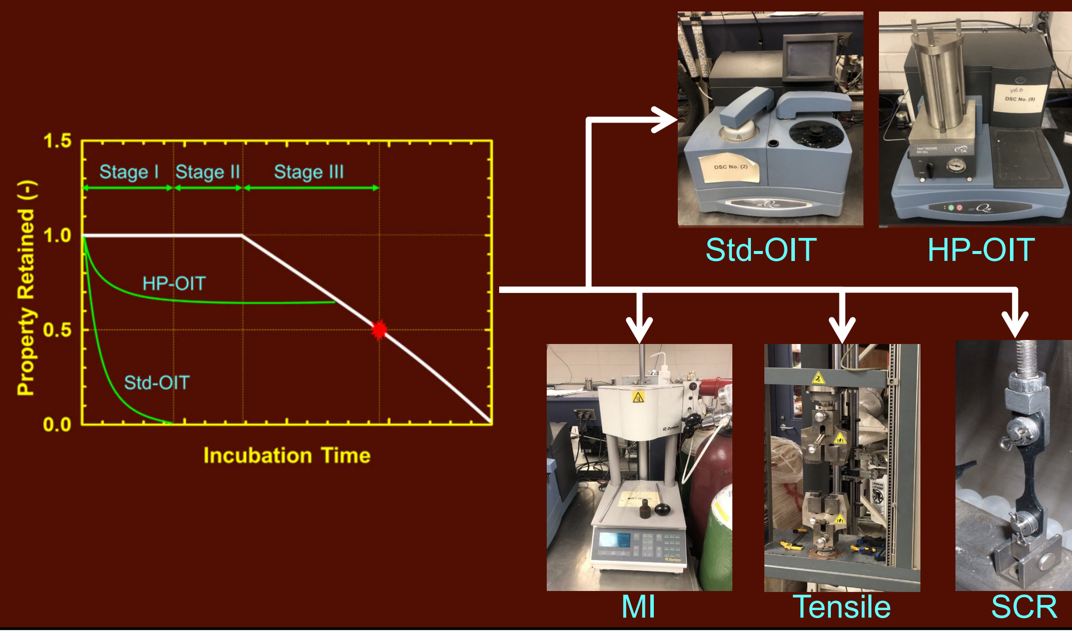
Jar with specimens in leachate

Reference Solution

Representative Solutions

18

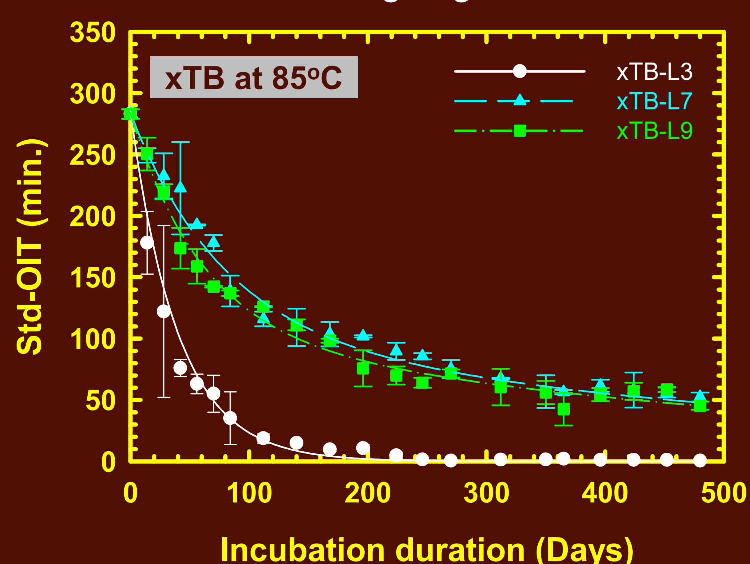
Assessment of Degradation



19

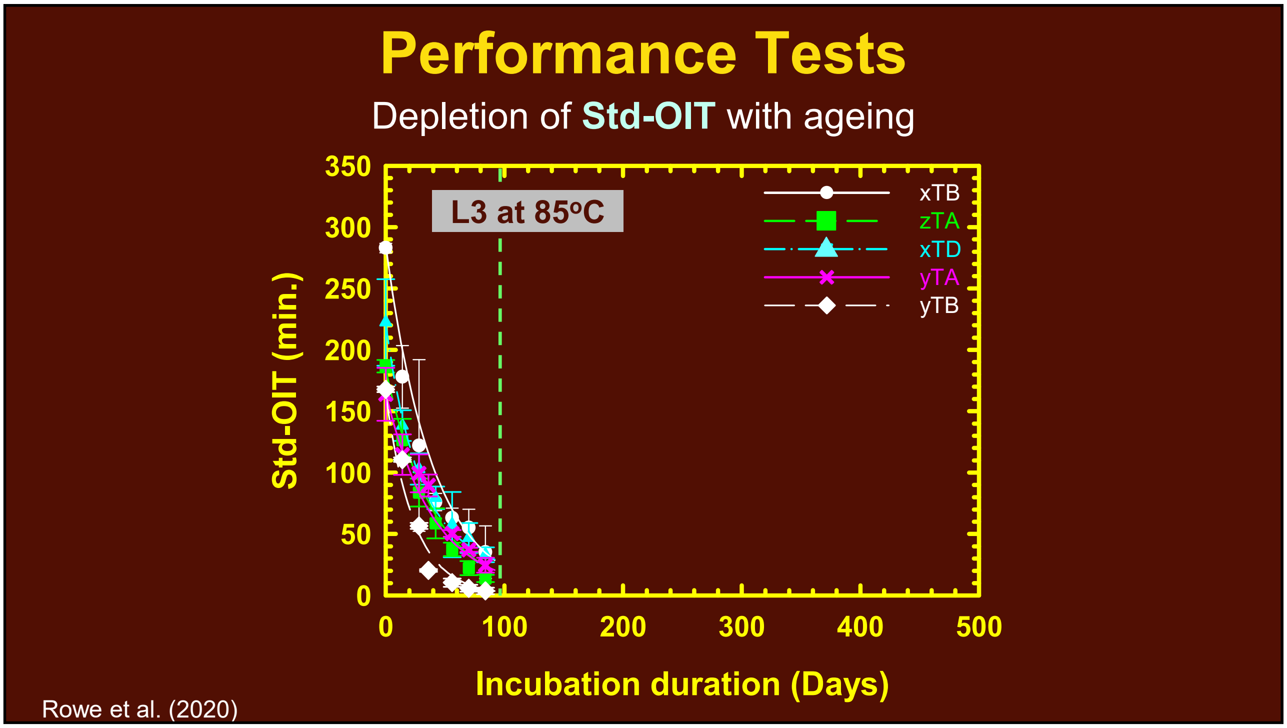
Performance Tests

Depletion of **Std-OIT** with ageing in **different solutions**

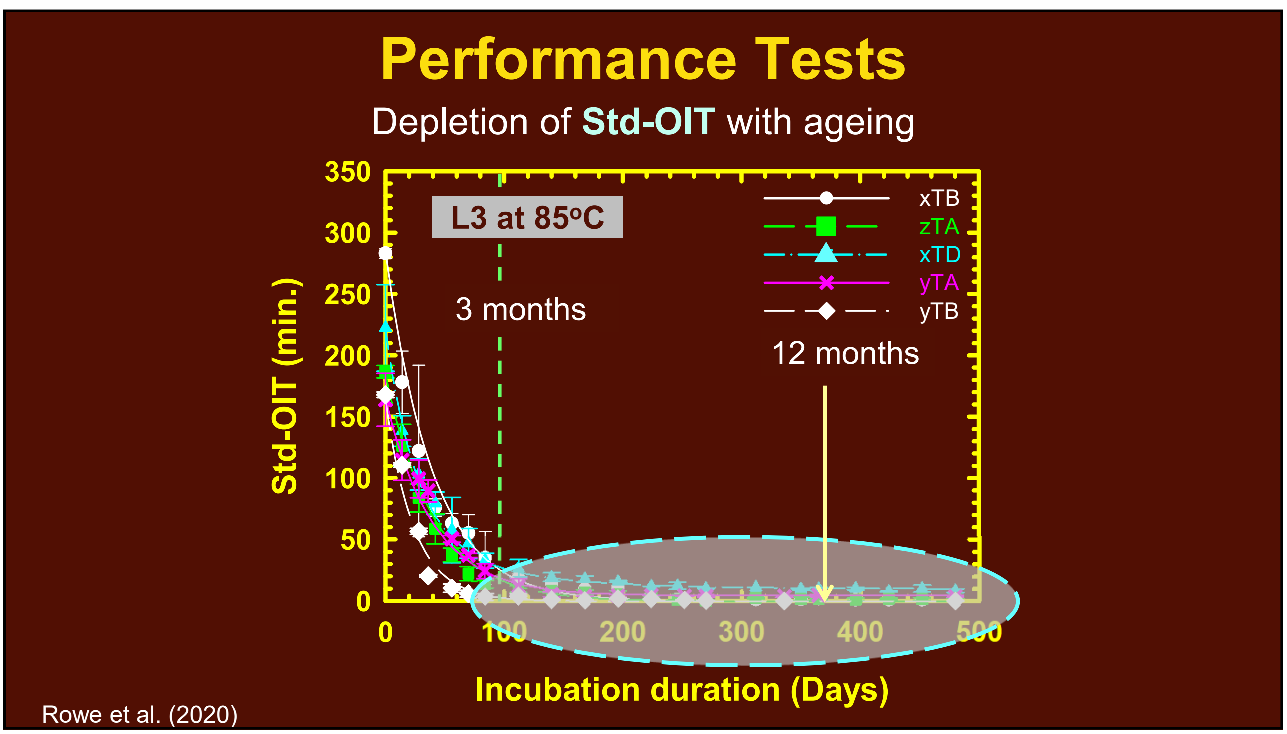


Rowe et al. (2020)

20


Performance Tests
Depletion of Std-OIT with ageing
L3 at 85°C
xTB
zTA
xTD
yTA
yTB
Std-OIT (min.)
Incubation duration (Days)
Rowe et al. (2020)

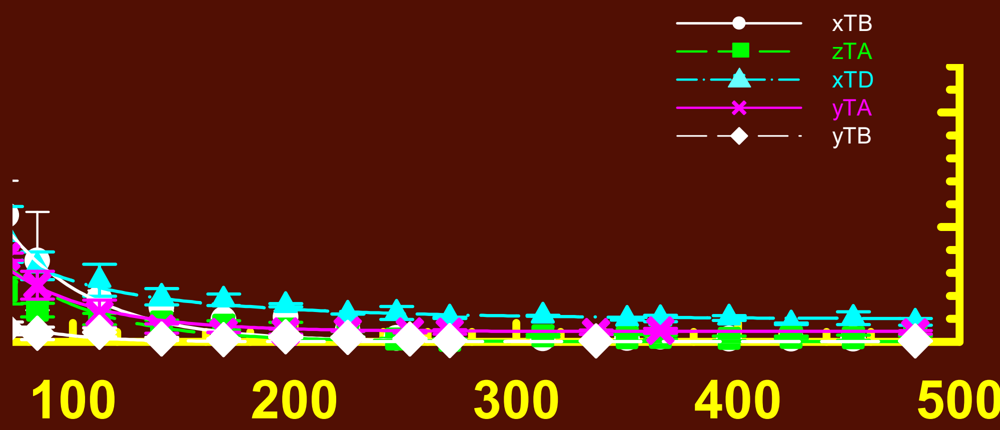
21


Performance Tests
Depletion of Std-OIT with ageing
L3 at 85°C
3 months
12 months
xTB
zTA
xTD
yTA
yTB
Std-OIT (min.)
Incubation duration (Days)
Rowe et al. (2020)

22

Performance Tests

Depletion of **Std-OIT** with ageing

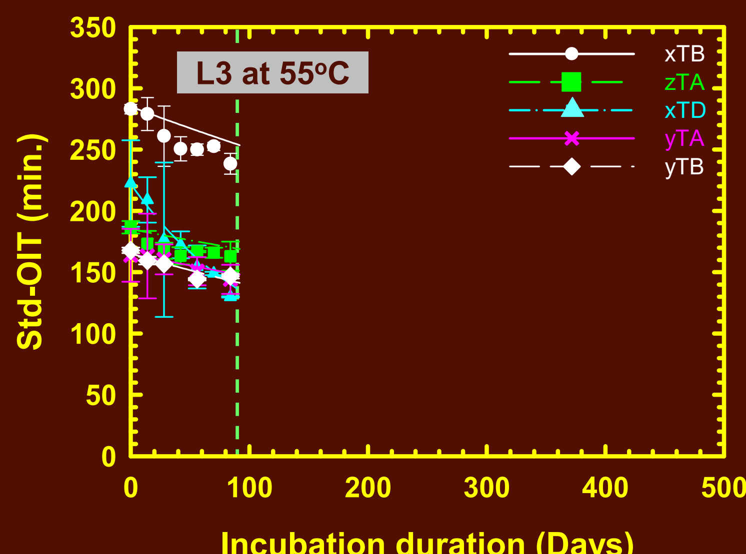


Rowe et al. (2020)

23

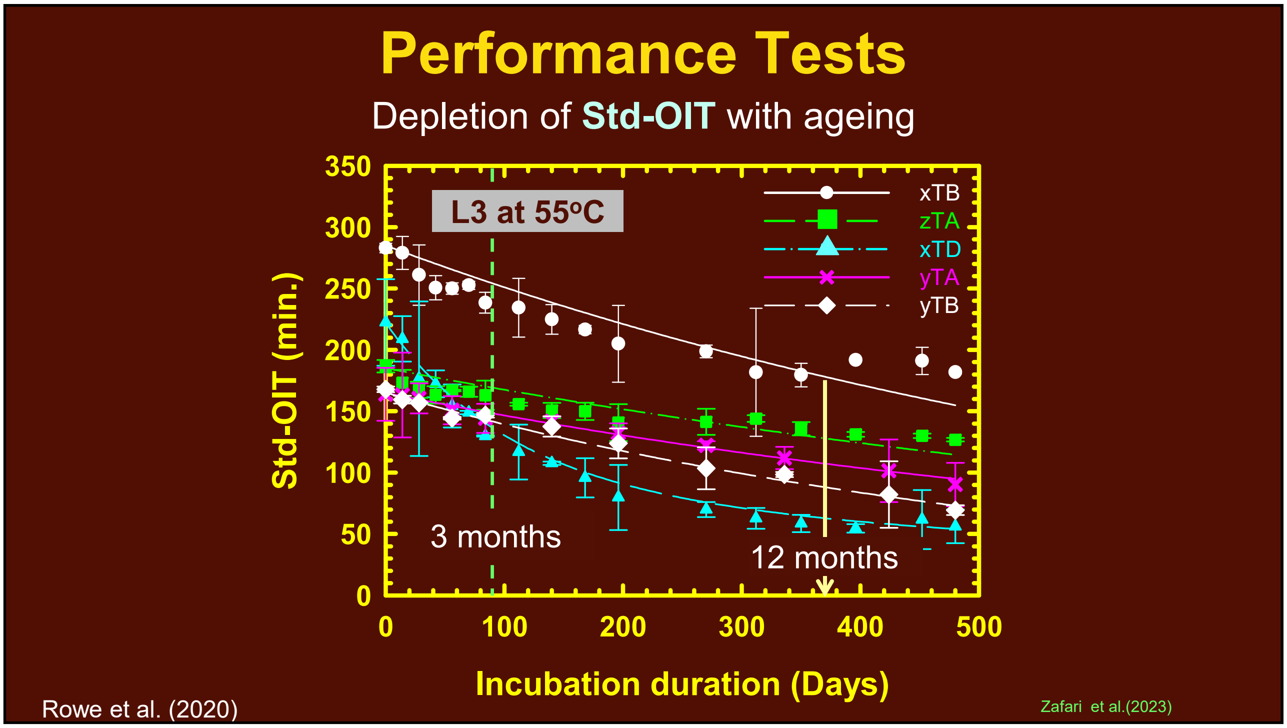
Performance Tests

Depletion of **Std-OIT** with ageing

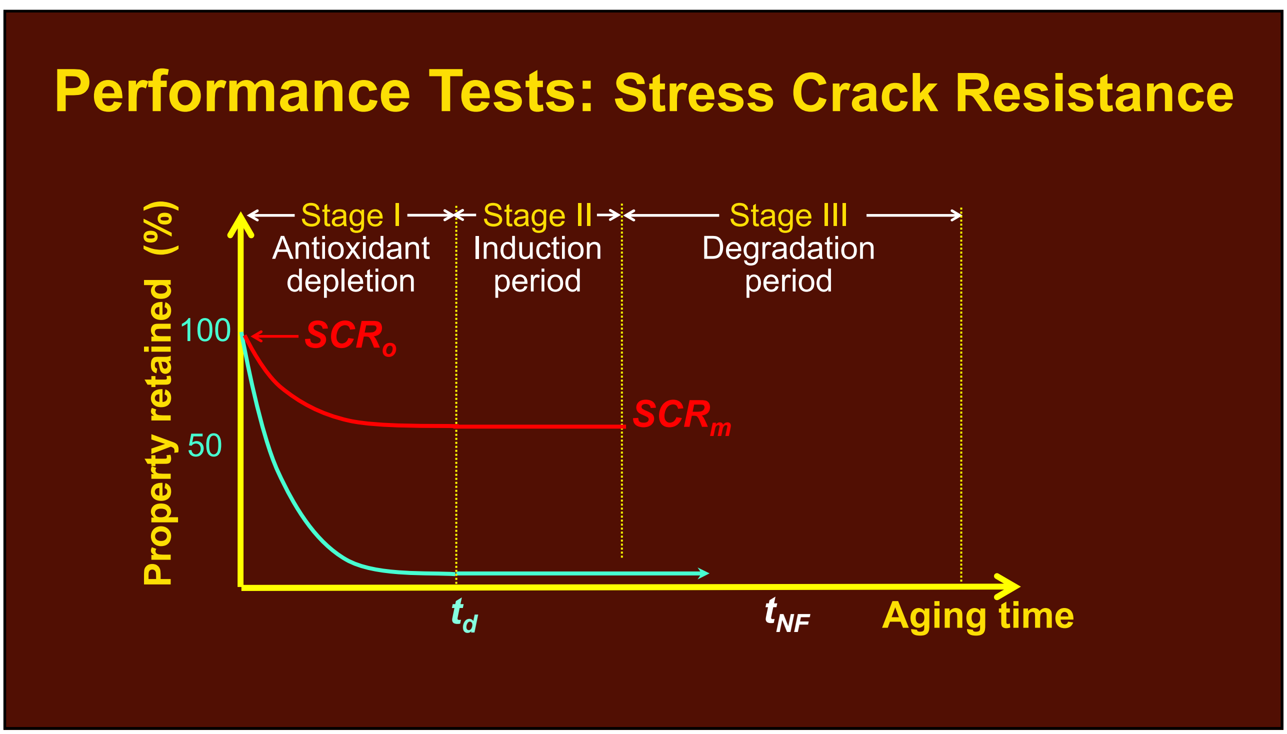


Rowe et al. (2020)

24


Performance Tests
Depletion of Std-OIT with ageing
L3 at 55°C
xTB
zTA
xTD
yTA
yTB
Std-OIT (min.)
3 months
12 months
Incubation duration (Days)
Rowe et al. (2020)
Zafari et al.(2023)

25


Performance Tests: Stress Crack Resistance
Stage I
Antioxidant depletion
Stage II
Induction period
Stage III
Degradation period
Property retained (%)
100
50
SCR_o
SCR_m
t_d
t_{NF}
Aging time

26

Performance Tests: Stress Crack Resistance

Stress Crack Resistance after stress relaxation and morphological change (SCR_m)

	HDPE					
Material Thickness (mm)	MyA 2.0	MxA 2.0	MxTBW 2.0	MyIWC 2.0	MxC 2.0	MxC 1.5
SCR_o (hrs)	5,200	1,300	1600	1600	950	800
SCR_m (hrs)	**2,000**	**600**	**500**	**900**	390	390
SCR_m/SCR_o	38%	~50%	~30%	~60%	~41%	~50%

Get an estimate of SCR_m by aging at 55-65°C for 3 months

27

5-Estimate Service-life & Select GMB

Factors need to be considered:

1. Some antioxidants deplete $OIT(t) = OIT_o \exp(-st)$
   where OiT_o= initial value, t= time, s=depletion rate at temperature T in your solution. s can be established from short-term tests and used to predict performance at lower temperatures.
2. Other antioxidant packages deplete
   $OIT(t) = a \exp(-s_1 t) + (OIT_o - a) \exp(-s_2 t)$
   where OiT_o= initial value, t= time, a is the amount depleting at a rate s_1 and (OIT_o-a) the amount depleting at a rate s_2 at temperature T in your solution.
   A short-term test may give s_1 at all temperatures tested but s_2 only at 85° and maybe 75°C.
   Comparing these with test data with other test data from much longer testing we may be able to infer the missing data and using s_2 gives much longer depletion times.

28

Take home messages

- You can eliminate some unsuitable GMBs but cannot select a GMB based on initial properties.
- You need to test a number of candidates in a solution as representative as possible of YOUR exposure conditions

  or
- ones tested by others for similar conditions – BUT make sure they ARE similar).

29

Take home messages

- 3 – 12 months of testing helps select the most compatible product

but
- predictions based on this data will often be very conservative
- You need to be able to use comparators and/or longer tests to get better predictions
- Start your selection process early – it takes time- and cost is small compared to the cost of getting it wrong

30

Topics in This Talk

Service life of HDPE

A framework for selection of GMB

Estimating Service Life of GMBs

Topics in This Talk

Factors in selection of the type of geomembrane

Bituminous geomembranes and HDPE

LLDPE and HDPE

The many faces of HDPE

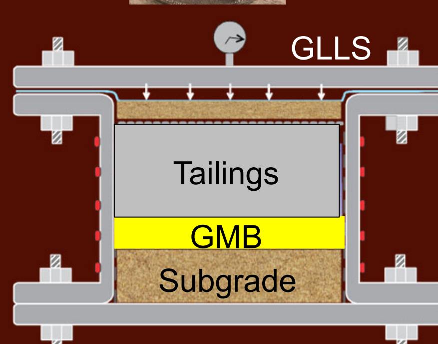
31

5-Estimate Service-life & Select GMB

Factors need to be considered:

1. Predictions presented are based on immersion tests for Stage I only →

2. So, we need to convert the depletion of antioxidants from immersion to liner in the field.
3. Need to add length of Stages II and III→ Using our data base for comparator GMBs.



32

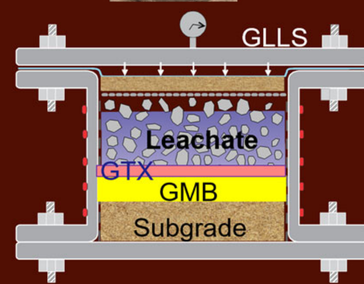
5-Estimate Service-life & Select GMB

Depletion adjustment for field performance

$t_{d\ field} = R_a * t_{d\ immersion}$	Rowe and Rimal (2008a,b)	
GMB	MyB15	
Thickness (mm)	1.5	
Protection	GTX	1.5 cm Sand
Ra at 55°C	3.3	4.4
Ra ~ 24 °C	3.7	**4.9**
Average	3.5	**4.6**

Use Ra = 3.4

Landfill



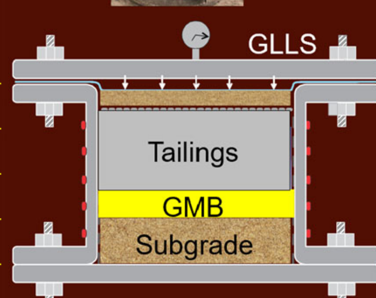
Rowe et al. (2020)

33

5-Estimate Service-life & Select GMB

Depletion adjustment for field performance

$t_{d\ field} = R_a * t_{d\ immersion}$	Rowe et al. (2010,2013)
GMB	MxA15
Thickness (mm)	1.5
Protection	15 cm Sand
Ra at 55°C	4.7
Ra ~ 24 °C	**10.6**
Average	**7.6**



Use Ra = 3.4

Tailings

Rowe et al. (2020)

34

5-Estimate Service-life & Select GMB

To estimate the service-life (t_{SL}) of the candidate GMBs:

Stage I: t_d from immersion test may be adjusted to get $t_{d\ field} = R_a * t_d$ from immersion study after application field liner factor, Ra

$$t_{SL} = \frac{t_{I\text{-}F} \text{ of the Candidate GMB}}{(t_{NF} - t_{I\text{-}I}) \text{ of the comparator GMB}}$$

Stages II & III: From Queen's database for GMBs immersed in a similar leachate for enough time to allow predictions at field specific temperatures

35

Some Recently Studied GMBs

Generic Name	MyC15	MyA20	MxTB
Thickness (mm)	1.5	2.0	2.0
Std-OIT$_o$ (minutes)	174	133	**285**
SCR$_o$ (hours)	1000	5200	1600
SCR$_m$ (hours)	1000	**2000**	500

All Meet GRI-GM13

36

Effect of temperature on t_d, t_{NFi} and $t_{NFfield\ d}$ (years) immersed in MSWL

GMB	MyC 1.5mm			MyA 2.0mm			MxTB 2.0mm		
T °C	t_d	t_{NFi}	$t_{NFfield}$	t_d	t_{NFi}	$t_{NFfield}$	t_d	t_{NFi}	$t_{NFfield}$
60	2.6	9	15	2.6	13	19	7	17	34
50	5.5	15	28	4	36	46	25	53	110
40	9.4	30	52	7	120	140	92	170	390
30	28	60	**130**	12	430	**460**	370	590	**1500**
20	70	130	300	23	1790	1900	1700	2300	>5000

MyC: 9 years data, Abdelaal, Rowe & Islam (2014) MxTB: 5 years data, Zafari, Rowe & Abdelaal (2023)
MyA: 17 years data, Ewais & Rowe (2018)

Could be shorter or longer for other GMBs and exposure conditions

37

Take home messages

- Antioxidant package (AO)+
- Resin +
- Additives (other chemicals, carbon black, etc)

can ALL greatly affect long term performance

- A geomembrane and have

AO	Resin	Additives	Service life
VG	VG	VG	VG
G	G	G	G
P	P	P	P

But it is rarely that simple; 27 different possible permutations with 3 quality rankings and 3 independent variables

The difference can be decades to millennia

38

Conclusions

- An approach for selecting a HDPE GMB for a long design-life was presented based on lab testing conducted for 3-12 months
- Immersion data was essential to ensure that GMB:
  - a) is highly likely to meet the required design life
  - b) has high resistance to leachate chemistry
  - c) is suitable for the design temperature
- If long-term performance is important – seek expert advice and be prepared to pay for testing

39

References

- Priyanto, D., Labriola, M., Whitelaw, B., Rowe, R.K., Barone, F., Abdelaal, F., Zafari, M., Buckley, J. (2019) “Implementation of Research and Development (R&D) Results in the Design of Liner System for the Near Surface Disposal Facility (NSDF) – 19089”, WM2019 Conference, March 3 – 7, 2019, Phoenix, Arizona, USA.
- Rowe, R.K., Priyanto, D. and Poonan, R. (2019) “Factors affecting the design life of HDPE geomembranes in an LLW disposal facility”, WM2019 Conference, March 3 – 7, 2019, Phoenix, Arizona, USA, 15p.
- Rowe, R.K., Abdelaal, F.B., Zafari, M. Morsy, M.S. and Priyanto, D.G. (2020). “An approach to geomembrane selection for challenging design requirements”, Canadian Geotechnical Journal, (in press but available at https://doi.org/10.1139/cgj-2019-0572)

40

Four "must read papers"

Leakage in GMBs below tailings

- Rowe, R.K. and Fan, J., 2022. A general solution for leakage through geomembrane defects overlain by saturated tailings and underlain by highly permeable subgrade. Geotext. Geomembr., 50(4):694-707.

Geomembranes – leakage and service-life

- Rowe, R.K. (2020) "Protecting the environment with geosynthetics - The 53rd Karl Terzaghi Lecture", ASCE J Geotech. Geoenviron., 146(9):04020081, 10.1061/(ASCE)GT.1943-5606.0002239

Geomembrane strains

- Rowe, R.K and Yu, Y. (2019) "Magnitude and significance of tensile strains in geomembrane landfill liners", Geotext. Geomembr., 47(3):429-458.

GCLs

- Rowe, R.K. (2020) "Geosynthetic clay liners: perceptions and misconceptions", *Geotext. Geomembr.*, **48**(2):137-156, https://doi.org/10.1016/j.geotexmem.2019.11.012

41

Other useful reading

Abdelaal, F.B., Rowe, R.K. and Brachman, R.W.I. (2014) "Brittle rupture of an aged HDPE geomembrane at local gravel indentations under simulated field conditions", ", Geosynth. Int., , 21(1): 1-23. http://dx.doi.org/10.1680/gein.13.00031

Ewais, A.M.R., Rowe, R.K., Brachman, R.W.I. and Arnepalli. D.N. (2014). "Service-life of a HDPE GMB under simulated landfill conditions at 85oC" ASCE Journal of Geotechnical and Geoenvironmental Engineering, 140(11): 04014060: 1-13. DOI: http://dx.doi.org/10.1061/(ASCE)GT.1943-5606.0001164

Rowe, R.K. 2005. Long-term performance of contaminant barrier systems, 45th Rankine Lecture. Geotechnique, 55(9):631-678.

Rowe, R.K. (2011). "Systems engineering the design and operations of municipal solid waste landfills to minimize leakage of contaminants to groundwater", Geosynth. Int., 16(6): 391-404.

Rowe, R.K. (2014) "Performance of GCLs in liners for landfill and mining applications", J. of Environmental Geotechnics, 1(1): 3-21; http://dx.doi.org/10.1680/envgeo.13.00031

Rowe, R.K. (2018) "Environmental geotechnics: looking back, looking forward" (16th Croce Lecture), Italian Geotechnical Journal, 2018(4):8-40, dx.doi.org/10.19199/2018.4.0557-1405.008Rowe, R.K. 2005. Long-term performance of contaminant barrier systems, 45th Rankine Lecture. Geotechnique, 55(9):631-678.

42

Other useful reading

Rowe, R.K. and Islam, M.Z. 2009. Impact on landfill liner time-temperature history on the service-life of HDPE geomembranes. Waste Management, 29: 2689-2699.

Rowe, R.K., Morsy, M.S. and Ewais, A.M.R. (2019) “A Representative Stress Crack Resistance for Polyolefin Geomembranes Used in Waste Management”, Waste Management, 100:18-27, https://doi.org/10.1016/j.wasman.2019.08.028

Rowe, R.K., Abdelaal, F.B., Zafari, M. Morsy, M.S. and Priyanto, D.G. (2020). “An approach to geomembrane selection for challenging design requirements”, Can. Geotech. J. , 57(10):1550–1565, doi:10.1139/cgj-2019-0572

Rowe, R.K., Islam, M.Z., Brachman, R.W.I., Arnepalli, D.N. and Ewais, A. (2010). “Antioxidant depletion from an HDPE geomembrane under simulated landfill conditions”, ASCE J Geotech. Geoenviron., ASCE, 136:(7): 930-939.

Rowe, R.K., Abdelaal, F.B. and Brachman, R.W.I. (2013) “Antioxidant depletion from an HDPE geomembrane with a sand protection layer”, Geosynth. Int., 20(2):73-89.

Rowe, R.K. and Rimal, S. (2008). “Depletion of antioxidants from an HDPE geomembrane in a composite liner”, ASCE J Geotech. Geoenviron., 134(1):68-78.

Rowe, R.K. and Rimal, S. (2008). “Ageing of HDPE geomembrane in three composite liner configurations”, ASCE J Geotech. Geoenviron., 134(7):906-916.

43

Other useful reading

Abdelaal, F.B., Rowe, R.K. and Islam, M.Z. (2014) “Effect of leachate composition on the long-term performance of a HDPE geomembrane”, Geotext. Geomembr., 42(4):348-362. http://dx.doi.org/10.1016/j.geotexmem.2014.06.001

Ewais, A.M.R., Rowe, R.K., Rimal, S. and Sangam, H.P. (2018) “17-year elevated temperature study of HDPE geomembrane longevity in air, water and leachate”, Geosynth. Int., 25(5):525-544.

Rowe, R.K., Rimal, S. and Sangam, H.P. (2009). “Ageing of HDPE geomembrane exposed to air, water and leachate at different temperatures”, Geotext. Geomembr. , 27(2):131-151.

Sangam, H.P. and Rowe, R.K 2002. Effects of exposure conditions on the depletion of antioxidants from HDPE geomembranes. CGJ, 39(6):1221-1230.

44