Exposure of various polymer lined carbon steel pipe section to a sour HC fluid at maximum service temperature: Methodology and Observations

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JOINING INNOVATION AND EXPERTISE

Marine Corrosion Forum
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Polymeric liners used for:

- Water conveyancing

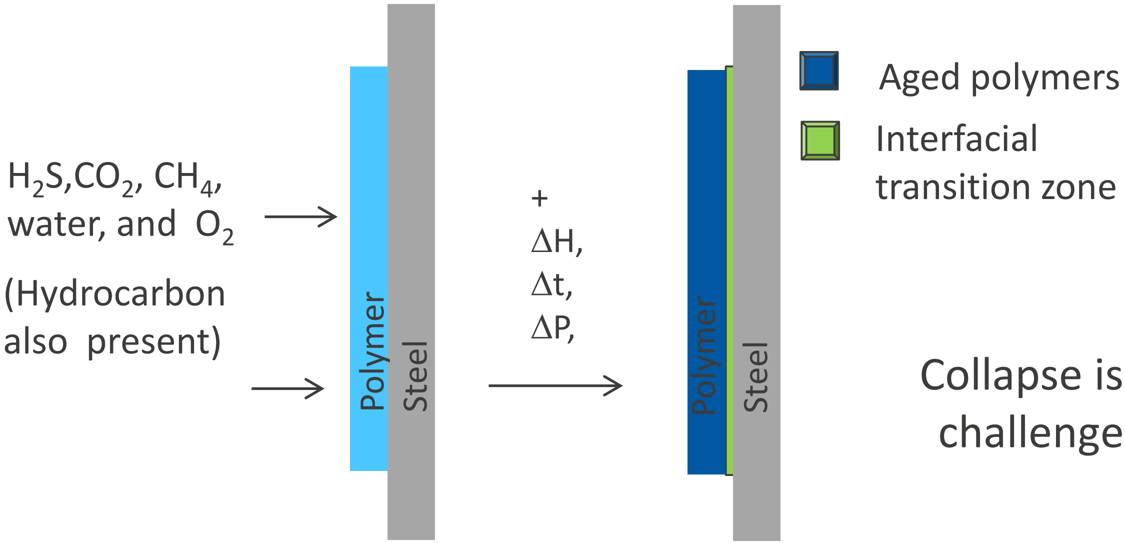
(on land and subsea water injection pipelines)

- ~20yrs in producing wellbores as lining for tubulars
- Chemical production plants

Increasing interest to use in:

- Subsea pipeline rehabilitation
- Sour hydrocarbon conveyancing

Overview and Objectives

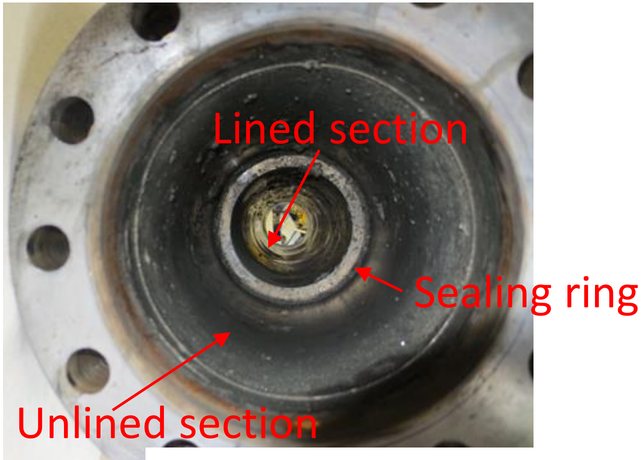


Collapse is a challenge!

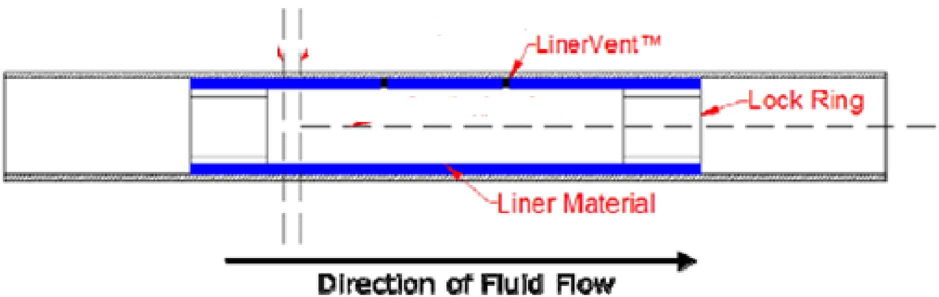
Establish the condition of X52 lined with a thermoplastic via flow loop testing in sour environment:

- Degree of alteration of 4 polymeric liners
- Surface condition of carbon steel under liner

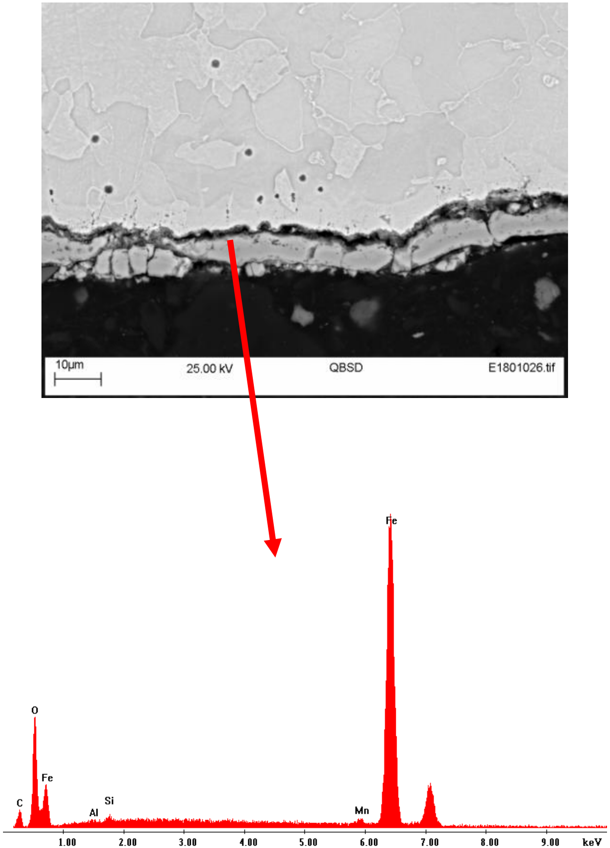
Test material

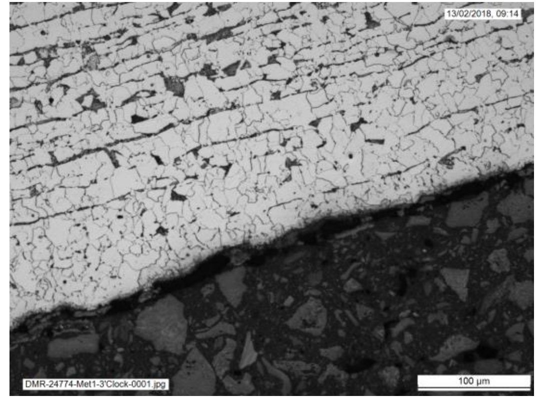


- A total length of 914mm with approx. 500mm lined pipe.
- 4 Liners (10-11mm thick):
  - Polyamide (Type 1 and 2)
  - PE-RT
  - PVDF



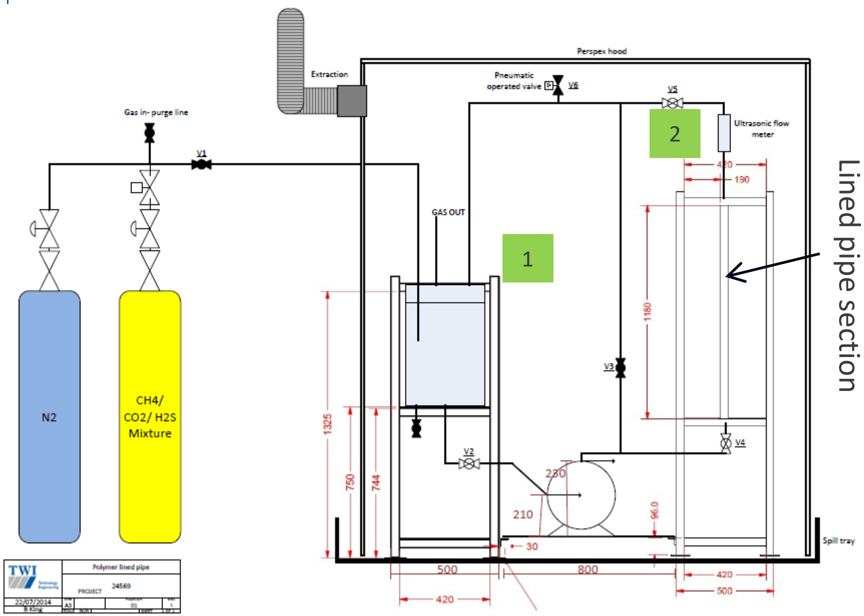
Test material prior to exposure





- X52 steel rated for sour service.
- Features due to manufacturing process and/or post manufacturing atmospheric exposure.
- Evidence of de-carburisation

The flow loop

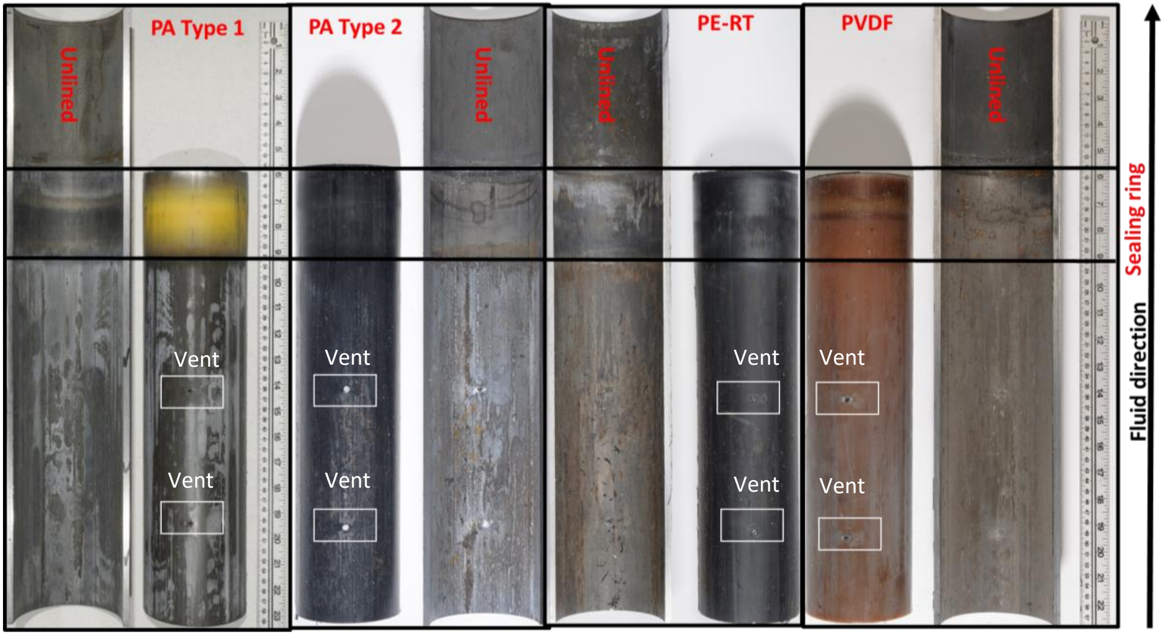


Test conditions

Material	Test temperature (°C)	Test pressure (barg)	Duration at test temperature (days)
PA type 1	**80**	**89**	**180**
PA type 2	**90**		
PE-RT	**90**		
PVDF	**130**		**180**

- Sour hydrocarbon fluid (ISO 23936-1:2009)
- Displacement rate of fluid: 5m/sec.
- Static period at 130°C for PVDF.
- Depressurisation at 70barg min^{-1} at 90 and 180days.

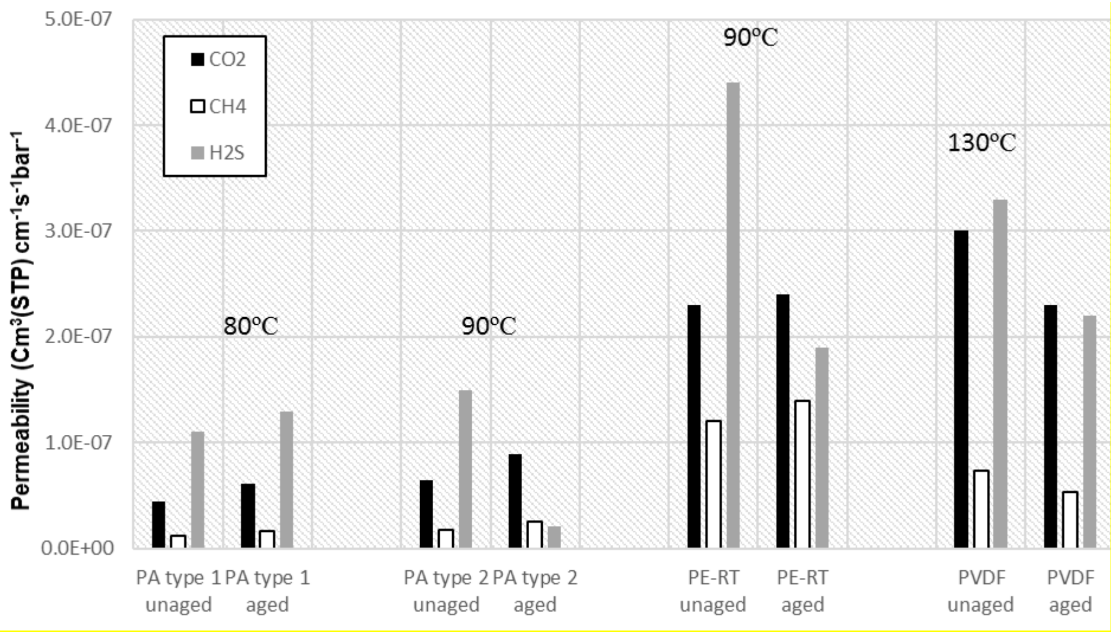
Sections after exposure



- Polymeric liner turned over for a view of the interfacial transition zone
- Visual observations made of liner and carbon steel surface
- Polymer sectioned for mechanical, permeability, calorimetric and spectroscopic comparison with unaged liners
- Carbon steel surface and bulk examined for cracking and corrosion using ultrasound, diffraction and microscopy

Properties of the tested polymeric liner

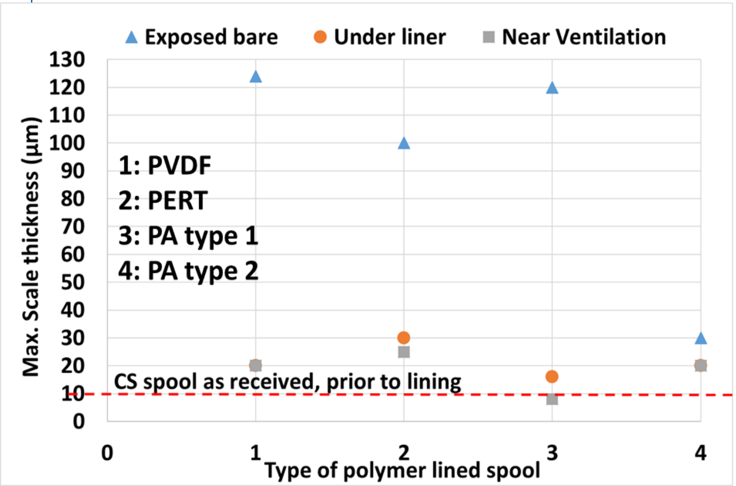
Permeability coefficients from dry gas mixture

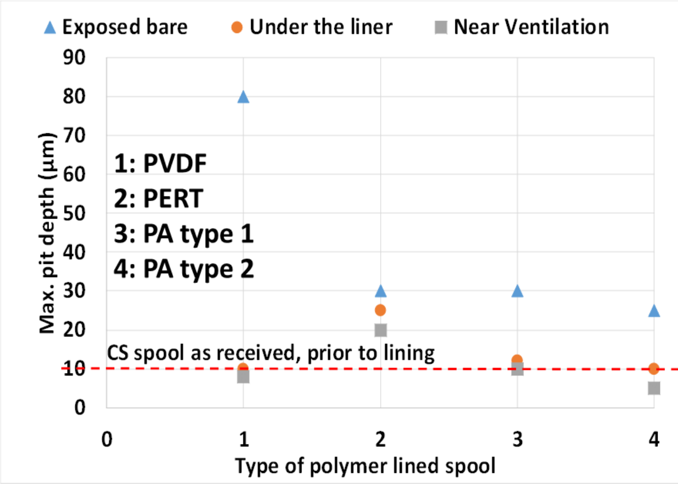


Properties of the tested polymeric liner

Material	Liner thickness (nominal, mm)	Colour	Enthalpy of Melt J g^{-1}	Melting point °C	Young's Modulus GPa (at test temperature)
PA type 1 (unaged)	10.8	Yellow	42	178	0.36 (80°C)
PA type 1	11.4	Black	46	178	0.41(80°C)
PA type 2 (unaged)	10.5	Black	31	193	0.26(90°C)
PA type 2	11.3	Black	39	196	0.34(90°C)
PE-RT (unaged)	10.8	Black	146	133	0.12(90°C)
PE-RT	12.2	Black	150	134	0.11(90°C)
PVDF (unaged)	10.5	White	48	170	0.12(130°C)
PVDF	11.3	Brown	46	168	0.16(130°C)

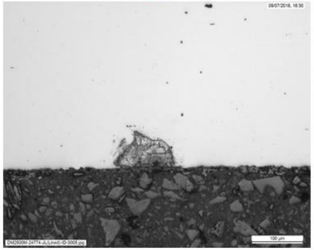
Surface morphology of CS test material



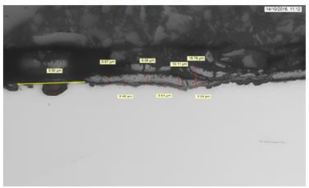


Pitting on CS test material

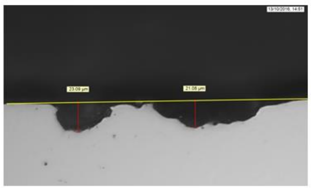
Under PA Type 1



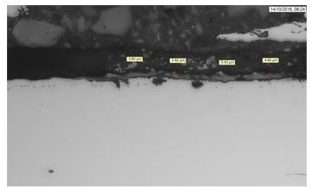
Under PA type 2



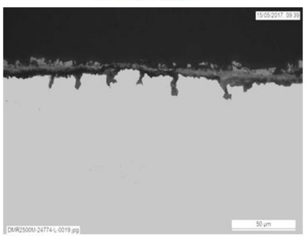
Unlined



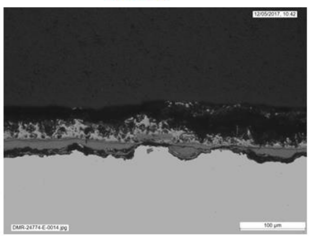
Near ventilation



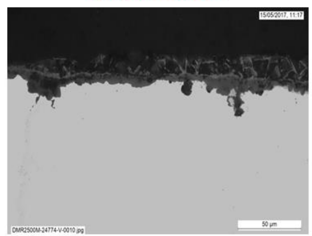
Under PERT



Unlined

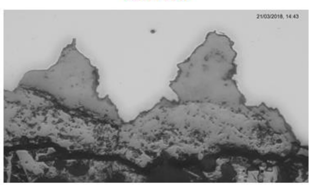


Near ventilation

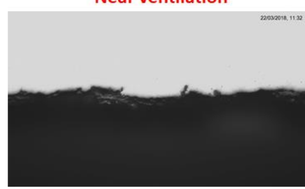


Under PVDF

Unlined

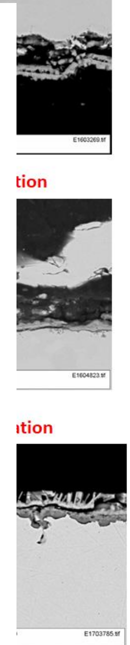


Near ventilation

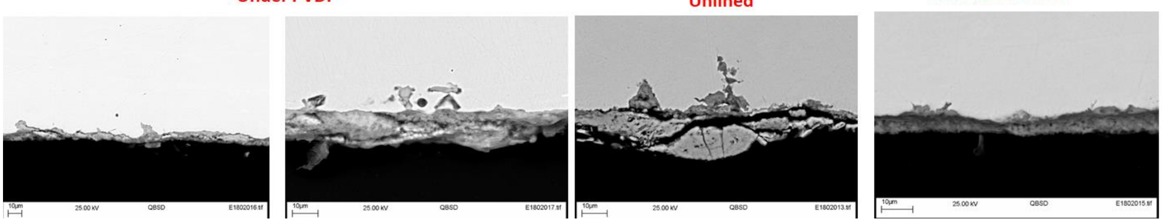


- Unlined the most affected.
- PA type 1 and PVDF lined sections the least affected.
- Change in pit shape + corrosion scaling → Wet sour corrosive environment at the CS-liner interface.
- Role of pre-existing flaws.

Corrosion scaling on CS test material



- Magnetite (Fe_3O_4) adjacent to the steel
- Mackinawite ($Fe_{1+x}S$)
  - Initial stage of exposure
- Greigite (Fe_3S_4)
- Pyrrhotite ($Fe_{1-x}S$), Pyrite (FeS_2)
  - Retardation of corrosion rate



Conclusions

- Condition of test material after 180 days at and above 80°C & 89 bar:
- Surface morphology (pitting & scaling thickness) of CS:
  - Corrosion resistance:

    PVDF>PA Type 2>PA Type 1> PE-RT>Bare carbon steel.
  - Iron sulfides acknowledged for their protective natures.
- Condition of the polymeric liners:
  - No collapse during rapid gas decompression events.
  - No substantial alteration in mechanical properties or crystallinity.
  - Swelling but no residual relaxation
  - Loss of additives, present at the ‘interfacial’ environment.

Future work

Laboratory and field tests of longer duration (1 year+) for:

- ❑ Quantitative corrosion rates and online NDT monitoring?
- ❑ Vapour permeation through the liner vs. time and level of condensation at the interface?
- ❑ Critical scale thickness (vs annular space) for eventual liner collapse?
- ❑ H_2S-containing brine & chloride permeation through the liner vs. time?
- ❑ Use of higher strength low alloy steel, x65 or X70? Hydrogen behind the liner vs. SSC?
- ❑ Presence of girth welds?

Thank you for your attention.
Any questions?
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Polymeric material swaged but not exposed

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PE-RT	10.8	Black	146	133	0.12(90°C)
PVDF	10.5	White	48	170	0.12(130°C)

Material	Temperature (°C)	Permeability (K)		
		10^{-7} $cm^2 s^{-1}$ bar^{-1}		
		CO_2	CH_4	H_2S
PA type 1	80	0.4	0.1	1.1
PA type 2	90	0.6	0.2	1.5
PE-RT	90	2.3	1.2	4.4
PVDF	130	3.0	0.7	3.3

Steady state flux through the liner after approximately 112 days. Experiments on dry gas supply.