A Study on the Impact of Hydrocarbon Contamination on Electrofusion Joints

Connor Cooper (Kinectrics), Michael Sabatini (Enbridge)

2025 | CGA Energy Nexus | Annual Technical Conference

Fuelling the Future

Presentation Outline

- What is Hydrocarbon Contamination?
- CSA Code Implications
- Project Testing
  - Gas Chromatography/Trending Analysis
  - Laboratory Immersion Study
  - Field Sample Study
- Key Takeaways

Contamination of Polyethylene Pipes Used in the Transmission and Distribution Network of Natural Gas

- Diffusion into the polymer occurs:
  - From the process fluid itself (internal)
  - Where liquid hydrocarbons condense (internal)
  - Contaminated soil (external)
- The theory (and code) suggests that the presence of these liquid hydrocarbons in the polymer has a negative influence on the pipe integrity:

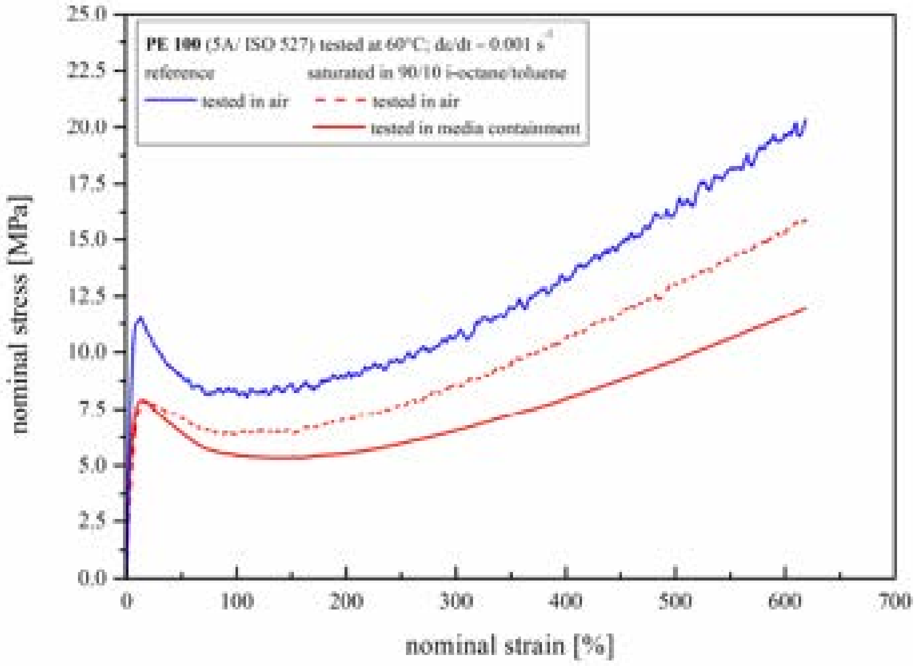
  ↓ Thermal fusion quality

  ↓ Pipe strength

  → Results in down-regulation and mechanical fittings

Effects of Heavy Hydrocarbon Contamination (HHC) on Mechanical Performance

- Literature studies provide examples of how the mechanical performance of a PE pipe changes once exposed to liquid hydrocarbon contamination:
  - Schoeffl et al. demonstrated a decrease in axial and hoop yield stress of 35% - 50% after saturating PE samples in a mixture of octane and toluene
  - Kuryndin et al. demonstrated a 50% reduction of Young’s Modulus as saturation increases
  - Crippen et. Al. demonstrated that the UTS in MDPE and HDPE is reduced following HHC saturation. Similarly significant strain reduction also occurs at low strains (<30%)



Nominal Stress / nominal strain curves of PE 100-2 comparing liquid hydrocarbon (LHC) fully saturated specimens tested either immersed in the LHC or in air, with a control provided as reference

Hydrocarbon Contamination in Practice

- Characterized by permeation of hydrocarbons into pipe wall
- Identified through the presence of pock-marks created by the application of heat during the conventional fusion process
- CSA Z662:23 limits joining to mechanical methods where contamination is confirmed

Pock-marking on cross-section of contaminated pipe with pock-marks formed during melt test

Pock-marking in fusion zone formed during conventional saddle fusion

CSA Z662

12.4.3.7

When liquid hydrocarbons might have been in external or internal contact with PE pipe, the operating company shall perform a melt pattern test to identify absorption of liquid hydrocarbons utilizing saddle fusion to inspect outer pipe surface or butt fusion to inspect full pipe wall thickness. If subsequent visual inspection indicates bubbles, a rough surface, or a pock-marked surface. The operating company shall conduct an evaluation to determine the extent of impacted pipe and take one of the following actions:

a) replace affected portions of the PE pipe; or

b) apply a chemical de-rating factor in accordance with Clause 12.4.2.4 and restrict the joining method in accordance with Clauses 12.7.7.4, 12.7.8.3, and 12.7.9.3.

Notes:

1) *Possible sources of liquid hydrocarbon include contaminated soil, contaminants in the gas stream, and liquid hydrocarbon condensation.*

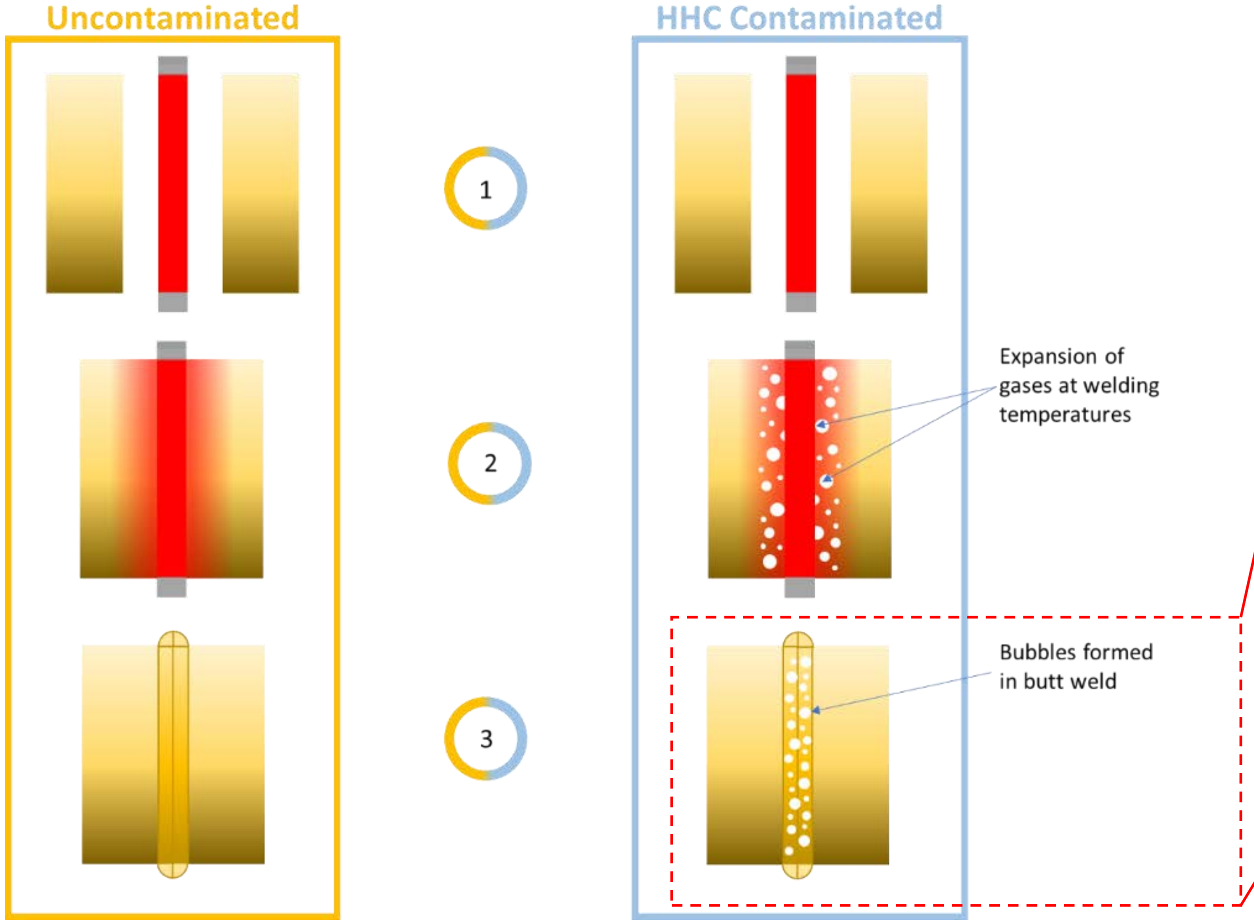
2) *Discoloration or a hydrocarbon fuel odour without any textural indications does not indicate hydrocarbon permeation.*

12.7.7.4

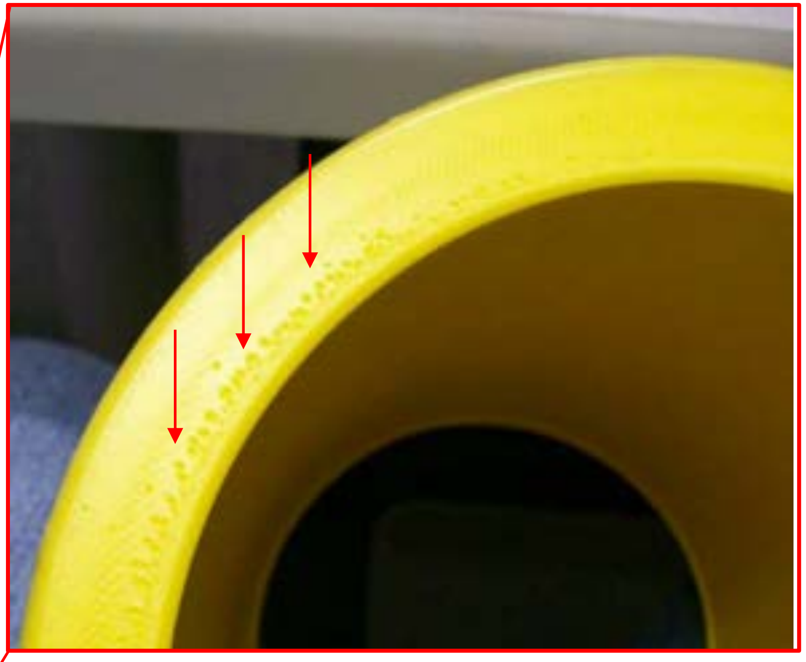
PE piping materials that have absorbed liquid hydrocarbons, where so identified by the melt pattern test in Clause 12.4.3.7, shall only be joined by mechanical fittings in accordance with Clause 12.7.10. This Clause does not apply to joining polyamide materials.

- Code does not mention gaseous hydrocarbon permeation
- Studies are limited to liquid hydrocarbon permeation impacts on yield strength

Effects of HHC on Fusion Operations

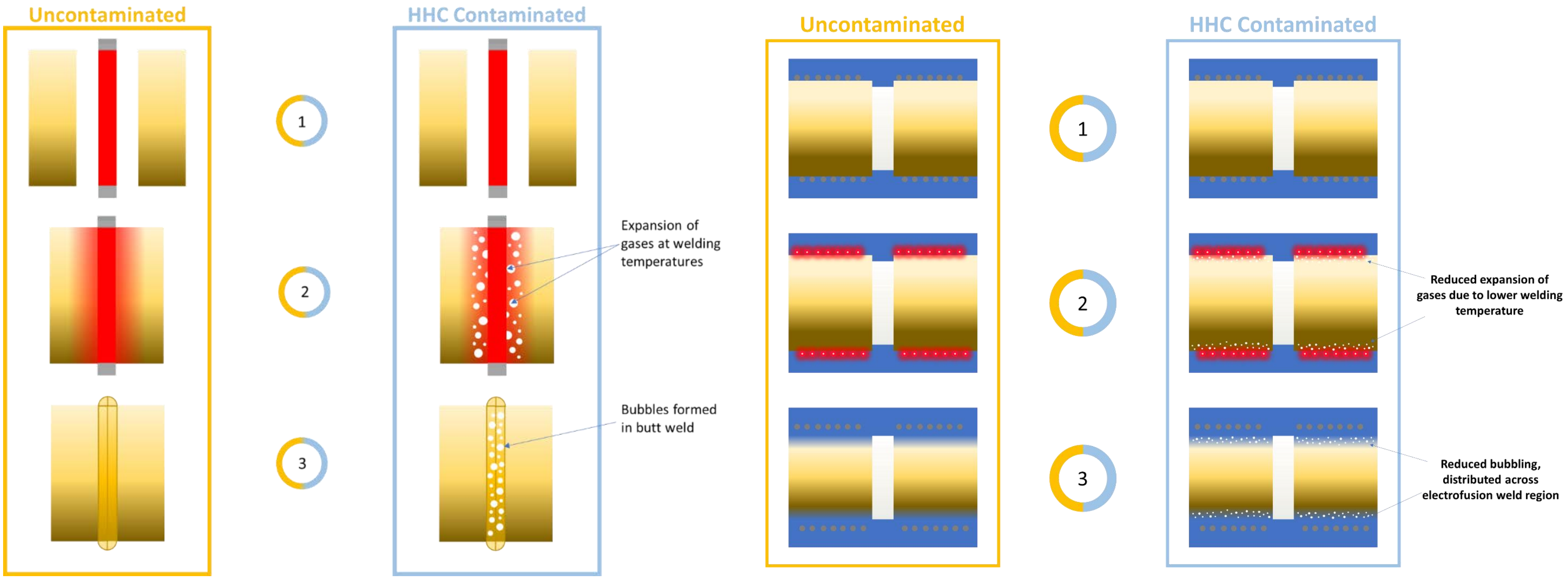


Schematic comparison of butt welds for uncontaminated and contaminated gas piping.

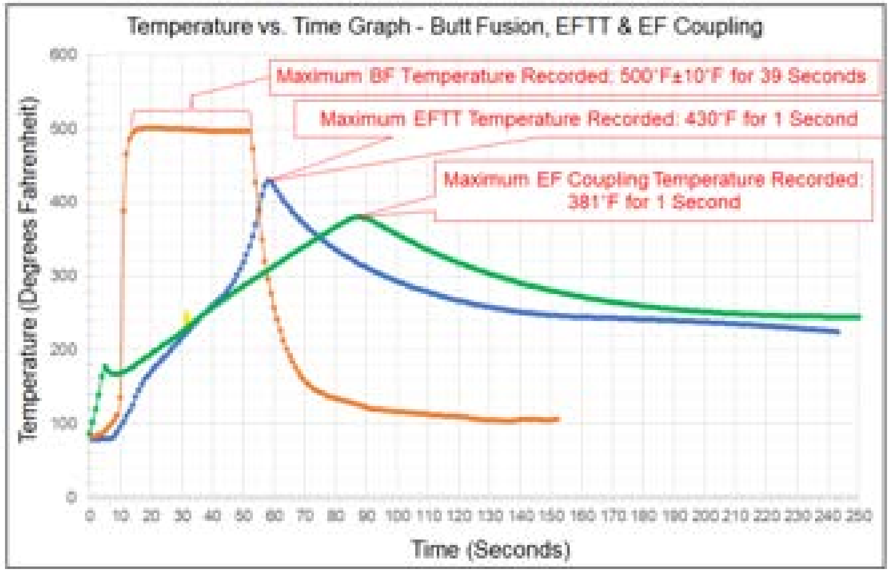


Example of bubbling (pock-marking) on a contamination PE pipe from a butt weld. Hydrocarbons within the contamination unknown.

Butt Fusion vs Electrofusion



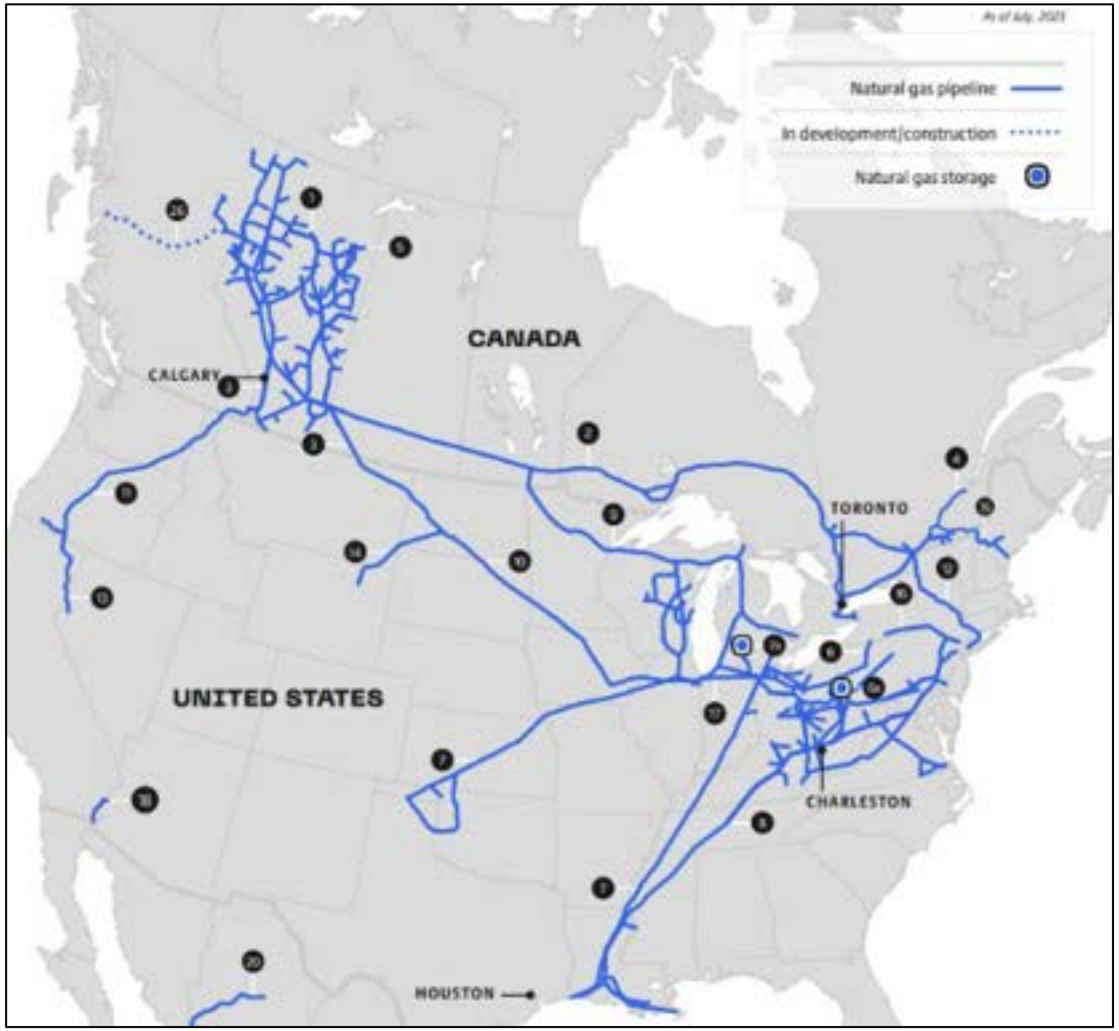
Fusion Interface Temperature Investigation



- In melt pattern gradient temperature tests ranging from 300ºF to 500ºF, pock-marking was observed to be more severe at high temperatures
- Pipe joined by conventional fusion sees temperatures of 500ºF, for 39 seconds
- Electrofusion joints see temperature of 381º-430ºF for 1 second

Gas Composition Analysis

- Initial gas trending analysis executed to determine variation in gas constituents and attempt to link contamination to gas composition
- Natural gas distribution system is dynamic and complex; Ontario has multiple sources of gas
- Laboratory immersion study conducted



Laboratory Immersion Study

- Objective: ID contaminant(s) responsible for pock-marking during fusion and to determine the time required for contaminant(s) to diffuse out of the pipe where pock-marking is no longer observed

Compound	Form
Water (reference)	Liquid
Pure Carbon Dioxide (CO_2)	Gaseous
Methane (C_1)	Gaseous
Ethane (C_2)	Gaseous
Commercial & Pure Propane (C_3)	Gaseous

Compound	Form
Butane (C_4)	Gaseous & Liquid
Hexane (C_6)	Liquid
Octane (C_8)	Liquid
Nonane (C_9)	Liquid
Toluene ($C_6H_5CH_3$)	Liquid
Diesel (mix of C_{12+})	Liquid

Laboratory Immersion Study – Experimental Design

Exposure Conditions
Duration: 10-30 days in each chemical
Temperature: Ambient
Pressure: 60 ± 5 psig (15 psig for gaseous butane)
Material
Infrapipe/Wehogas PE2708 (Yellow)

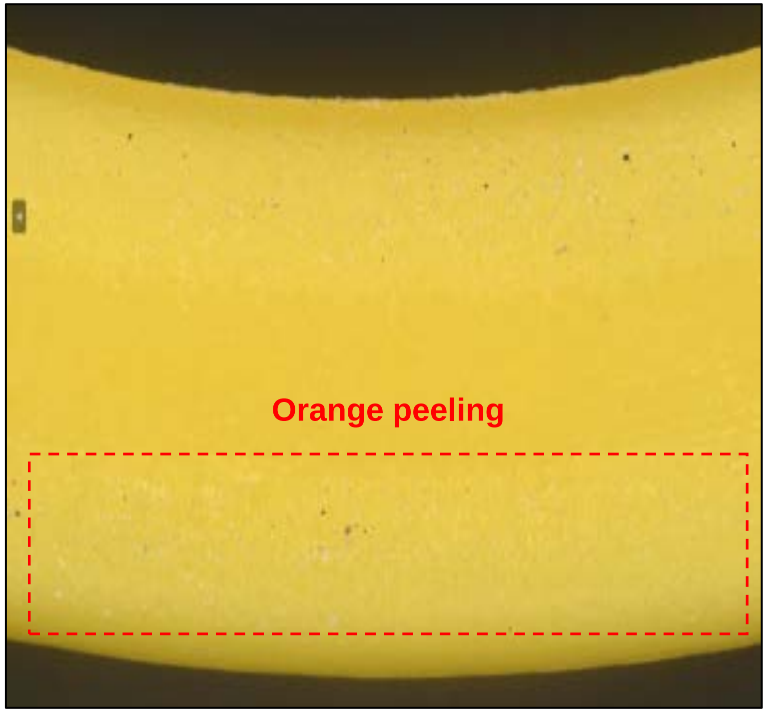
Part 1: Immersion

Part 2 – Test Melts

Laboratory Immersion Study – Observations

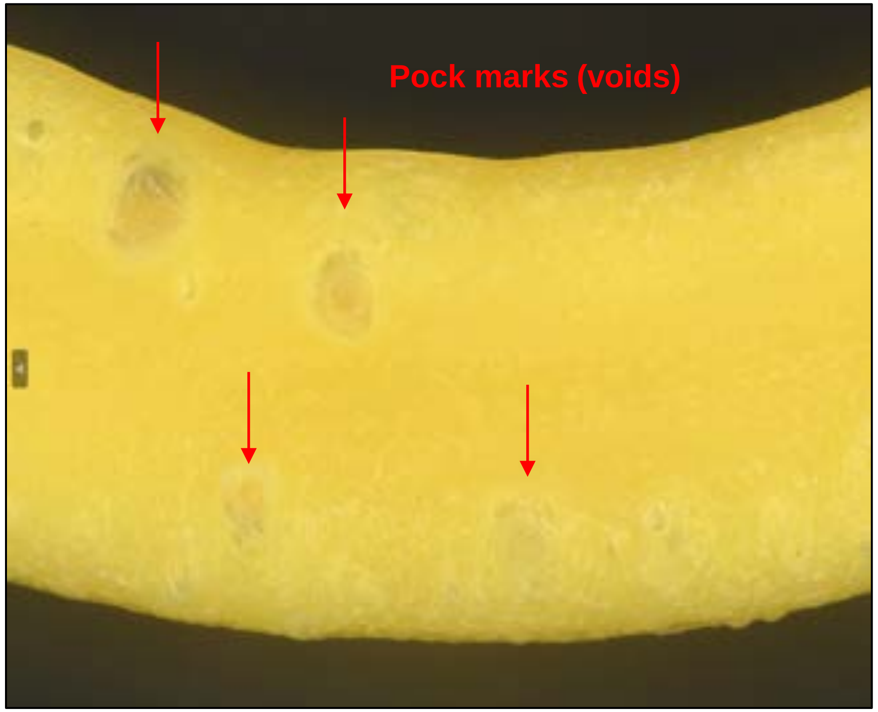
None

Immersion in Diesel



Minor

Immersion in Nonane



Aggressive

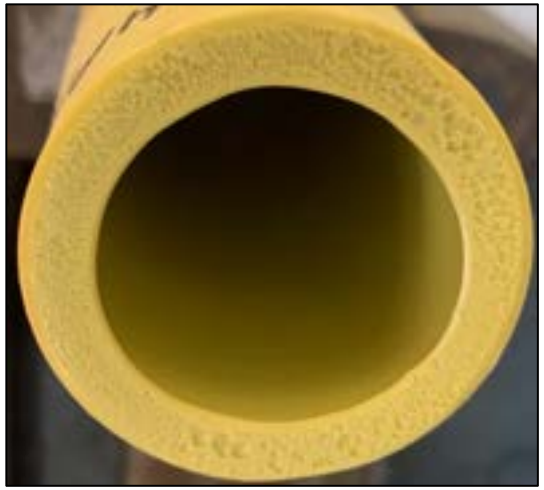
Immersion in Propane

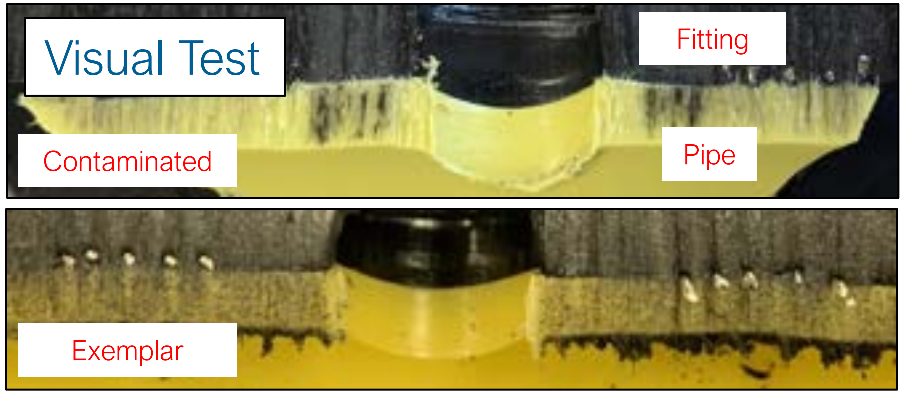
Laboratory Immersion Study – Observations

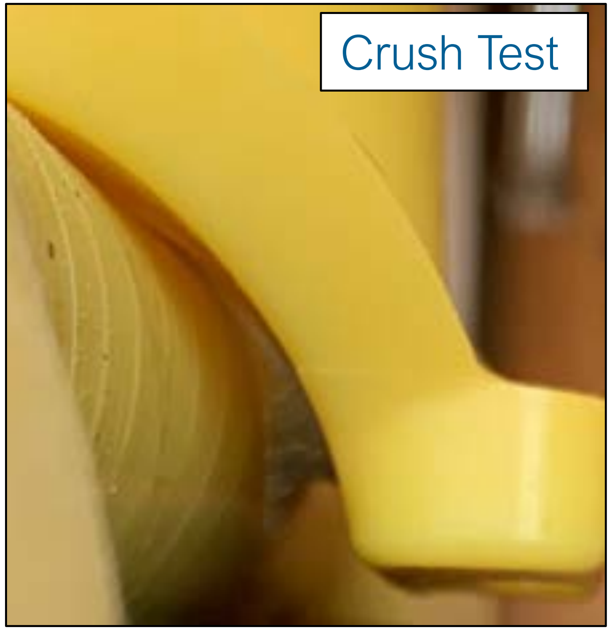
Chemical	Level of Pock Marking Observed
Water, *liquid*	None
Carbon Dioxide (CO_2), *gaseous*	Minor
Methane (C_1), *gaseous*	None
Ethane (C_2), *gaseous*	None/Minor/Aggressive
Pure Propane (C_3), *gaseous*	Aggressive
Commercial Propane (C_3), *gaseous*	Moderate/Aggressive
Gaseous Butane (C_4), *gaseous*	Aggressive
Butane (C_4), *liquid*	Minor/Moderate/Aggressive
Hexane (C_6), *liquid*	None
Octane (C_8), *liquid*	Minor
Nonane (C_9), *liquid*	None/Minor
Toluene ($C_6H_5CH_3$), *liquid*	Minor
Diesel (mix of C_{12+}), *liquid*	None

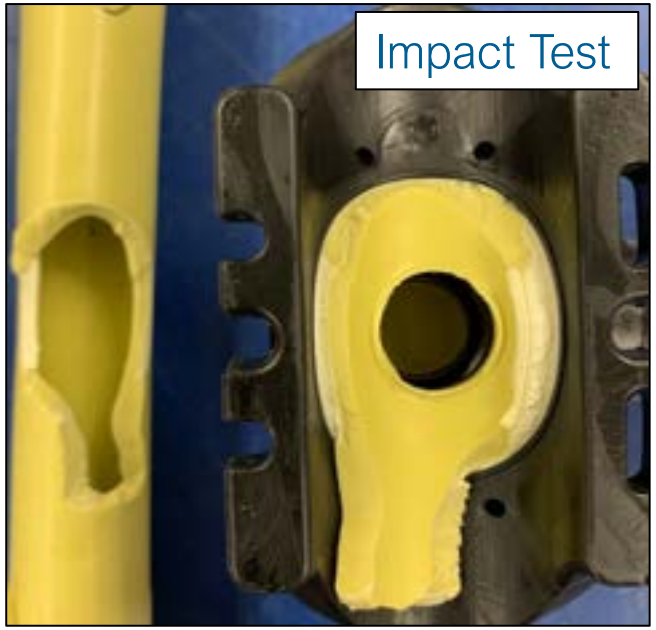
Opportunistic Field Testing

- Initial field testing took place at location of severe contamination in Greater Toronto Area (1980s vintage pipe)
- 20 electrofusion joints were evaluated for pressure testing, crush testing, impact testing, and visual inspection of fusion interface
- All samples passed the qualitative testing providing basis for current quantitative testing plan



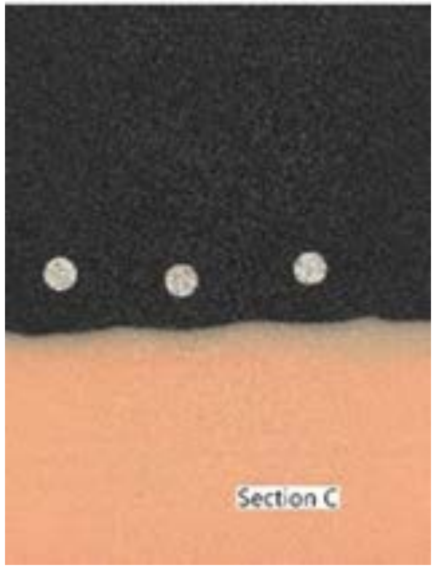






Testing Plan

Elevated Pressure/Temperature Testing (Enbridge)	Decohesion Test (Kinectrics)	Optical Microscopy (Kinectrics)
• Quantify time to failure of fittings joined to contaminated pipe	• Quantify strength of electrofusion fittings joined to contaminated and non-contaminated pipe	• Quantify percentage of voids (if any) at pipe/electrofusion fitting interface



Does pock-marking impact fusion integrity?

Testing Plan

Material	Year of Install	Years in Service
Aldyl-A PE2306	N/A	0
Infrapipe/Wehogas PE2708 (Yellow)	N/A	0
Aldyl-A PE2306	1978	46
Wehogas PE2406 (Yellow)	1995	30
Plexco PE2406 (Yellow)	1993	32

- Melt test locations selected based on confirmation of previous contamination
- Several resins selected for testing to:
    1. Determine differences in known resin performance that may be impacted by hydrocarbon contamination
    2. Ensure sufficient testing time for ETPT

Elevated Temperature/Pressure Testing

Material	Average Testing Time (hours)	
	Saddle Tee	Coupling
Contaminated Aldyl-A PE2306	31	43
Contaminated Yellow (Wehogas PE2406)	672	528
Contaminated Yellow (Plexco PE2406)	On test	On test

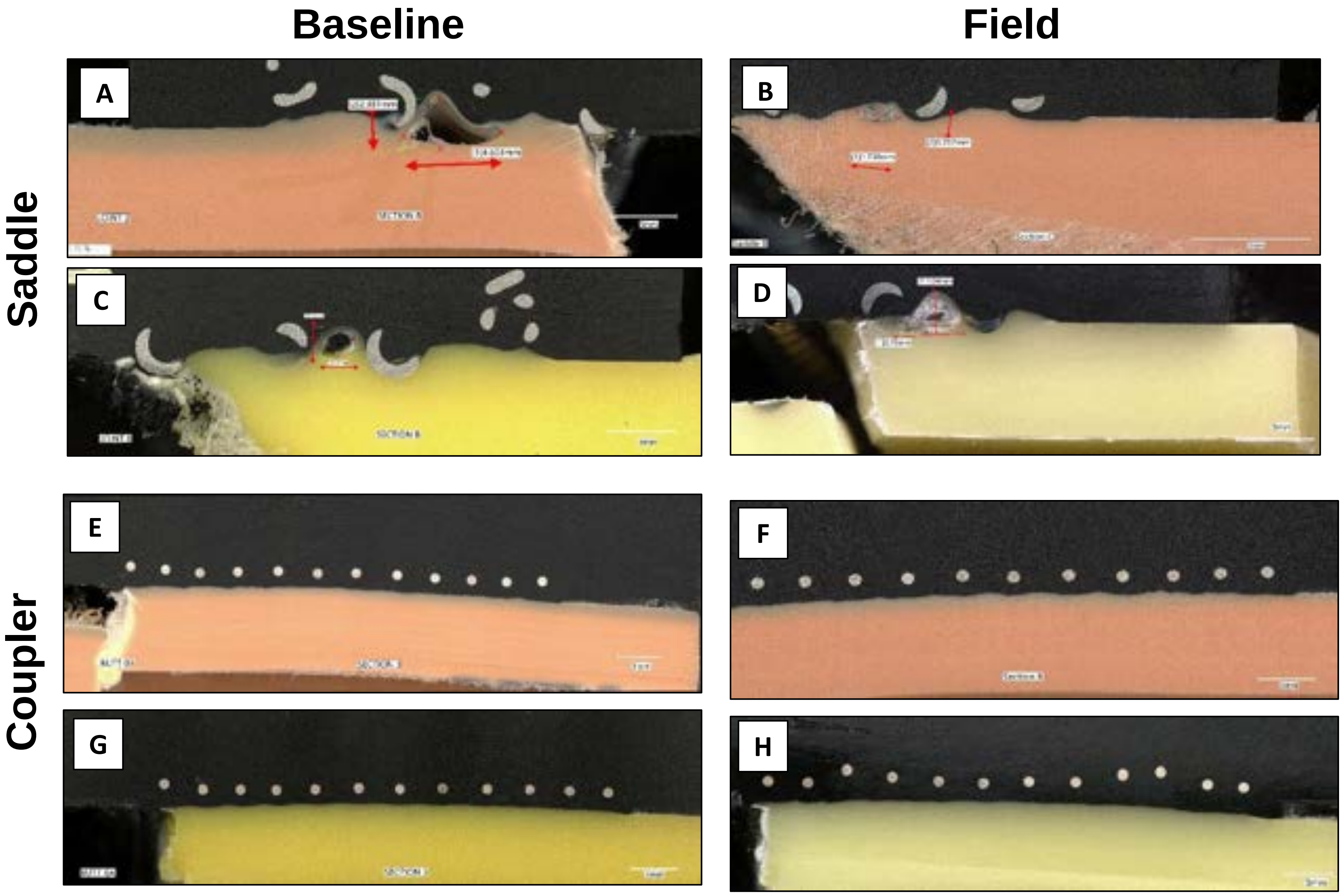
- Tested in accordance with CSA B137.4.1
- Samples were pressurized to 120 psi at 80ºC
- For joints fused to contaminated plastic the pipe was the point of failure for all the field samples and materials tested
- Indicates that electrofusion to contaminated pipe does not compromise joint integrity

Decohesion Testing

- Tested in accordance with ISO 13956-10
- For contaminated and non-contaminated pipe, fusion remained intact, pipe was the point of failure
- Indicates that electrofusion to contaminated pipe does not compromise joint integrity

Material	Saddle Tee		Coupling	
	Average Max Load (Lbf)	Displacement at Max Load (in.)	Average Max Load (Lbf)	Displacement at Max Load (in.)
Baseline Aldyl-A PE2306	4,899.3 ± 24.1	0.75 ± 0.02	2,398.1 ± 85.4	1.47 ± 0.15
Contaminated Aldyl-A PE2306	4,864.8 ± 183.0	0.70 ± 0.03	2,509.6 ± 164.4	1.58 ± 0.23
Baseline Yellow (Infrapipe/Wehogas PE2708)	4,930.8 ± 84.2	0.73 ± 0.07	2,401.2 ± 143.7	1.59 ± 0.14
Contaminated Yellow (Wehogas PE2406)	4,477.5 ± 342.5	0.64 ± 0.15	2,245.6 ± 111.3	2.42 ± 0.49

Optical Microscopy



Tensile Strength

- Samples tested in accordance with CSA B137.0
- Preliminary testing of contaminated Yellow (Plexco PE2406) pipe indicates the material properties are stable and meets/exceeds specification

Test Time (Days After Pipe Removal)	Ring Tensile Strength (MPa)	Wall Thickness (mm)
1	22.2	5.79
2	22.2	5.80
4	21.3	5.80
8	22.1	5.80

Pipe Tensile Strength Test (MEC)

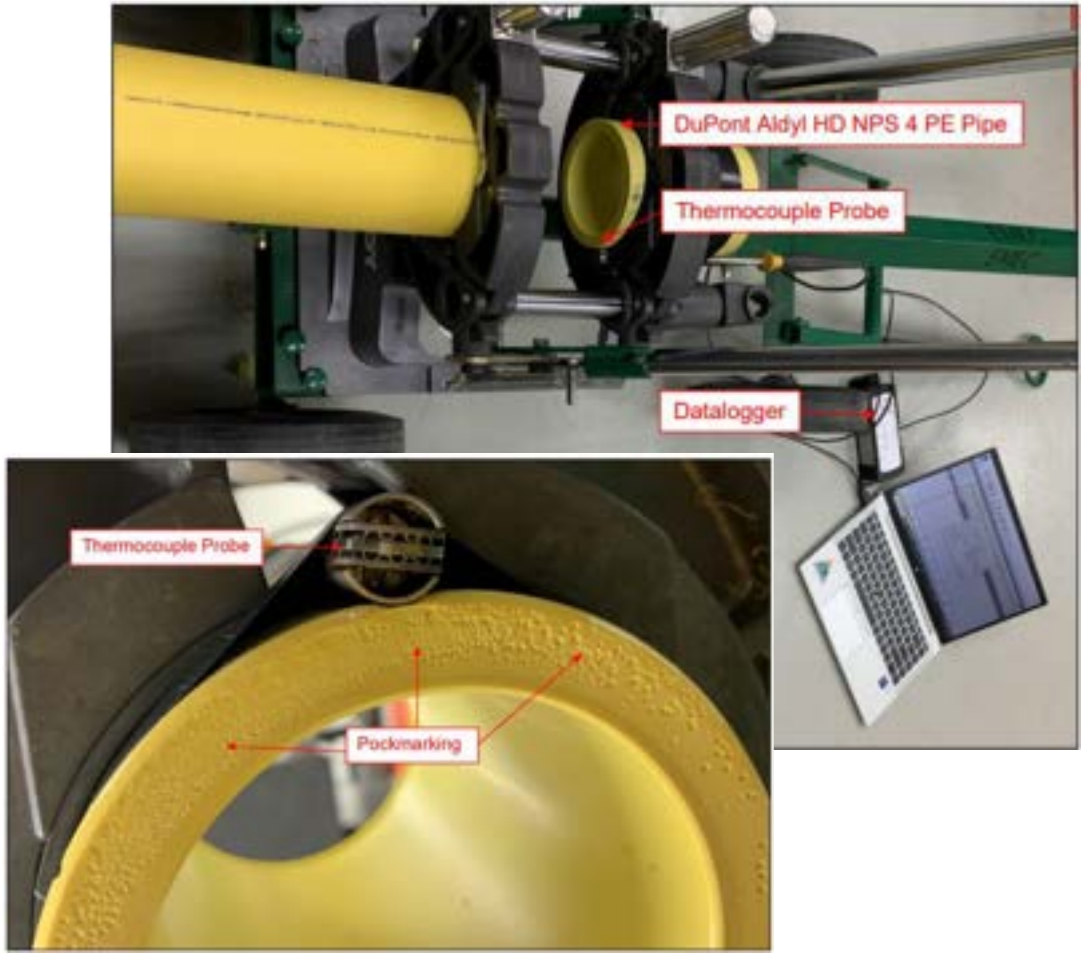
- Quantify strength of contaminated pipe to discern if tensile strength is impacted

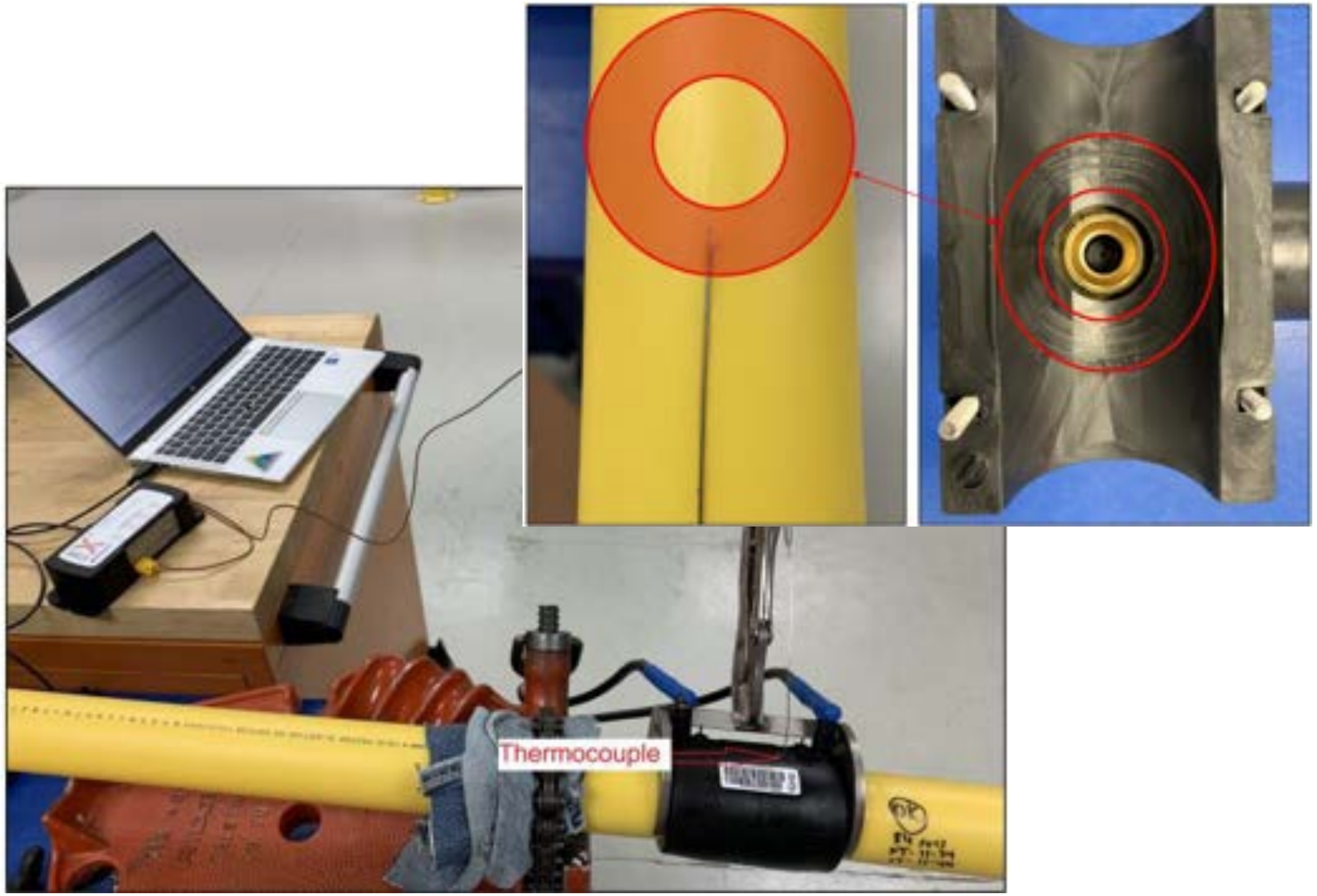
Does the pipe need a de-rating factor?

Summary

1. Formation of pock-marking increases as temperature of fusion increases
2. Electrofusion fittings joined to contaminated pipe passed qualitative evaluations
3. ETPT on contaminated pipe indicate pipe (not the joint) is the weakest point of the assembly
4. Decohesion tests of electrofusion fittings joined to contaminated and baseline pipe show negligible difference in decohesion strength
5. Optical microscopy of fitting/pipe interface indicates minimal formation of voids during fusion process on contaminated and baseline samples
6. Preliminary material/tensile strength testing indicates contaminated pipe properties are stable and exceed minimum strength specifications up to 8 days after being removed from service

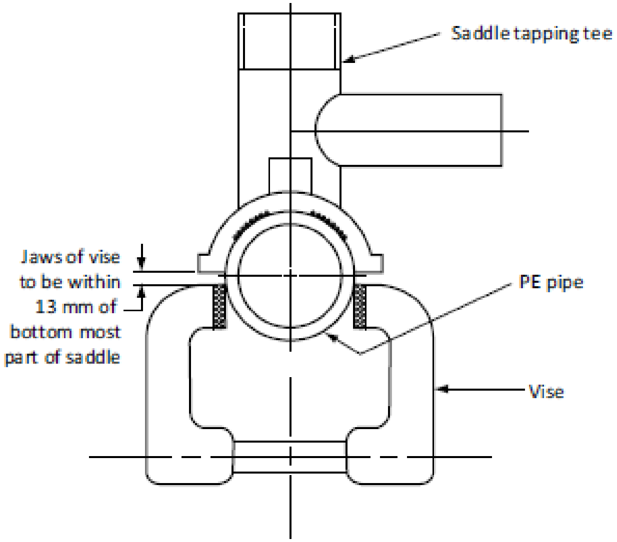
Fusion Interface Temperature Investigation

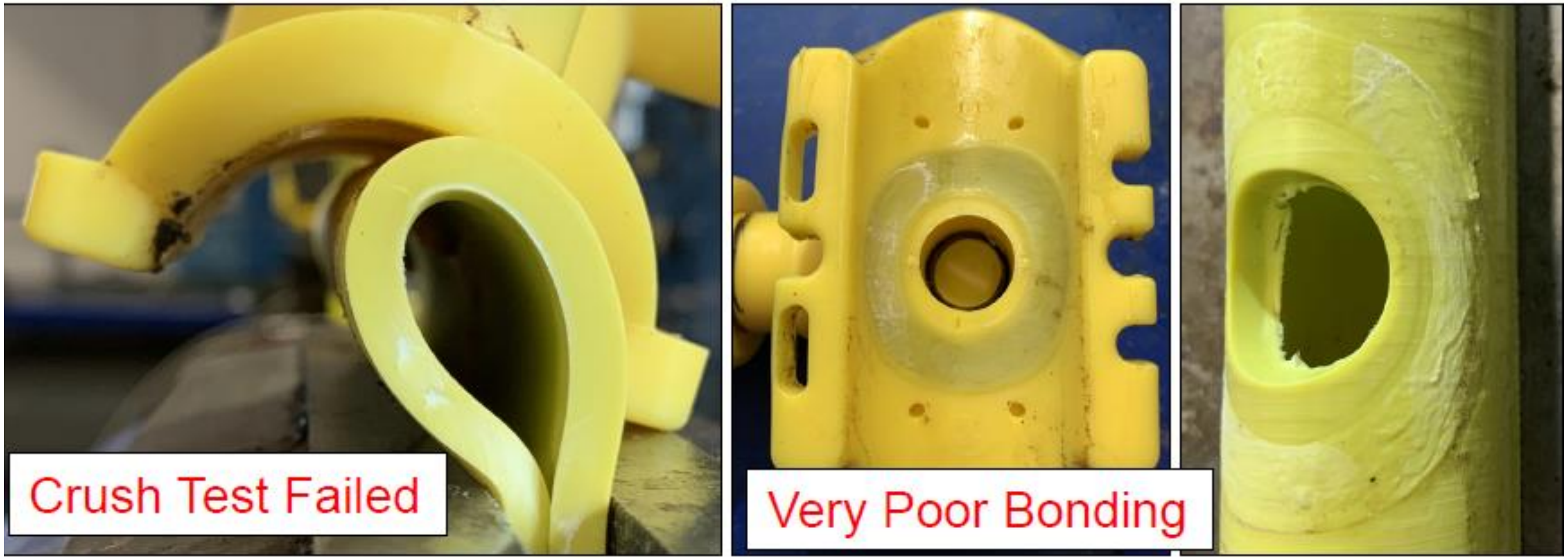




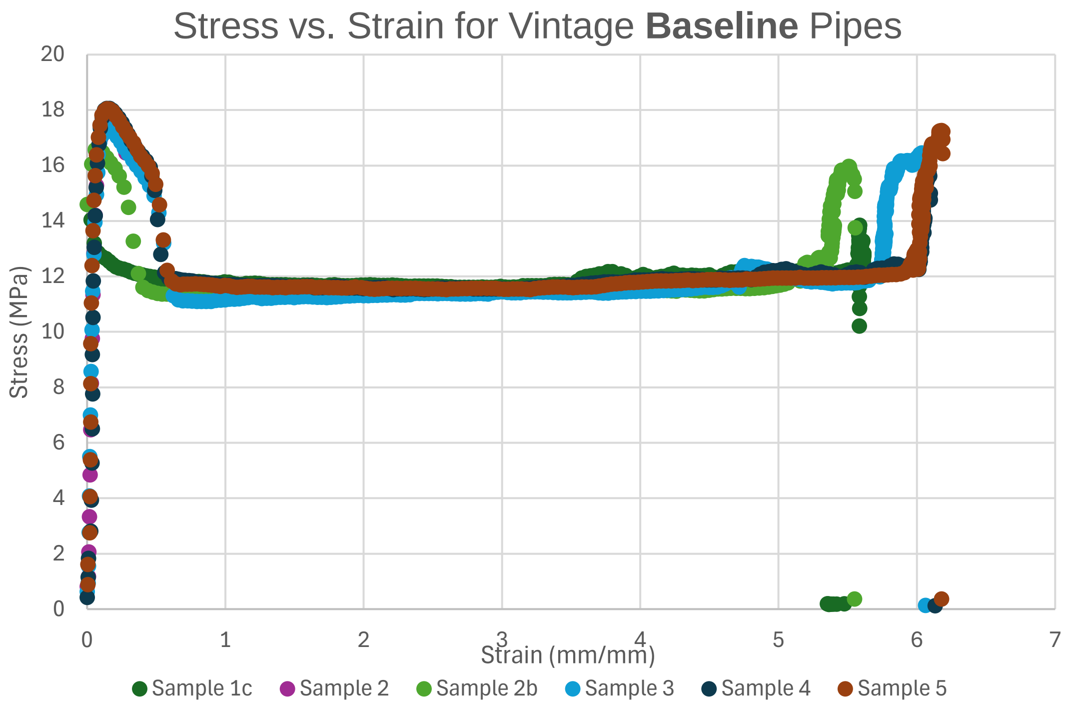
Visual Indication of Crush Test Failure

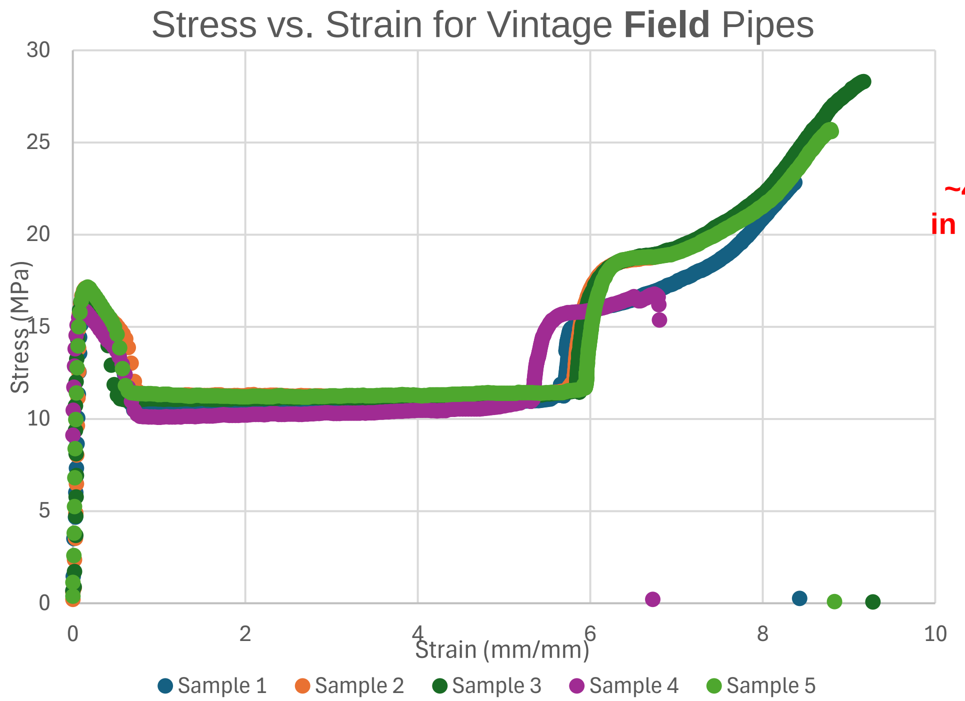
Figure 5
Saddle fitting position before the joint crush test
(See Clause 6.4.3.)





Impact of Contamination on Tensile

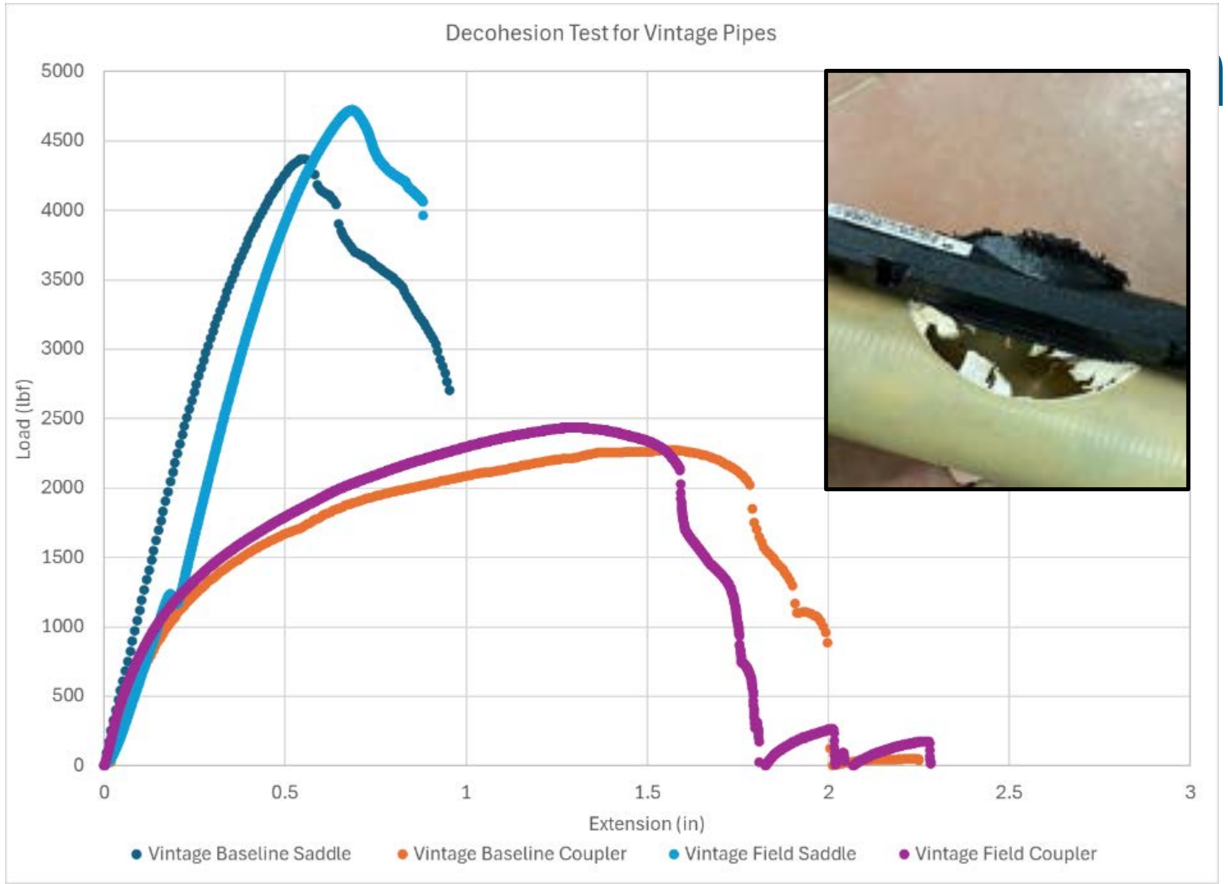


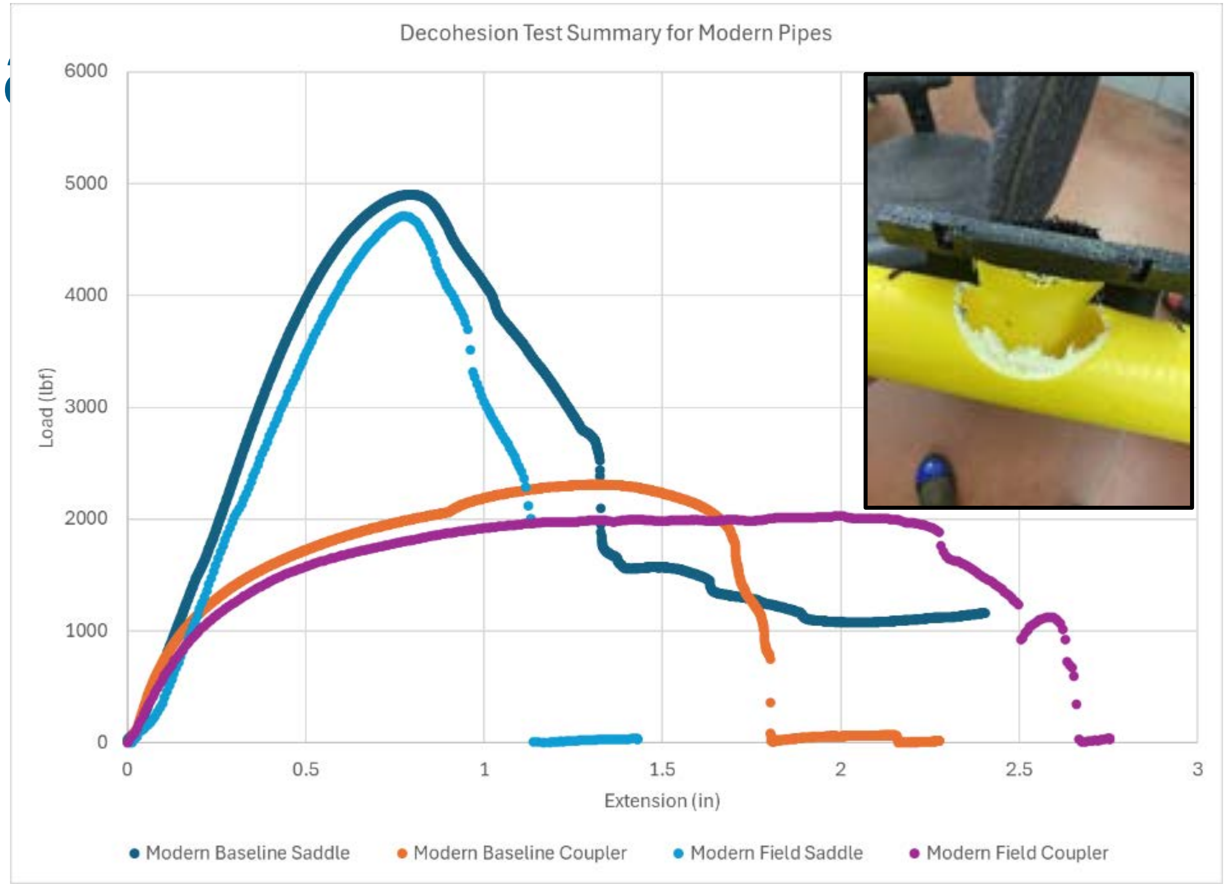


~43% increase in elongation at break

Sample ID	Average Extension at Break (%)	Average Stress at Break (MPa)	Average Stress at Yield (MPa)
Vintage Baseline	591 ± 30	17.57 ± 0.61	16.26 ± 1.62
Vintage Field	848 ± 99	24.16 ± 4.62	16.61 ± 0.61
Modern Baseline	747 ±15	15.46 ± 0.40	21.12 ± 2.27
Modern Field	563 ± 24	11.37 ± 0.21	16.73 ± 0.16

CGA Energy Nexus & Annual Technical Conference 2025





Custom decohesion rig produced repeatable failures for both saddle and coupler joints at the electrofusion joint interface.

Optical Microscopy

Sample ID	Type of Cut	Approximate Void Size w.r.t Fusion Zone Length (%)	Approximate Size of Voids (mm^2)
Modern Baseline Saddle – Sample 4	Axial	N/A	N/A
	Circumferential	N/A	
Modern Baseline Saddle – Sample 8	Axial	1.37 ± 0.0	0.20 and 1.37
	Circumferential	0.20 ± 0.0	
Modern Baseline Saddle – Sample 9	Axial	2.86 ± 0.0	2.86
	Circumferential	N/A	
Modern Field Saddle - Sample 6	Axial	9.52 ± 6.11	0.13, 0.19, 0.22, 0.34, 1.29, 2.33, 2.63, 4.13
	Circumferential	10.81 ± 2.45	
Modern Field Saddle - Sample 9	Axial	5.40 ± 4.85	0.58, 0.58, 1.31, 1.33, 1.02, 2.12, 3.01, 3.38, 3.75
	Circumferential	14.53 ± 13.84	
Modern Field Saddle – Sample 11	Axial	5.40 ± 4.53	0.25, 0.32, 0.43, 1.00, 3.21, 3.34
	Circumferential	2.57 ± 1.49	
Vintage Baseline Saddle – Sample 2	Axial	9.55 ± 5.76	1.51, 2.20, 3.62, 8.61
	Circumferential	7.29 ± 3.24	
Vintage Field Saddle -Sample 8	Axial	7.19 ± 0.55	1.37, 2.14, 1.08, 3.83, and 3.33
	Circumferential	29.96 ± 0.0	
Vintage Field Saddle – Sample 9	Axial	N/A	3.46, 10.65, and 7.71
	Circumferential	19.68 ± 13.62	
Vintage Field Saddle -Sample 11	Axial	N/A	0.005 and 10.67
	Circumferential	7.54 ± 10.21	

Laboratory Immersion Study – Observations

Chemical	Level of Pock Marking Observed	Duration
Water, *liquid*	None	No pock marking observed after immersion
Carbon Dioxide (CO_2), *gaseous*	Minor	Minor pock marking observed up to 24 hours after immersion
Methane (C_1), *gaseous*	None	No pock marking observed after immersion
Ethane (C_2), *gaseous*	None/Minor/Aggressive	Aggressive pock marking observed up to 24 hours, minor after 48 hours and none after 7 days after immersion
Pure Propane (C_3), *gaseous*	Aggressive	Aggressive pock marking observed up to 7 days after immersion
Commercial Propane (C_3), *gaseous*	Moderate/Aggressive	Aggressive pock marking observed up to 90 mins, moderate up to 96 hours after immersion
Gaseous Butane (C_4), *gaseous*	Aggressive	Aggressive pock marking observed up to 7 days after immersion
Butane (C_4), *liquid*	Minor/Moderate/Aggressive	Aggressive pock marking observed up to 24 hours, moderate after 48 hours and none after 7 days after immersion
Hexane (C_6), *liquid*	None	No pock marking observed after 30 days of immersion
Octane (C_8), *liquid*	Minor	Minor pock marking observed up to 96 hours after immersion
Nonane (C_9), *liquid*	None/Minor	Minor pock marking up to 48 hours, none up to 120 hours after immersion
Toluene ($C_6H_5CH_3$), *liquid*	Minor	Minor pock marking observed up to 7 days after immersion
Diesel (mix of C[illegible]), *liquid*	None	No pock marking observed after 30 days of immersion