



Team #36: Freeze Plug Analysis

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Background

- Freeze Plugs: Solid ice barriers that form in piping under cryogenic conditions
- Non-invasive method of pipeline isolation that requires no flow within pipe and subjects pipe to low temperatures
- Phillips 66 believes freeze plugs are a safe and economical alternative to existing invasive isolation methods.

Project Description

Objective Statement

Develop an apparatus (Jacket) that will cryogenically freeze water-containing pipes, determine if the plug can withstand a maximum pressure of 20 psig, and evaluate pipe strength and hardness of A106B carbon steel pipe after plug removal.

Design Specifications

Pipe Assembly		Achieved
P66 Cooling Water Pipe Specifications	4" ASTM A106B SCH 40. PIPE (0.237") with compatible connections piping	✓
	$P_{max} = 20$ psig	✓
	$T_{i, water} =$ Ambient Conditions	✓
ASME PCC II	Length of pipe = 13*ODpipe	✓
	No flow in pipe	✓
Data Collection	Modular, robust & self-supported system	✓

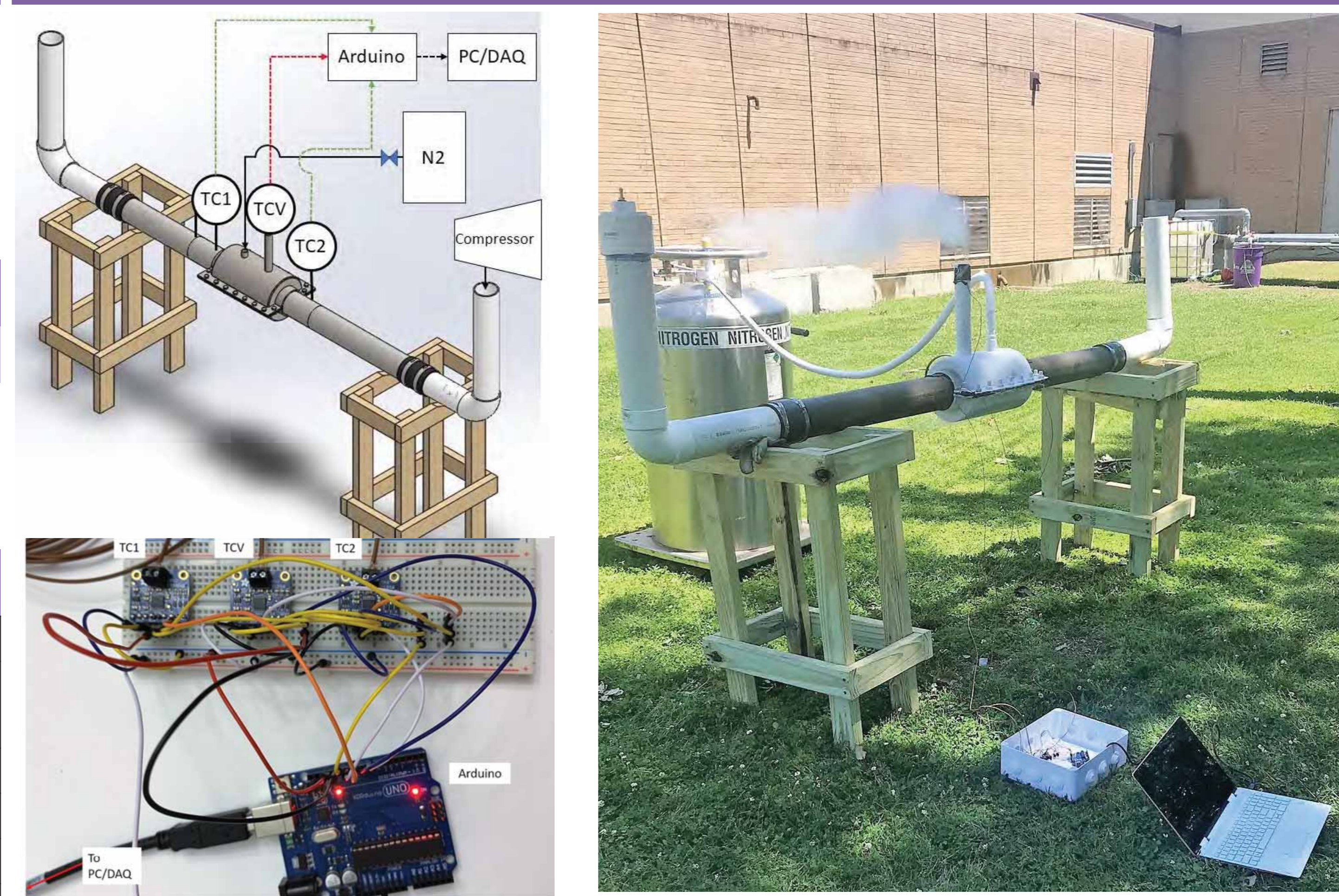
Freeze Apparatus		Achieved
ASME PCC II	Jacket Length = 3*(Pipe Diameter)	✓
	Jacket Diameter= 2*(Pipe Diameter)	✓
	Fabricated for cryogenic conditions following an impact tested procedure	✓

Instrumentation		Achieved
Temperature Data Collection	Collection of temperature data	✓
	Safe and efficient formation of freeze plug	✓
	Monitor formation of plug	✓

Project Management

Milestones	Budget
Design & Embodiment (8/2018-12/2019)	
Realization (Procurement (1/2019-2/2019) Manufacturing (2/2019-3/2019))	
Testing & Validation (Subsystem Testing (3/1/2019-3/31/2019) System Testing (4/1/2019-4/15/2019))	
Completion (Analysis (4/4/2019-4/21/2019))	

Freeze-Master 2200



Results & Validation

Hardness				Charpy Impact Strength					
	n	\bar{x}	σ	s^2		\bar{x}	σ	s^2	
Frozen Samples	45	78.77 HRB	2.48 HRB	6.15 HRB	Frozen Samples	9	75.44 J	15.21 J	231.28
Unfrozen Samples	45	76.2 HRB	3.62 HRB	13.15 HRB	Unfrozen Samples	9	64.67 J	10.30 J	106

2-Sample t-Test for Means of Unequal Variance		2-Sample t-Test for Means of Unequal Variance	
$H_0: \mu_{unfrozen} = \mu_{frozen}$	78 Degrees of Freedom	$H_0: \mu_{unfrozen} = \mu_{frozen}$	16 Degrees of Freedom
$\alpha = 0.05$	$P(T \leq t)_{2-tail} \ll 0.05$	$\alpha = 0.05$	$P(T \leq t)_{2-tail} = 0.09$
$t_{critical} = 3.93$	$t_{2-tail} = 1.99$	$t_{critical} = 1.76$	$t_{2-tail} = 2.12$

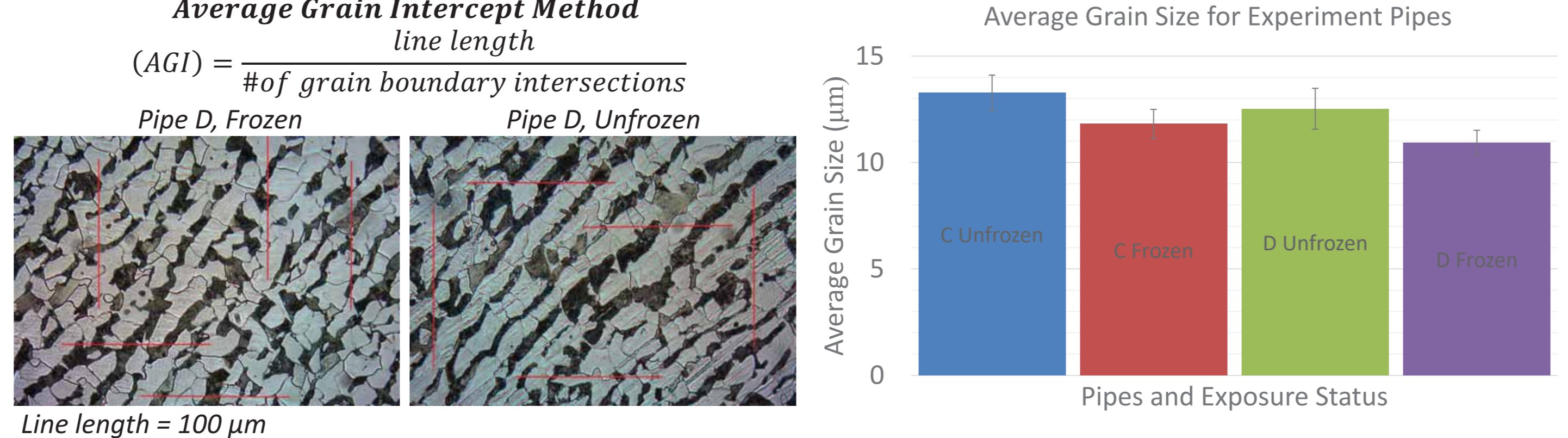
Result: Reject null hypothesis
 $\mu_{unfrozen} \neq \mu_{frozen} \left\{ \begin{matrix} t_{2-tail} < t_{critical} \\ P(T \leq t)_{2-tail} < \alpha \end{matrix} \right.$

Results: Do Not Reject Null Hypothesis
 $\mu_{unfrozen} = \mu_{frozen} \left\{ \begin{matrix} t_{critical} < t_{2-tail} \\ \alpha < P(T \leq t)_{2-tail} \end{matrix} \right.$

The difference in hardness is significant. Freezing contributed to increased hardness.

Impact strength of frozen and unfrozen pipe is not significantly different

Metallography



Safety

- Cryogenic materials: Proper PPE must be worn at all times: cryogenic gloves and safety glasses
- Nitrogen Breathing Hazard – Testing outside, monitoring upwind of apparatus.

Manufacturing

- Drilling, water-jet cutting, welding.
- Apparatus fabricated using 316 SS.
- All welding procedures must be successfully impact tested at -320°F. (Fabrication performed by GEO Heat Exchangers, LLC)

Testing

- Calibrate instrumentation and identify the minimum time required to form a solid ice plug (3 repeatable trials).
- Perform one additional trial and apply 20 psig pressure to the ice plug.
- Cut the test pipes into samples for charpy testing and hardness testing.

	Trial 1 (Pipe D)	Trial 2 (Pipe C)	Trial 3 (Pipe A)	Trial 4 (Pipe B)
Ambient Outside Temp. (°F)	68.80	70.70	71.10	77.20
Initial Water Temp. (°F)	95.30	94.50	94.80	90.10
Freeze Time (minutes)	73.00	45.00	45.00	42.00
Average Vent Temp. (°F)	N/A*	-253.60	-281.74	-242.97
Min. Temp TC 1(°F)	-34.76	-14.26	-19.21	38.46
Min. Temp. TC 2 (°F)	12.81	35.83	26.40	54.97

* First Trial Involved Excessive Troubleshooting with the liquid Nitrogen Supply



Analysis

