

Tankless Water Quenching of Production Steel Castings

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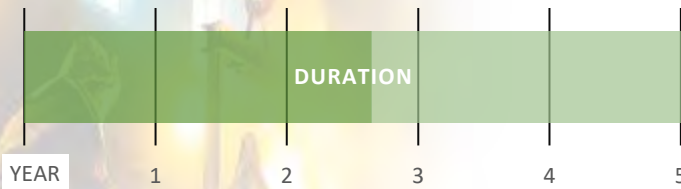
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Emergent Metal Casting Technologies (EMCS)

AMC Technology Review

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Overview

- **Needs and Benefits**

- This project will benefit DoW/DLA in producing steel castings that possess desired properties by a properly controlled spray quench that allow specific areas of a part to have a higher strength where needed but also produce specific areas where higher toughness is required

- **Progress**

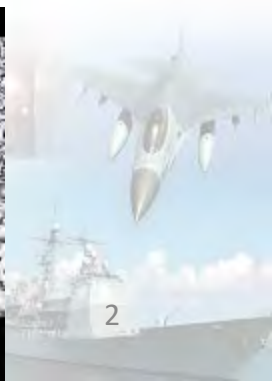
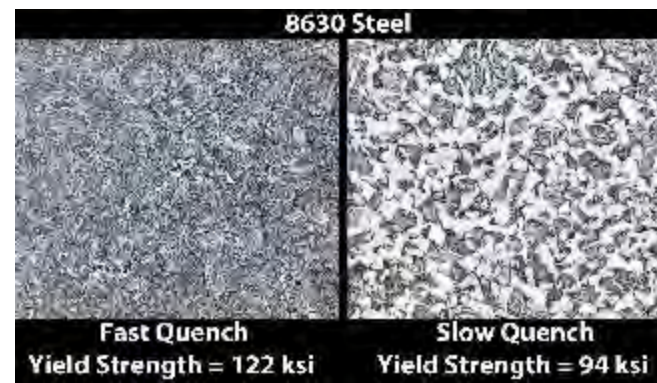
- Spray Quench rig has been built and tested with 1" and 2" diameter probes

- **Transition**

- Communication has been made to a local company Pinson Valley Heat Company to discuss the transition of the results into industry

- **Cost Share Provided**

- \$47,215 to Date



Needs

- Problem and relevance to DoW)
 - Traditional immersion quench tanks produce satisfactory properties every day for both commercial and military steel castings. However, if uniform hardness and/or low distortion are important/critical, casting geometries such as deep pockets/through holes/blind holes or thin and thick sections are a challenge to handle with immersion quenching. A limitation of immersion quenching is that the quench rate can not be specifically tailored to a particular casting area.
- Objective
 - Objective is to develop a quenching methodology capable of producing variable quench rates tailored to the geometry of the casting and customer requirements.
- Technology
 - Spray quenching has been used for decades to produce custom-made cooling rates for everything including steel production. Spray nozzles can be specially located for specific casting geometries and adjusted to produce a wide range of quench rates.

Benefits

Benefits:

- DoW

- Spray quenching has the ability to provide more uniform mechanical properties and quench difficult areas better than immersion quenching

- Potential cost savings by reducing cracking in thin sections
 - More uniform properties should improve performance of parts
 - Could potentially replace oil quenching
 - Eliminate environmental issues with oil quenching
 - Eliminate fire hazard with oil quenching
 - Potential cost savings by not using oil

Milestones/Tasks

- Completed
 - Task 1 - Design and build a small spray quench system
- In Progress
 - Task 2 – Measuring thermal profile in quenched casting
 - Task 3 - Quenching, testing and characterization of castings
- Planned
 - Task 4 - Design and build a large tankless quench system
 - Task 5 - Quenching, testing and characterization of castings
 - Task 6 - Optimization of the large quenching setup
 - Task 7 - Final Best Practices Manual



Technical Progress



Literature Review

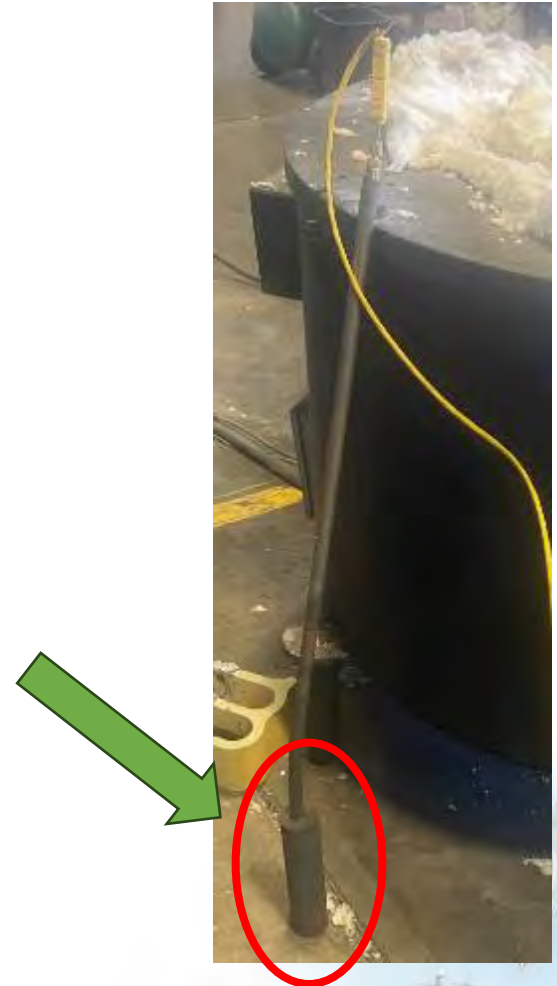
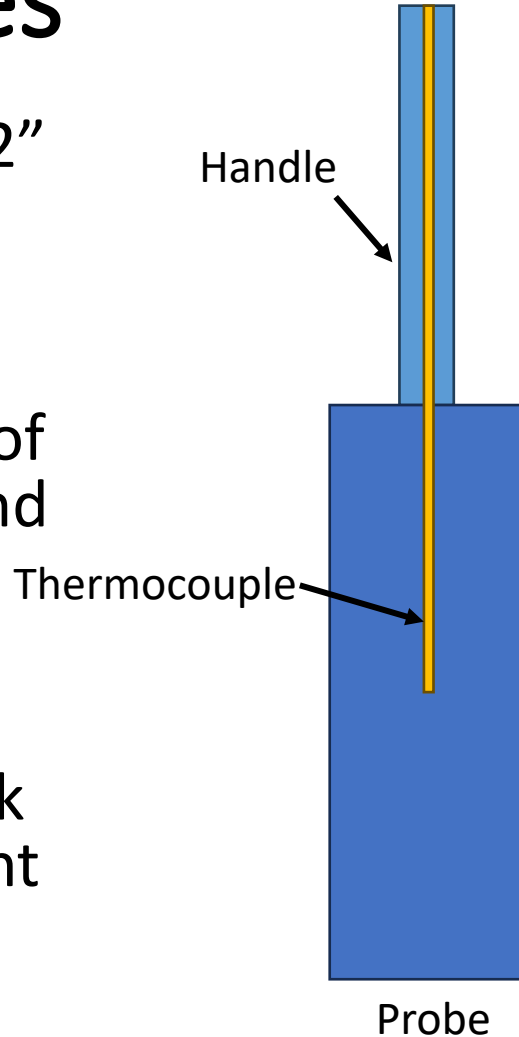
- Over 1,000 papers and articles were examined for the literature review. Spray quenching is a mature process and is being used in a wide variety of industries, cooling ranges, coolants, and objectives, such as cooling people, semiconductors or steel. Furthermore, some information regarding spray quenching may be considered either proprietary or too specific to be released into the public domain.
- Obviously, many of the papers did not directly or indirectly address the specific objectives of this project. For a first cut, only papers that specifically discussed the cooling of steel at or near the austenization temperature using sprayed water were summarized.

Contacted Local Spray Nozzle Manufacturer

- Met with Spraying Systems Co.
 - Talked about nozzle options, spraying technology, how to get a severe quench
 - They suggest a hybrid nozzle (uses both air and water)
- Shared immersion quench data asking for a nozzle setup to achieve the same cooling rates or better
- They did NOT provide nozzle details, pressure settings, or flow rate settings to achieve the desired cooling rates
- They also could not test in house

Produce Baseline of Immersion Quench Rates

- Fabricated 1" and 2" diameter stainless steel probes
- Thermocouples installed in center of mass away from end effect
- Measured quench rates in small (30 gallon) quench tank in house at different flow rates.



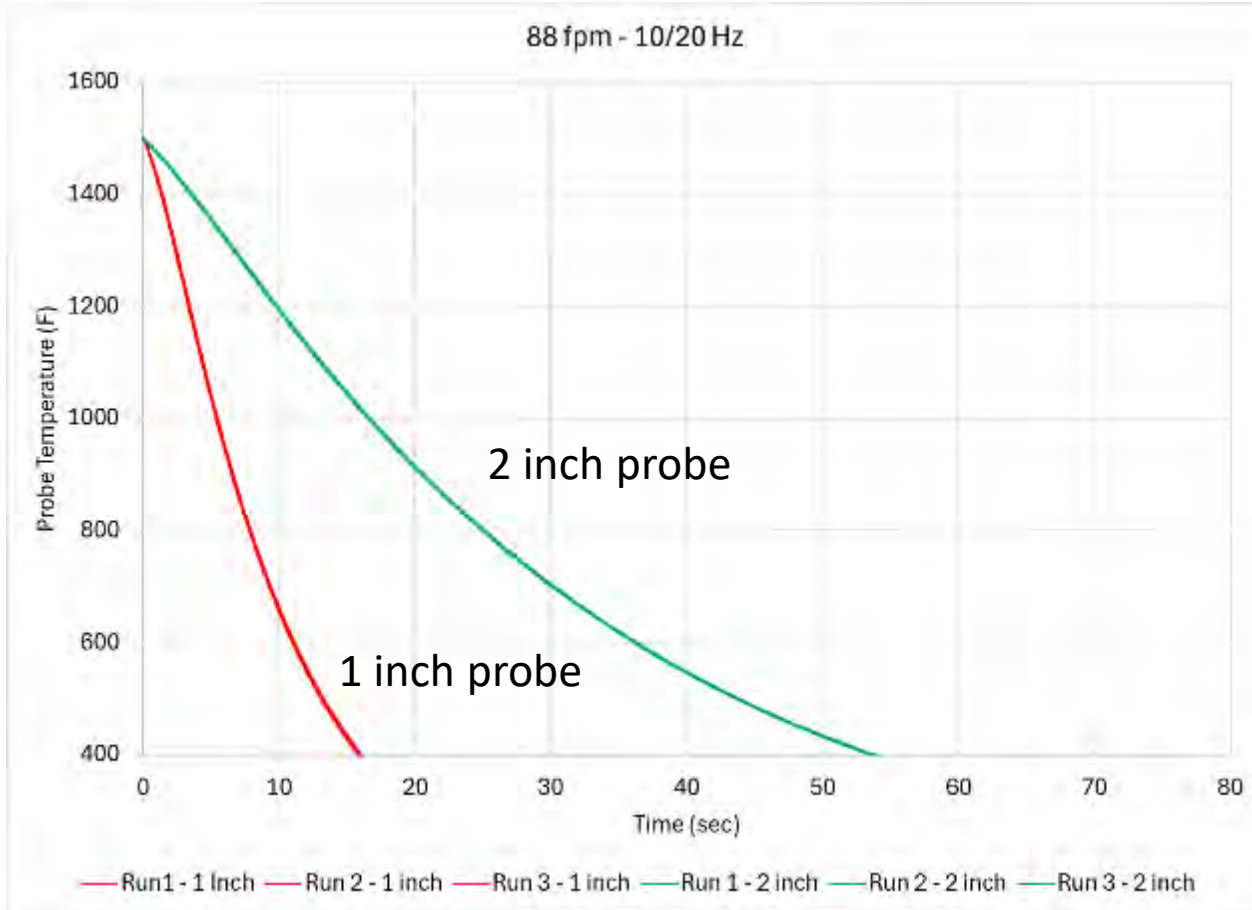
Produce Baseline of Immersion Quench Rates



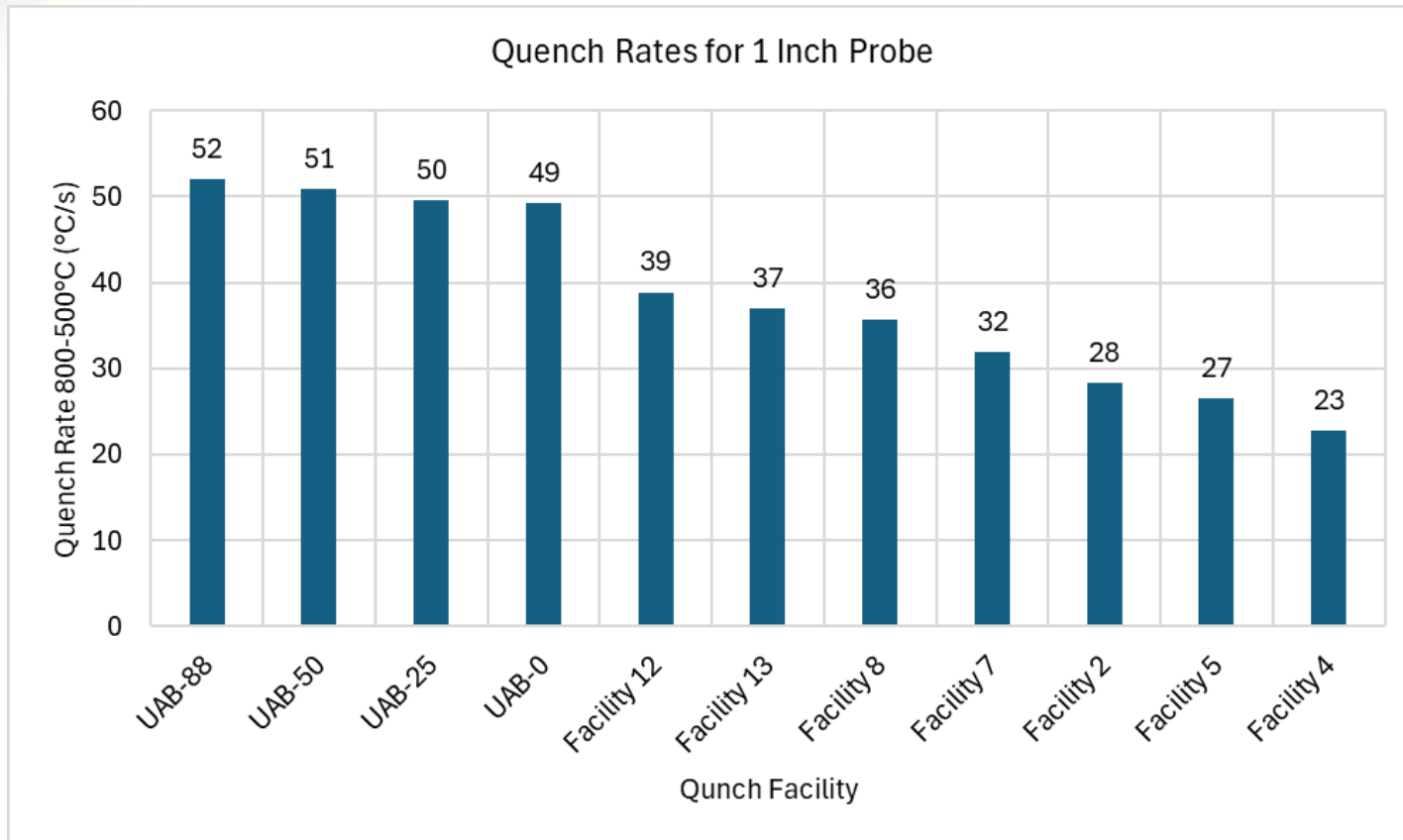
20 Gallon Quench Tank



Produce Baseline of Immersion Quench Rates

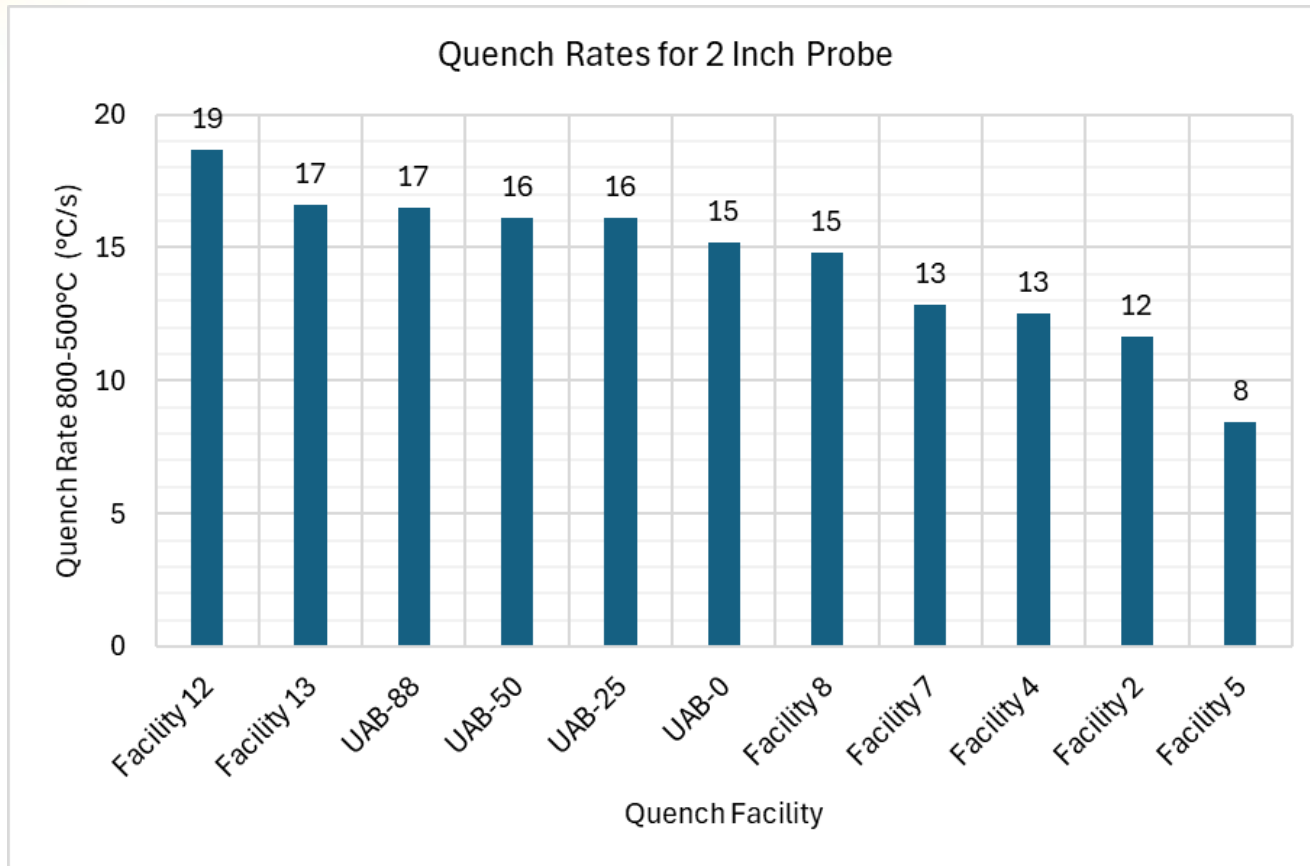


Baseline Quench Rates from Industry – 1” Probe



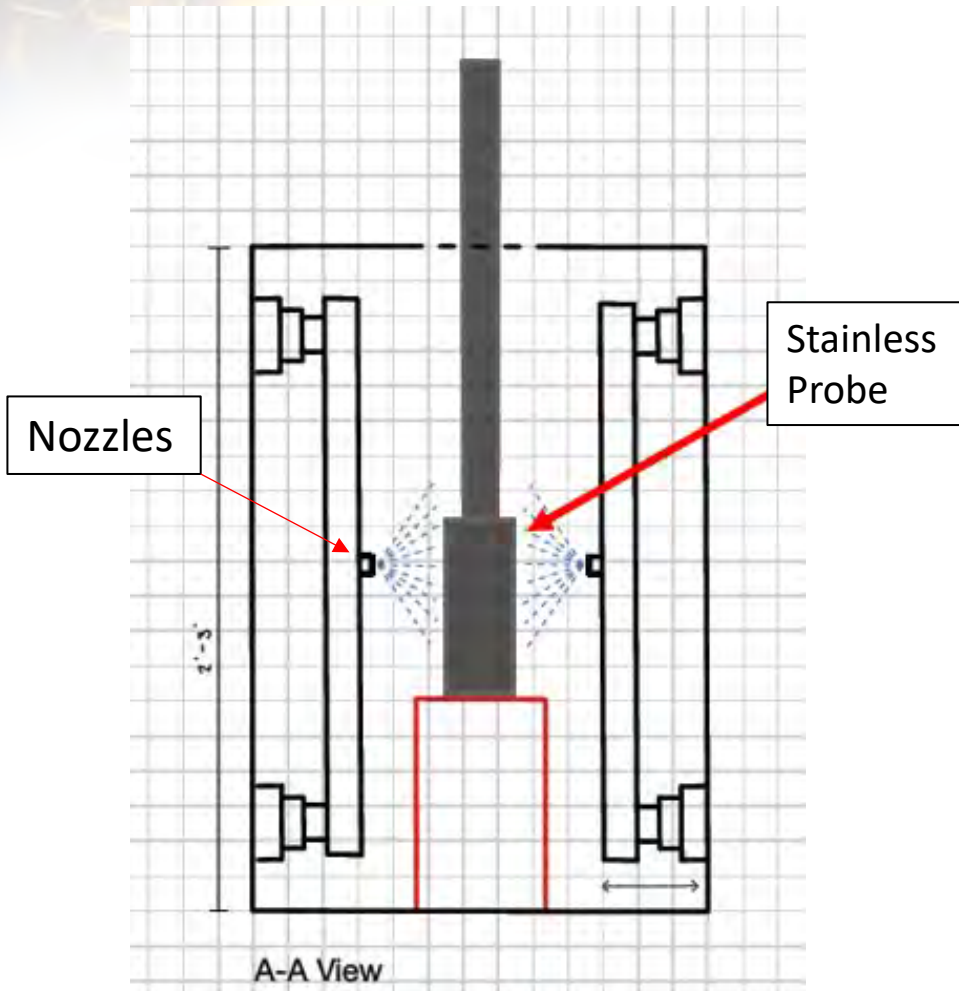
*Data collected at facilities was sampled at 1 Hz, data collected at UAB was sampled at 20 Hz

Baseline Quench Rates from Industry – 2” Probe

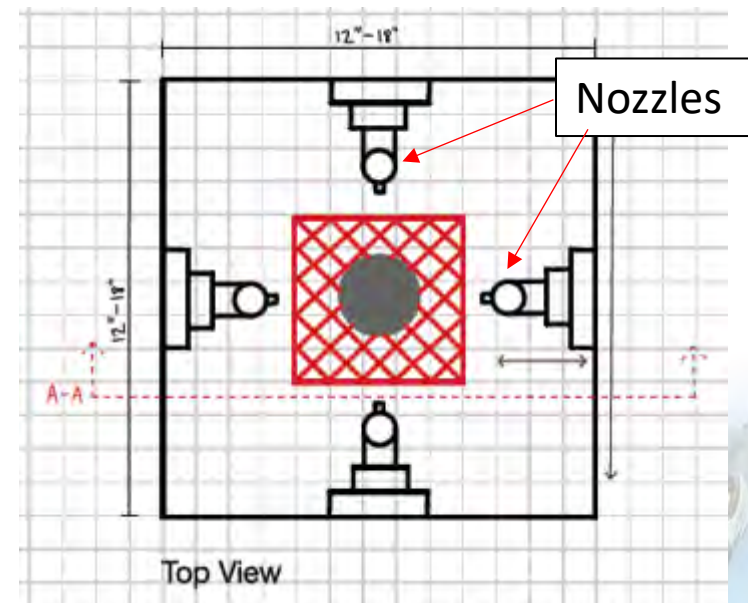


*Data collected at facilities was sampled at 1 Hz, data collected at UAB was sampled at 20 Hz

Designed Spray Quench Rig



- Design consists of an extruded aluminum frame with 4 nozzles placed 90° apart
- Nozzle positions are adjustable
- Stainless probe in center



Nozzle Selection

- Air atomizing nozzles were chosen
- Flat spray pattern
- Two different nozzle setups were chosen
 - SUN23 (0.84 to 16.7 gallons per hour water flow)
 - SU43 (5 to 44.7 gallons per hour water flow)

*Nozzle setup includes a fluid cap and an air cap

PERFORMANCE DATA:
PRESSURE SPRAY SET-UPS | INTERNAL MIX | FLAT SPRAY

For a flat spray pattern, "A" and "B" are the pattern widths at distances from the nozzle.

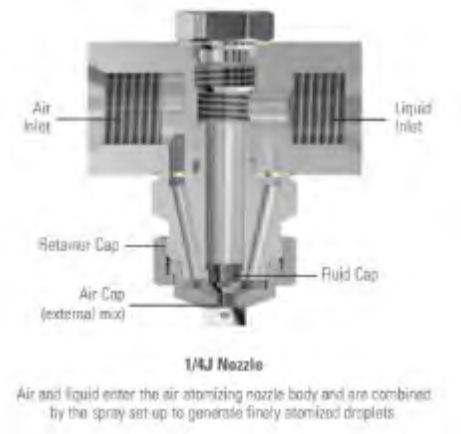
The total distance of spray projection from the nozzle to the maximum dispersal point is represented by "C".

Liquid is supplied to this spray set-up under pressure.

Liquid and compressed air or gas are mixed internally to produce a completely atomized spray.

When ordering only a spray set-up, 3199 retainer ring and 3612 gasket must be ordered separately. These components are included in a complete air atomizing nozzle assembly.

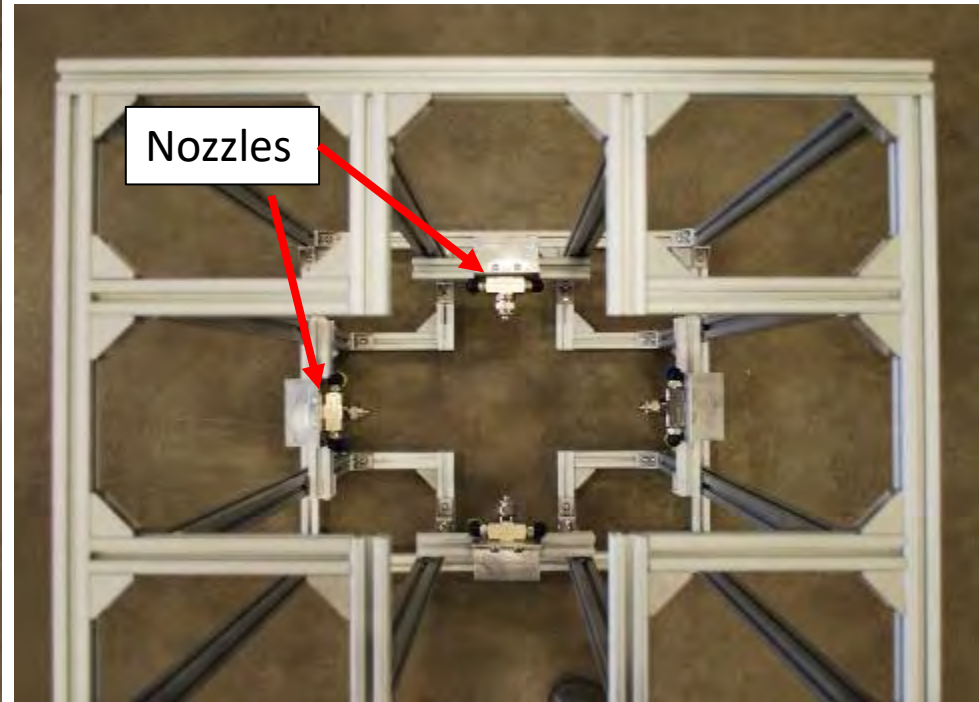
Please contact your sales engineer for more information



Construction of Spray Quench Rig



Extruded aluminum frame



Construction of Spray Quench Rig

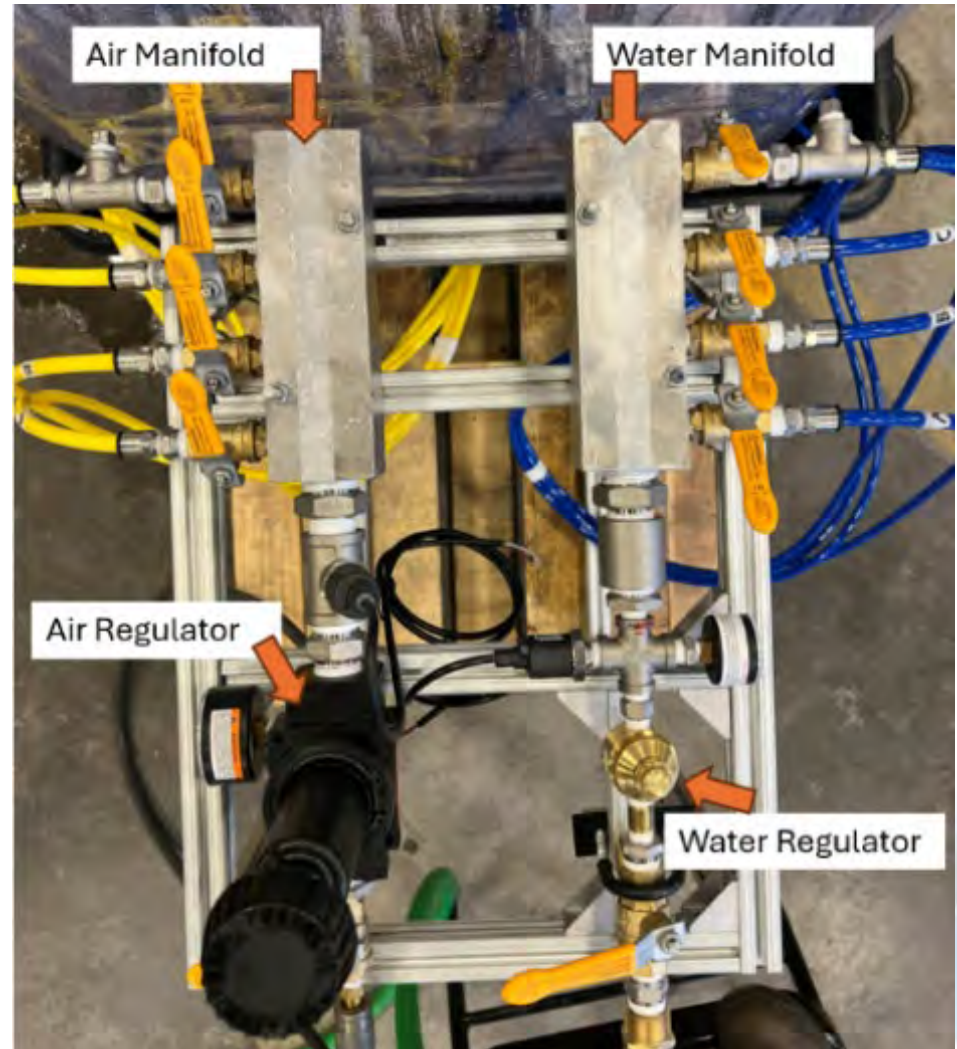


Air and Water Supply

- Each nozzle has its own connection for compressed air and for water
- The compressed air is coming from an air compressor at 175 psi through a ¼" air line, then reduced via a regulator before going into the manifold to feed the sprays
- The water is coming from the building water pipe. It is a ½" copper pipe at 65 psi static pressure. That is fed through a ¼" regulator before going into the manifold to feed the sprays.

Initial Air and Water Supply

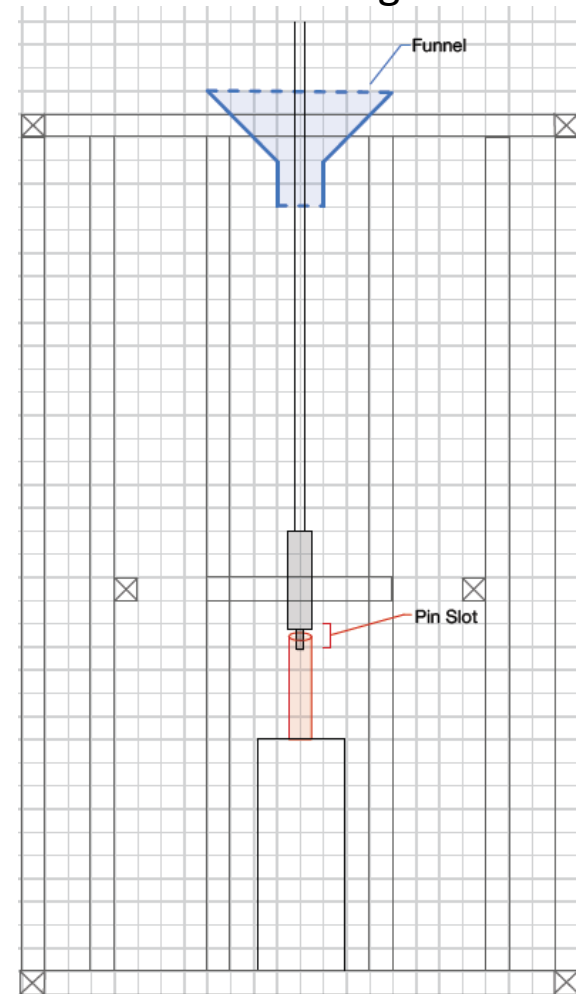
- Air manifold on the left
 - $\frac{3}{4}$ " pipe air regulator
 - 0 to 100 psi pressure transducer
- Water manifold on the right
 - $\frac{1}{4}$ " pipe water regulator
 - 0 to 100 psi pressure transducer



Probe Alignment

- Needed consistent placement of probes for every test
- Needed it to be easy and quick
- Design was to use a funnel in the top part of the rig to guide the probe and something like a pin and slot in the bottom to hold the probe in place
- Settled on using a conical alignment pin in the bottom of the spray rig and a conical hole in the bottom of the probes

Initial Design



Probe Alignment

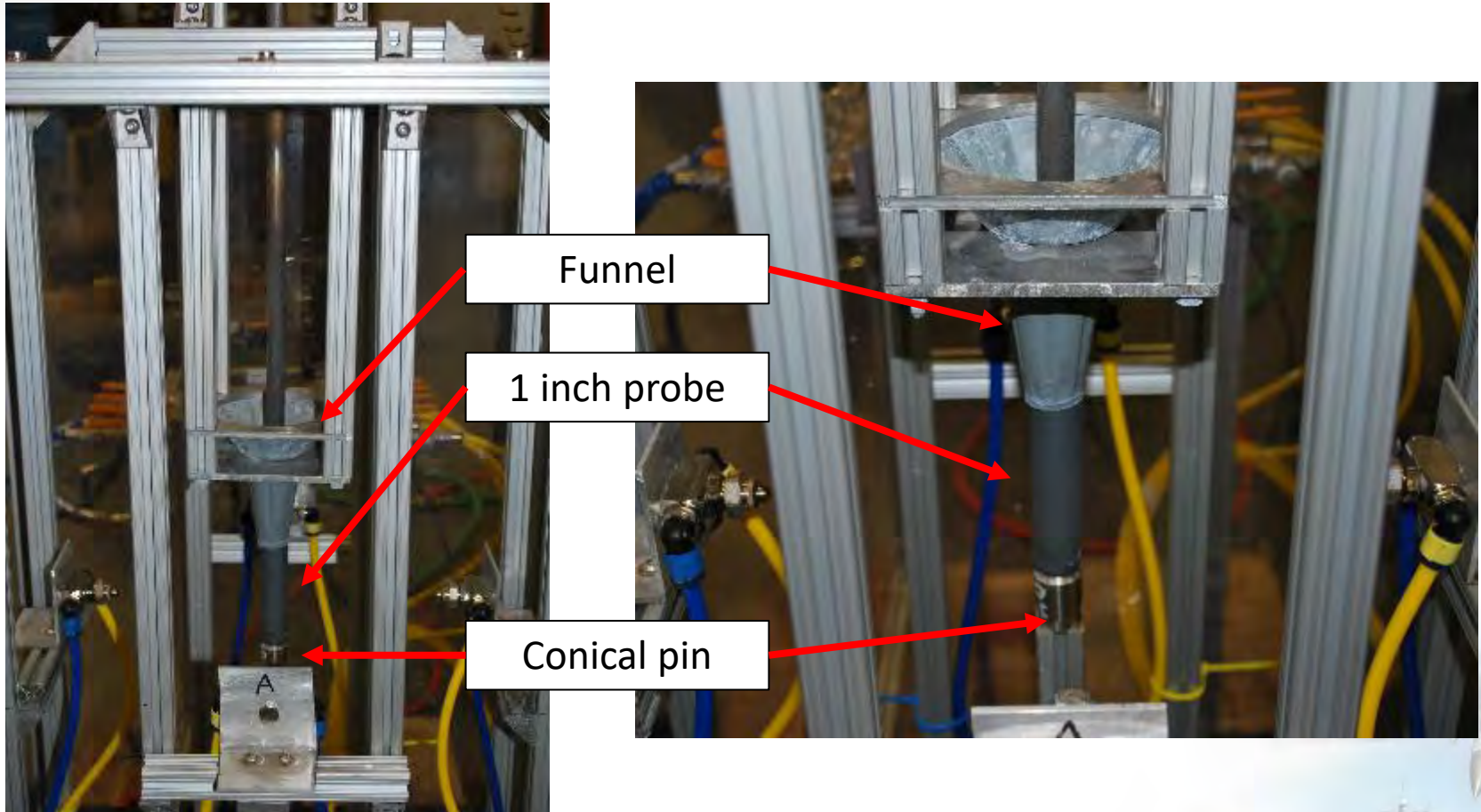


Conical holes in bottom of probes

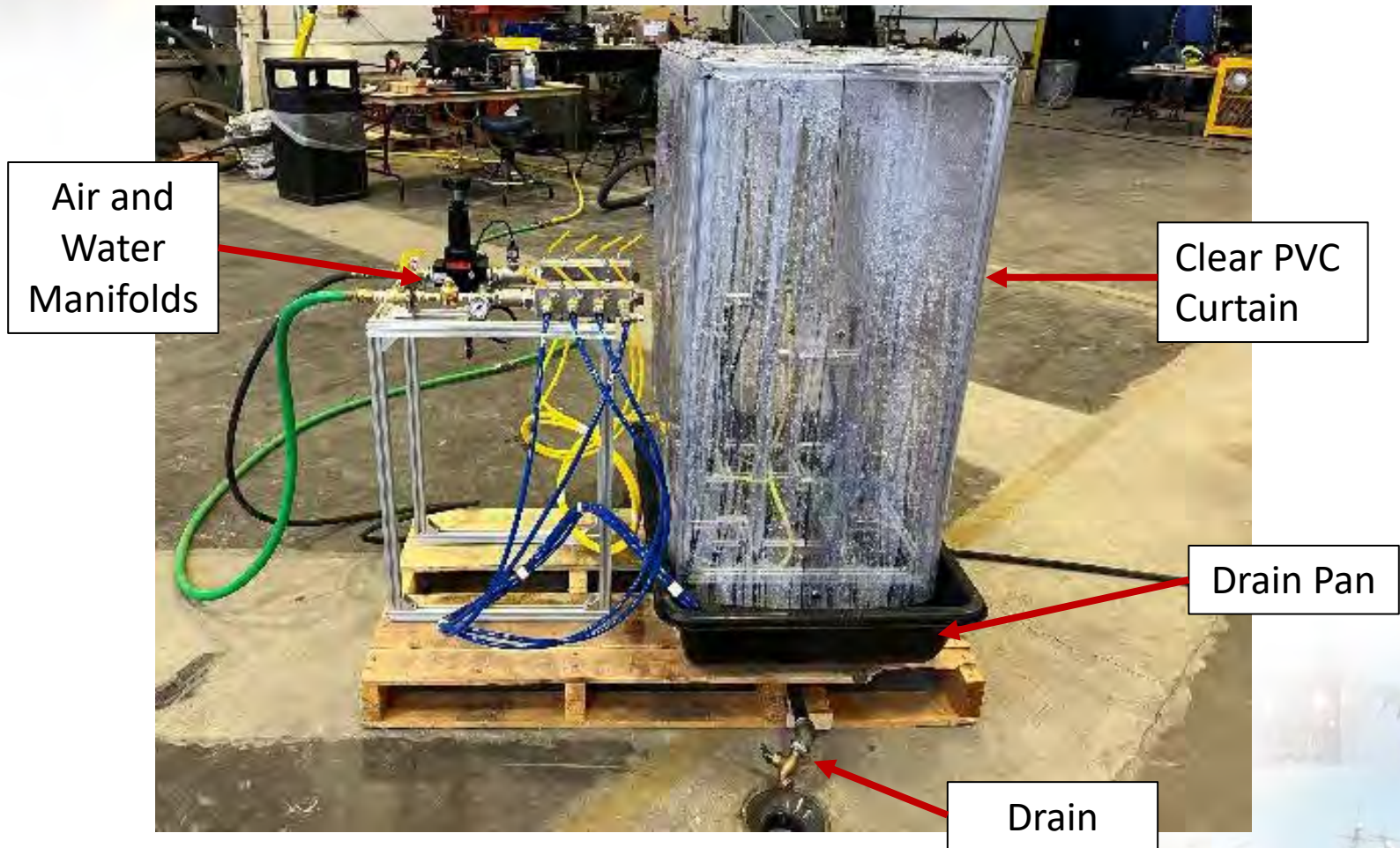


Conical pin

Probe Alignment Completed

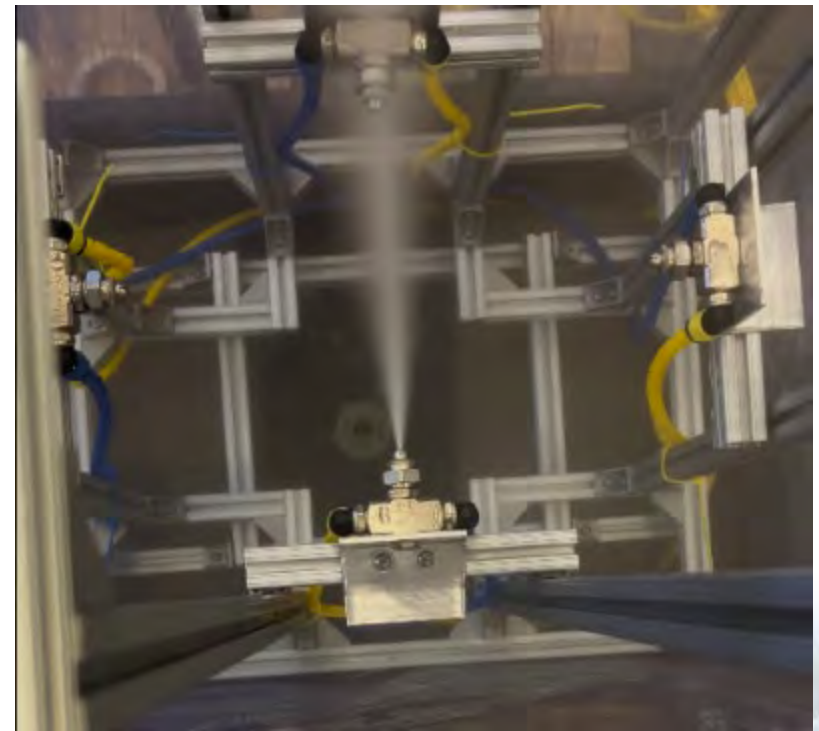


Clear PVC Curtain and Drain Pan



Testing Sprays without Probe

- Flow rates were verified at 30 psi water and 32 psi air on one nozzle while all 4 nozzles were running
 - A hose was attached to the nozzle and ran to a bucket with volume markings. The flow rates were in range with published data from the nozzle manufacturer.



Testing Procedure

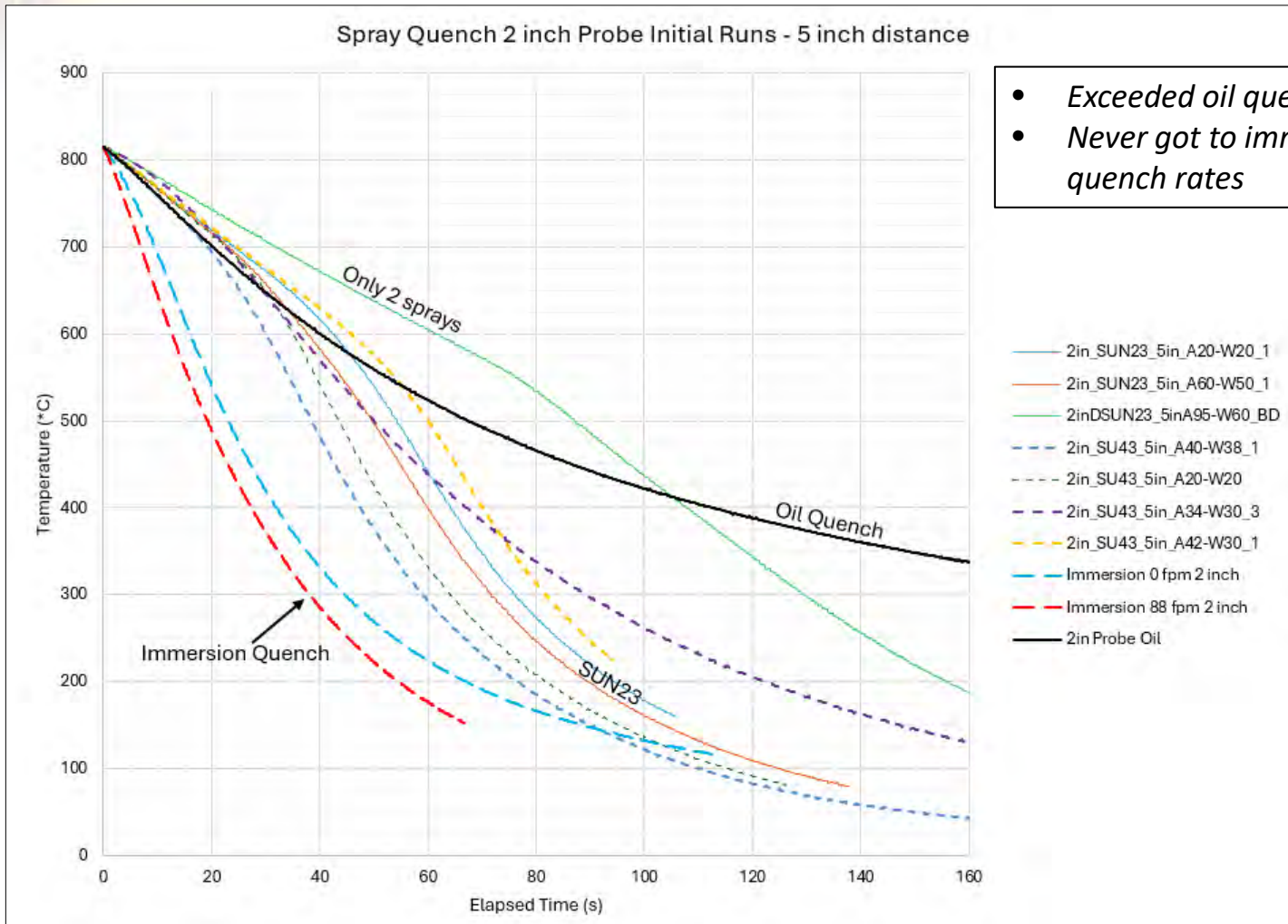
- Probe is heated in pit furnace to above 820 C
- Air and water are turned on and pressures are adjusted without probe using the mechanical pressure gauges
- Both air and water have on/off ball valves that are shut once the pressures are set
- The hot probe is pulled out of the pit furnace
- The data logger is started
- The hot probe is placed in the spray quench rig
- Air and water valves are opened
- Probe temperature is recorded during cooling process

Initial Testing With 2 Inch Probe

- 9 runs performed initially
- Quench rate calculated from 800 to 500°C and 1380 to 1220°F
- Runs 1 through 3 runs with setup SUN23
 - Fastest cooling rate achieved was 6.5°C/s
- Runs 4 through 9 with setup SU43 (increased flow rate)
 - Fastest cooling rate achieved was 8.4°C/s
- Immersion quench rates for the 2” probe range from 14 to 17 °C/s
- Oil quench rates for the 2” probe are 4.6 to 4.7 °C/s

Run	Probe Diam (in)	Air Pressure (psi)	Water Pressure (psi)	Spray Distance from Surface of Probe (in)	Spray A	Spray B	Spray C	Spray D	Time from 800 to 500c (s)	Time from 1380 to 1220 °F (s)	Quench Rate 800 to 500 (°C/s)	Quench Rate from 1380 to 1220 (°F/s)	Setup	Notes
1	2	20	20	5	On	On	On	On	51.0	18.8	5.9	8.5	SUN23	
2	2	60	50	5	On	On	On	On	46.4	16.1	6.5	9.9	SUN23	
3	2	95	60	5	Off	On	Off	On	82.6	25.0	3.6	6.4	SUN23	2 sprays only
4	2	40	38	5	On	On	On	On	35.6	12.5	8.4	12.8	SU43	
5	2	20	20	5	On	On	On	On	40.1	15.2	7.5	10.5	SU43	
6	2	34	30	5	On	On	On	On	44.6	13.0	6.7	12.3	SU43	
7	2	34	30	5	On	On	On	On	46.0	13.2	6.5	12.1	SU43	
8	2	34	30	5	On	On	On	On	45.4	13.0	6.6	12.3	SU43	
9	2	42	30	5	On	On	On	On	56.6	19.2	5.3	8.3	SU43	

Graph of Initial Results with 2" Probe

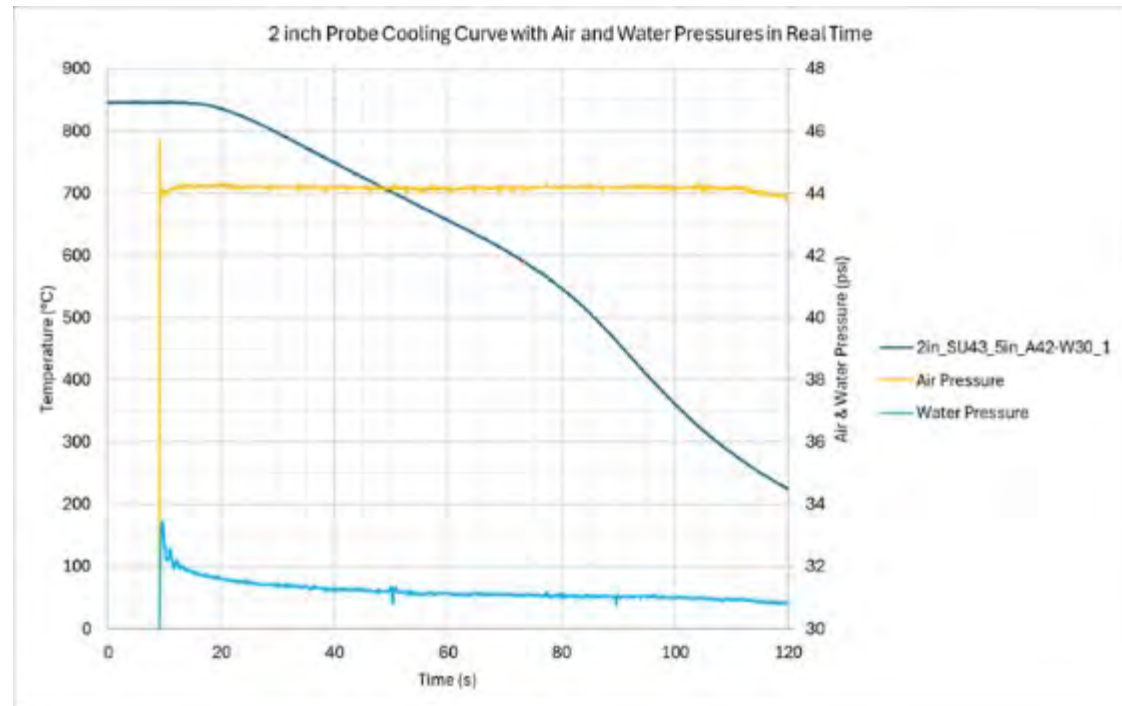


Flow Restrictions on Air and Water

- Through testing it was found that both water pressures and air pressures were limited. It was not possible to achieve the higher pressures listed in the product literature
- Inlet pressure gauges were added to determine root cause
- The air pressure is limited by the ¼" ID air hose coming from the air compressor; the incoming air pressure drops to ~40 psi (from 175psi) when running sprays
- The water pressure is limited by the ¼" pipe and/or the regulator used; the incoming water pressure stayed up at 65 psi when running sprays but could not get over 35 psi water after the regulator.

Transducer Data

- Using the inline transducers gives much more information than mechanical gauges
- The transducers output a voltage (0 to 5) that correlates to 0 to 100 psi
- Our data logger captures those voltages
- There are pressure fluctuations during most runs
- An average pressure is taken from 800 to 500°C for use in analysis



1 Inch Probe Testing

- With the flow restrictions encountered with 2” probe it was decided to test the 1” probe
- All runs were with setup SU43 which is the highest flow rate nozzle setup for the body used
- Did multiples of 3 runs for each air and water setting
- Also used transducer data to set pressures instead of mechanical gauges

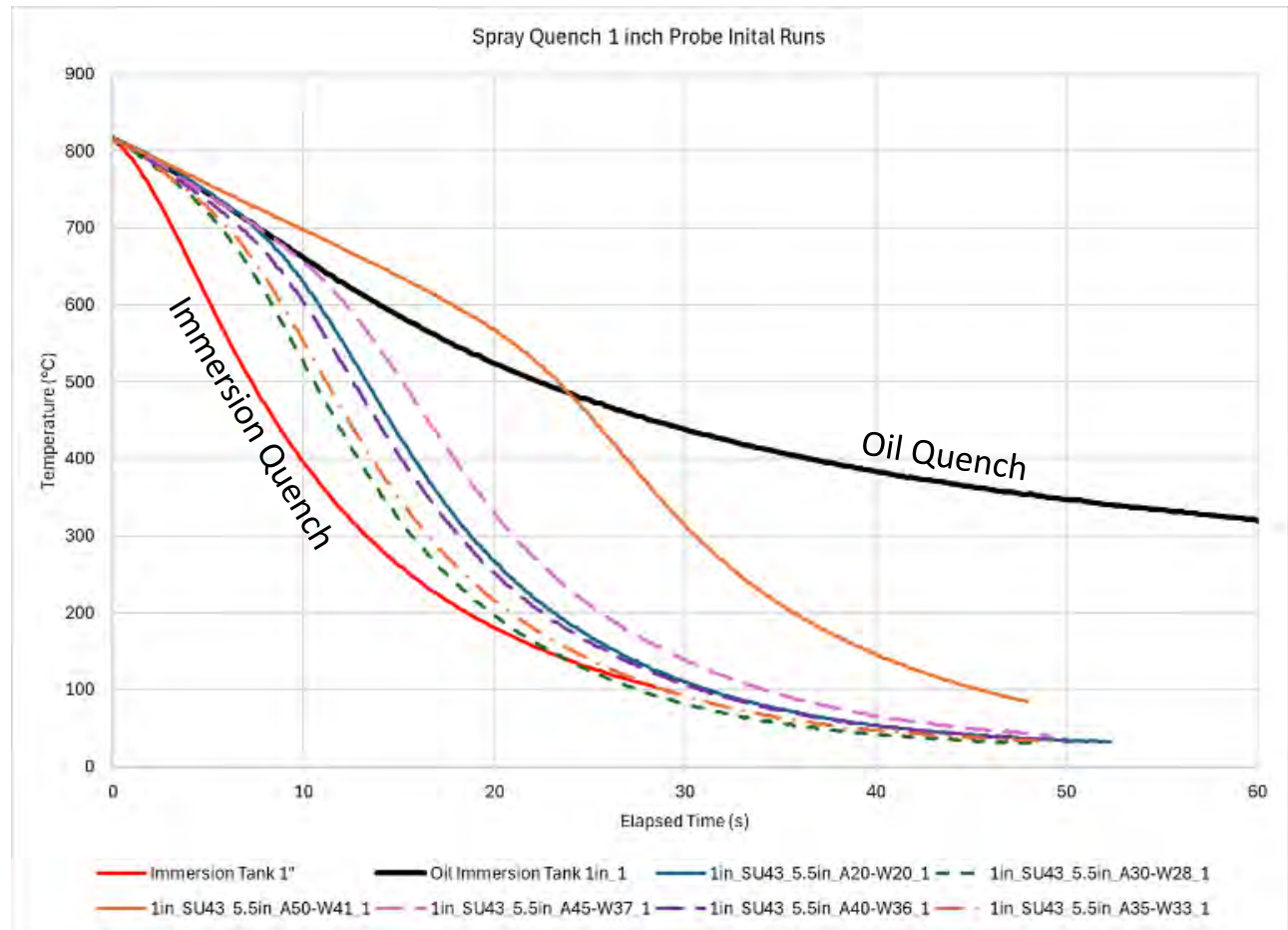
Initial Run Parameters & Results – 1” Probe

Run	Probe Diam (in)	Set Air Pressure (psi)	Actual Air Pressure (psi)	Set Water Pressure (psi)	Actual Water Pressure (psi)	Spray Distance from Surface of Probe (in)	Time from 800 to 500c (s)	Time from 1380 to 1220 °F (s)	Quench Rate 800 to 500 (°C/s)	Quench Rate from 1380 to 1220 (°F/s)	Setup
1	1	20	22	20	20	5.5	11.8	4.2	25.4	38.1	SU43
2	1	20	22	20	20	5.5	11.7	4.1	25.6	39.0	SU43
3	1	20	21	20	19	5.5	13.1	4.5	22.9	35.6	Same Parameters
4	1	30	31	28	31	5.5	9.5	3.2	31.6	50.0	
5	1	30	31	28	28	5.5	13.2	4.9	22.7	32.7	SU43
6	1	30	32	28	29	5.5	12.8	4.7	23.4	34.0	SU43
7	1	50	56	41	45	5.5	22.0	7.5	13.6	21.3	SU43
8	1	50	56	41	45	5.5	22.1	7.6	13.6	21.1	Highest Pressures!
9	1	50	53	41	43	5.5	20.3	7.1	14.8	22.5	SU43
10	1	45	45	37	39	5.5	13.9	5.2	21.6	30.8	SU43
11	1	45	45	37	39	5.5	13.8	5.2	21.7	30.8	SU43
12	1	45	45	37	39	5.5	14.3	5.2	21.0	30.8	SU43
13	1	40	40	36	36	5.5	11.6	4.1	25.9	39.0	SU43
14	1	40	40	36	36	5.5	12.0	4.4	25.0	36.4	SU43
15	1	40	40	36	36	5.5	13.3	5.0	22.6	32.0	SU43
16	1	35	35	33	33	5.5	10.2	3.4	29.4	47.1	SU43
17	1	35	34	33	33	5.5	9.4	3.1	31.9	51.6	Best Run
18	1	35	34	33	33	5.5	9.8	3.3	30.6	48.5	SU43

- Immersion quench rates for 1” probe are ~ 50°C/s
- Oil quench rates for 1” probe are ~14.5°C/s

1 Inch Probe – Initial Runs Chart

- All runs use setup SU43
- Beat oil quench
- Did not beat immersion quench
- Also limited by water supply



Evaluation of Data

- Did not achieve quench rates as fast as immersion
- Highest pressures produced worst quench rate
- Even with the flow restrictions, things were not making sense
- Performed a flow rate regression analysis on published data
- Performed a quench rate regression analysis on data collected from initial experiments

Flow Rate Analysis from Product Literature

Used air and water pressures and flowrates from the table below

PERFORMANCE DATA: PRESSURE SPRAY SET-UPS INTERNAL MIX FLAT SPRAY																				
Spray Set-up No.	Spray Set-up Consists of Fluid and Air Cap Combination	Liquid Capacity (gallons per hour)* and Air Capacity (standard cubic feet per minute)*															Spray Dimensions			
		Liquid Pressure																		
		10 psi			20 psi			30 psi			40 psi			60 psi			A (in.)	B (in.)	C (ft.)	
Air Press.	gph	scfm	Air Press.	gph	scfm	Air Press.	gph	scfm	Air Press.	gph	scfm	Air Press.	gph	scfm	Air Press.	gph	scfm			
SU23	Fluid Cap 60100 + Air Cap 125328	12.0	7.0	1.15	22	11.5	1.65	34	12.4	2.20	46	13.7	2.75	65	18.3	3.56	7 - 13	12 - 20	11 - 14-1/2	
		16.0	4.2	1.57	30	6.0	2.40	42	7.8	2.95	54	8.7	3.51	80	10.6	4.95				
		20	2.7	1.97	34	4.3	2.78	48	5.0	3.52	60	6.4	4.06	90	6.9	5.85				
		22	2.0	2.20	36	3.6	2.97	50	4.3	3.71	65	4.6	4.53	95	5.5	6.30				
		-	-	-	38	3.0	3.16	52	3.7	3.90	70	3.3	5.00	100	4.5	6.76				
SU43	Fluid Cap 100150 + Air Cap 189351	14.0	7.7	3.17	26	10.5	4.55	34	20.8	4.75	42	29.4	5.15	58	44.7	6.05	7 - 14	10 - 23	11 - 17	
		16.0	5.0	3.83	28	7.0	5.15	36	16.6	5.25	44	25.1	5.6	60	41.0	6.42				
		-	-	-	-	-	-	38	12.8	5.8	46	20.8	6.05	65	31.4	7.45				
		-	-	-	-	-	-	42	6.7	6.85	50	13.1	7.15	75	15.0	10.1				
		-	-	-	-	-	-	-	-	-	52	10.0	7.75	80	8.7	11.45				
-	-	-	-	-	-	-	-	-	54	7.3	8.3	-	-	-						

Linear Regression of Flow Rate Tables

Setup SU43		
Water Pressure (psi)	Air Pressure (psi)	Water Flow Rate (gpm)
10	14	7.7
10	16	5.0
20	26	10.5
20	28	7.0
30	34	20.8
30	36	16.6
30	38	12.8
30	42	6.7
40	42	29.4
40	44	25.1
40	46	20.8
40	50	13.1
40	52	10.0
40	54	7.3
60	58	44.7
60	60	41.0
60	65	31.4
60	75	15.0
60	80	8.7

SUMMARY OUTPUT									
Regression Statistics									
Multiple R	0.996755653								
R Square	0.993521832								
Adjusted R Square	0.992712061								
Standard Error	1.010266279								
Observations	19								
ANOVA									
	df	SS	MS	F	Significance F				
Regression	2	2504.476109	1252.23805	1226.917	3.1E-18				
Residual	16	16.33020727	1.02063795						
Total	18	2520.806316							
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%	Lower 95.0%
Intercept	10.655	0.650	16.393	2E-11	9.3	12.0	9.3	12.0	
Water Pressure	2.205	0.048	46.022	1.97E-18	2.1	2.3	2.1	2.3	
Air Pressure	-1.694	0.044	-38.380	3.51E-17	-1.8	-1.6	-1.8	-1.6	

$$\text{Water Flow Rate} = 10.655 + 2.205(\text{Water Pressure}) - 1.694(\text{Air Pressure})$$

Water Flow Rate Heat Map

- Used regression equation from flow rate tables
- Higher flow rates occur at higher water pressures AND lower air pressures
- Negative values are not real
- Values in orange are where tests have been performed
 - Best cooling rate at highest flow tested
 - Worst cooling rate at lowest flow tested

		Water Pressure (psi)										
		10	15	20	25	30	35	40	45	50	55	60
Air Pressure (psi)	10	16	27	38	49	60	71	82	93	104	115	126
	15	7	18	29	40	51	62	73	84	95	107	118
	20	-1	10	21	32	43	54	65	76	87	98	109
	25	-10	1	12	23	34	45	57	68	79	90	101
	30	-18	-7	4	15	26	37	48	59	70	81	92
	35	-27	-16	-5	6	18	29	40	51	62	73	84
	40	-35	-24	-13	-2	9	20	31	42	53	64	75
	45	-44	-33	-21	-10	1	12	23	34	45	56	67
	50	-52	-41	-30	-19	-8	3	14	25	36	47	58
	55	-60	-49	-38	-27	-16	-5	6	17	28	39	50
60	-69	-58	-47	-36	-25	-14	-3	8	19	30	41	

Flow rate values in GPH

Best quench rate

Worst quench rate

$$\text{Water Flow Rate} = 10.655 + 2.205(\text{Water Pressure}) - 1.694(\text{Air Pressure})$$

Quench Rate Linear Regression

Actual Air Pressure (psi)	Actual Water Pressure (psi)	Time from 800 to 500c (s)	Time from 1380 to 1220 °F (s)	Quench Rate 800 to 500 (°C/s)
22	20	11.8	4.2	25.4
22	20	11.7	4.1	25.6
21	19	13.1	4.5	22.9
31	31	9.5	3.2	31.6
31	28	13.2	4.9	22.7
32	29	12.8	4.7	23.4
56	45	22	7.5	13.6
56	45	22.1	7.6	13.6
53	43	20.3	7.1	14.8
45	39	13.9	5.2	21.6
45	39	13.8	5.2	21.7
45	39	14.3	5.2	21.0
40	36	11.6	4.1	25.9
40	36	12	4.4	25.0
40	36	13.3	5	22.6
35	33	10.2	3.4	29.4
34	33	9.4	3.1	31.9
34	33	9.8	3.3	30.6

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.978882							
R Square	0.95821							
Adjusted R Square	0.952638							
Standard Error	1.208909							
Observations	18							
ANOVA								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	2	502.6516	251.3258	171.9687	4.55E-11			
Residual	15	21.92193	1.461462					
Total	17	524.5735						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	22.182	1.545	14.35574	3.6E-10	18.88888	25.47589	18.88888	25.47589
Actual Air	-2.099	0.136	-15.4637	1.26E-10	-2.38823	-1.80962	-2.38823	-1.80962
Actual Wa	2.410	0.184	13.12016	1.26E-09	2.018341	2.801325	2.018341	2.801325

$$\text{Quench Rate} = 22.182 + 2.410(\text{Water Pressure}) - 2.099(\text{Air Pressure})$$

Quench Rate Heat Map

- Used regression equation from quench rate data collected
- Negative values are not real
- Values in orange are where tests have been performed
- Bold values are 45°C/s or higher
- It became obvious testing needed to be done closer to 30 psi water and 10 psi air

		Water Pressure (psi)										
		10	15	20	25	30	35	40	45	50	55	60
Air Pressure (psi)	10	25	37	49	61	73	86	98	110	122	134	146
	15	15	27	39	51	63	75	87	99	111	123	135
	20	4	16	28	40	53	65	77	89	101	113	125
	25	-6	6	18	30	42	54	66	78	90	102	114
	30	-17	-5	7	19	32	44	56	68	80	92	104
	35	-27	-15	-3	9	21	33	45	57	69	81	93
	40	-38	-26	-14	-2	11	23	35	47	59	71	83
	45	-48	-36	-24	-12	0	12	24	36	48	60	72
	50	-59	-47	-35	-23	-10	2	14	26	38	50	62
	55	-69	-57	-45	-33	-21	-9	3	15	27	39	51
60	-80	-68	-56	-44	-31	-19	-7	5	17	29	41	

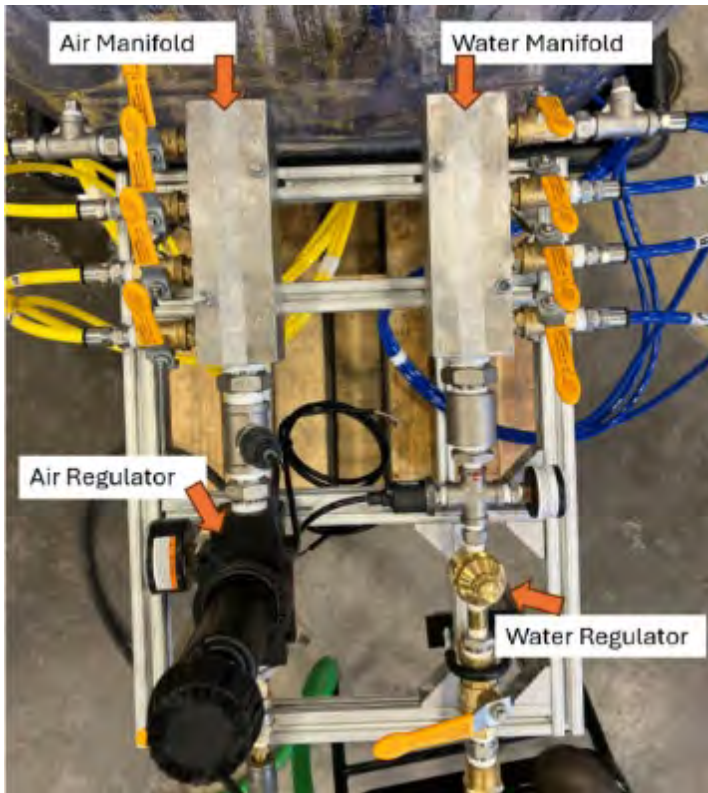
Cooling rate values in °C/s

$$\text{Quench Rate} = 22.182 + 2.410(\text{Water Pressure}) - 2.099(\text{Air Pressure})$$

Testing 30psi Water & 10psi Air

- These settings are outside the published data table
- Were able to hit pressures with a single nozzle and existing piping
- Did flow rate measurements to verify calculations
 - Calculated 60 GPH
 - Measured 64 GPH
- Deleted water regulator to get more flow for proof of concept

Deleting Water Regulator – Before & After



Before



After

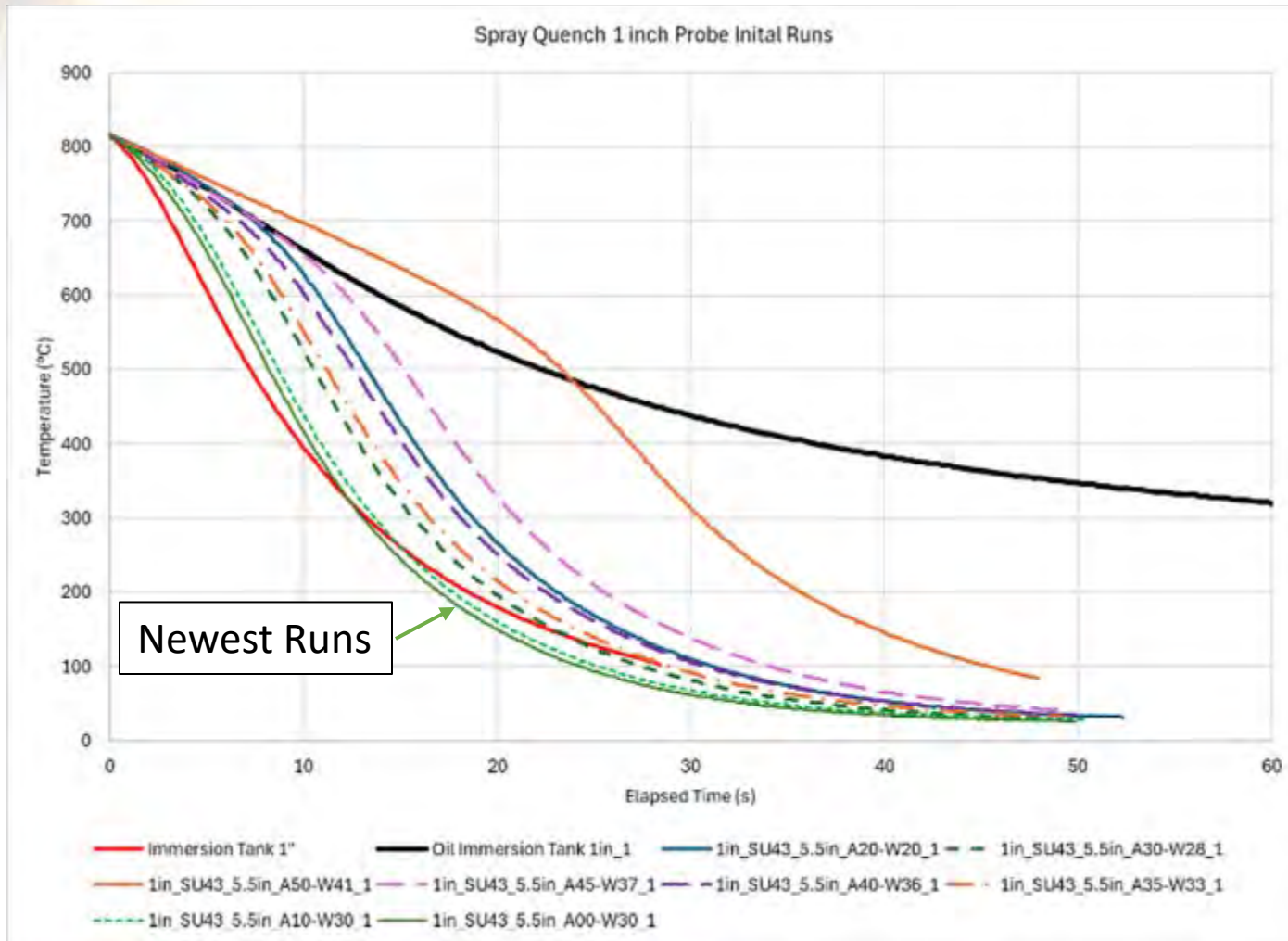
- Water regulator removed
- ½" pipe is now the smallest restriction
- Were able to run all 4 nozzles with 30 psi water and 10 psi air!

Results from Optimized Flow Rates

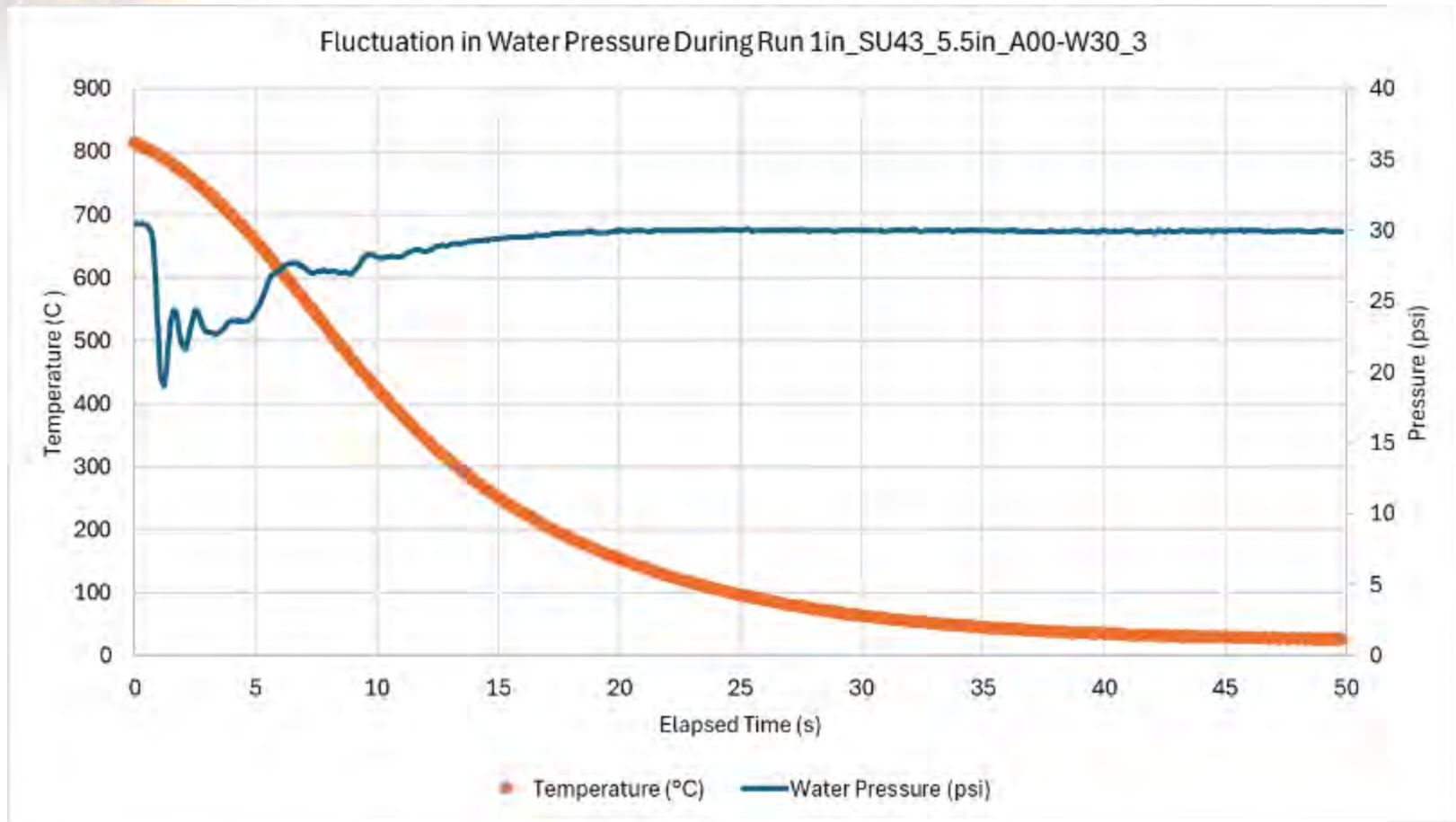
Run	Probe Diam (in)	Set Air Pressure (psi)	Actual Air Pressure (psi)	Set Water Pressure (psi)	Actual Water Pressure (psi)	Spray Distance from Surface of Probe (in)	Time from 800 to 500c (s)	Time from 1380 to 1220 °F (s)	Quench Rate 800 to 500 (°C/s)	Quench Rate from 1380 to 1220 (°F/s)	Setup	Notes
1	1	20	22	20	20	5.5	11.8	4.2	25.4	38.1	SU43	
2	1	20	22	20	20	5.5	11.7	4.1	25.6	39.0	SU43	
3	1	20	21	20	19	5.5	13.1	4.5	22.9	35.6	SU43	
4	1	30	31	28	31	5.5	9.5	3.2	31.6	50.0	SU43	
5	1	30	31	28	28	5.5	13.2	4.9	22.7	32.7	SU43	
6	1	30	32	28	29	5.5	12.8	4.7	23.4	34.0	SU43	
7	1	50	56	41	45	5.5	22.0	7.5	13.6	21.3	SU43	Pressure not constant
8	1	50	56	41	45	5.5	22.1	7.6	13.6	21.1	SU43	
9	1	50	53	41	43	5.5	20.3	7.1	14.8	22.5	SU43	
10	1	45	45	37	39	5.5	13.9	5.2	21.6	30.8	SU43	
11	1	45	45	37	39	5.5	13.8	5.2	21.7	30.8	SU43	
12	1	45	45	37	39	5.5	14.3	5.2	21.0	30.8	SU43	
13	1	40	40	36	36	5.5	11.6	4.1	25.9	39.0	SU43	
14	1	40	40	36	36	5.5	12.0	4.4	25.0	36.4	SU43	
15	1	40	40	36	36	5.5	13.3	5.0	22.6	32.0	SU43	
16	1	35	35	33	33	5.5	10.2	3.4	29.4	47.1	SU43	
17	1	35	34	33	33	5.5	9.4	3.1	31.9	51.6	SU43	
18	1	35	34	33	33	5.5	9.8	3.3	30.6	48.5	SU43	
19	1	10	9.71	30	30.31	5.5	7.7	2.3	39.0	69.6	SU43	Water Regulator Removed
20	1	10	9.98	30	30.32	5.5	7.4	2.2	40.5	72.7	SU43	Water Regulator Removed
21	1	10	9.99	30	30.33	5.5	7.2	2.2	41.7	72.7	SU43	Water Regulator Removed
22	1	0	0	30	30.07	5.5	7.3	2.3	41.1	69.6	SU43	Water Regulator Removed
23	1	0	0	30	30.11	5.5	7.2	2.2	41.7	72.7	SU43	Water Regulator Removed
24	1	0	0	30	24.84	5.5	7.6	2.4	39.7	67.8	SU43	Water Regulator Removed

- Better cooling rates but still lacking water flow
- Got up to 40°C/s!

Results Cont'd



City Water Pressure Fluctuation

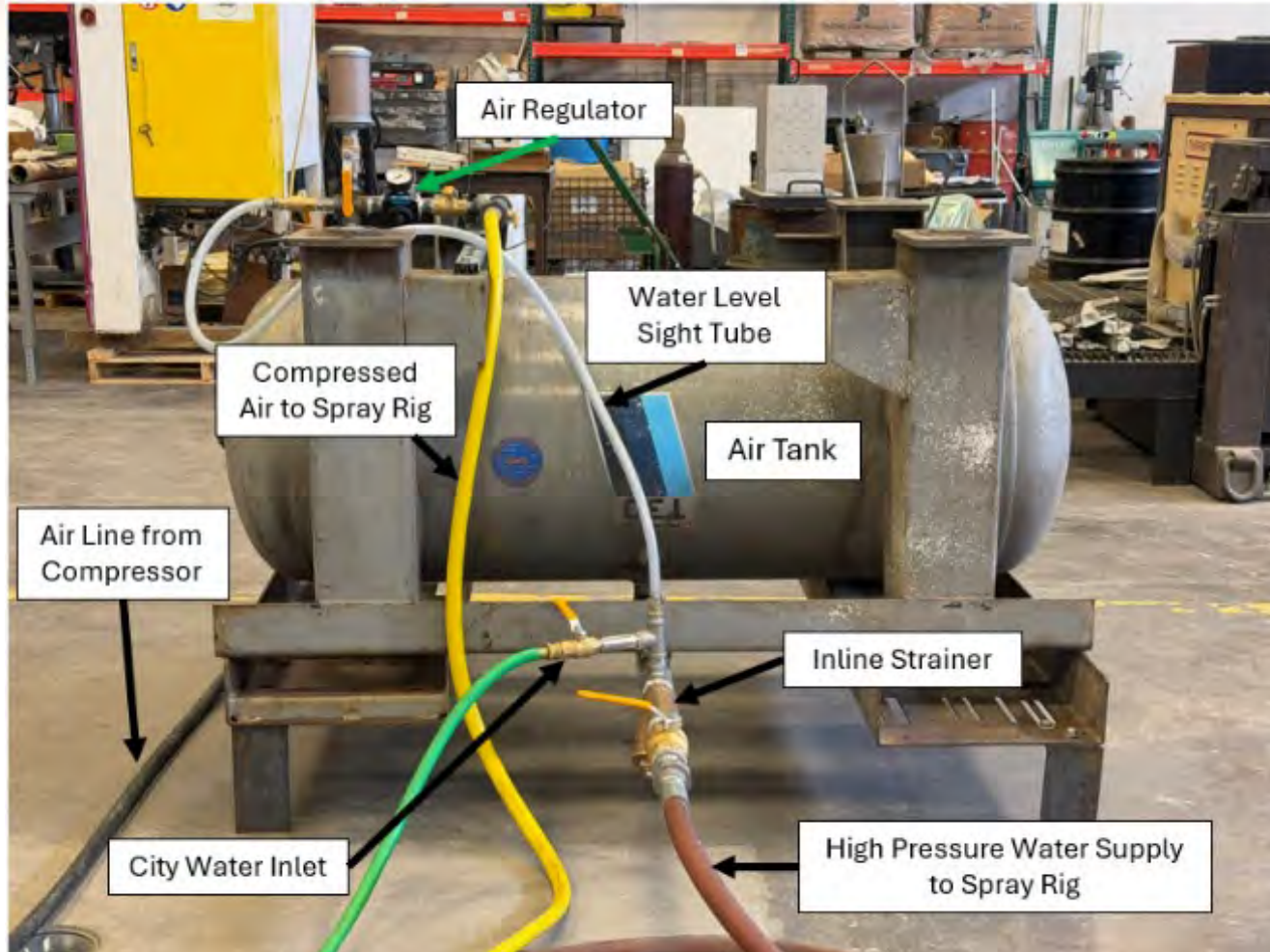


- Not only can the city water not deliver enough flow/ pressure, but it also varies in the middle of runs

How to Overcome Limitations with Air and Water Supply

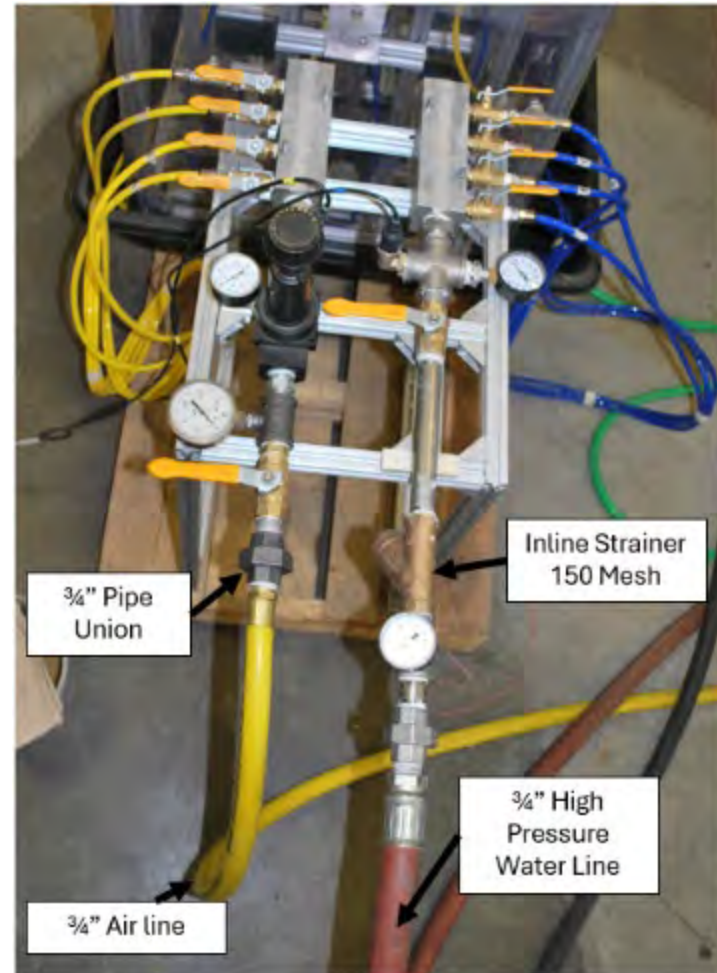
- Water limitations
 - Pressurized Reservoir
 - Convert a large air tank to hold water
 - Pressurize tank to needed levels with compressed air
 - Deliver water to spray rig through a $\frac{3}{4}$ " hose with pipe unions
 - No water regulator
- Air
 - $\frac{3}{4}$ " air line from compressor to rig (currently using $\frac{1}{4}$ " airline)

Pressurized Reservoir Construction



Modified Valve Stand

- All piping is $\frac{3}{4}$ " ID for both air and water
- Pipe unions used in place of quick disconnects (restrictive)
- Water pressure regulated at reservoir
- Inline 150 mesh strainer to protect nozzles



Pressurized Reservoir Testing

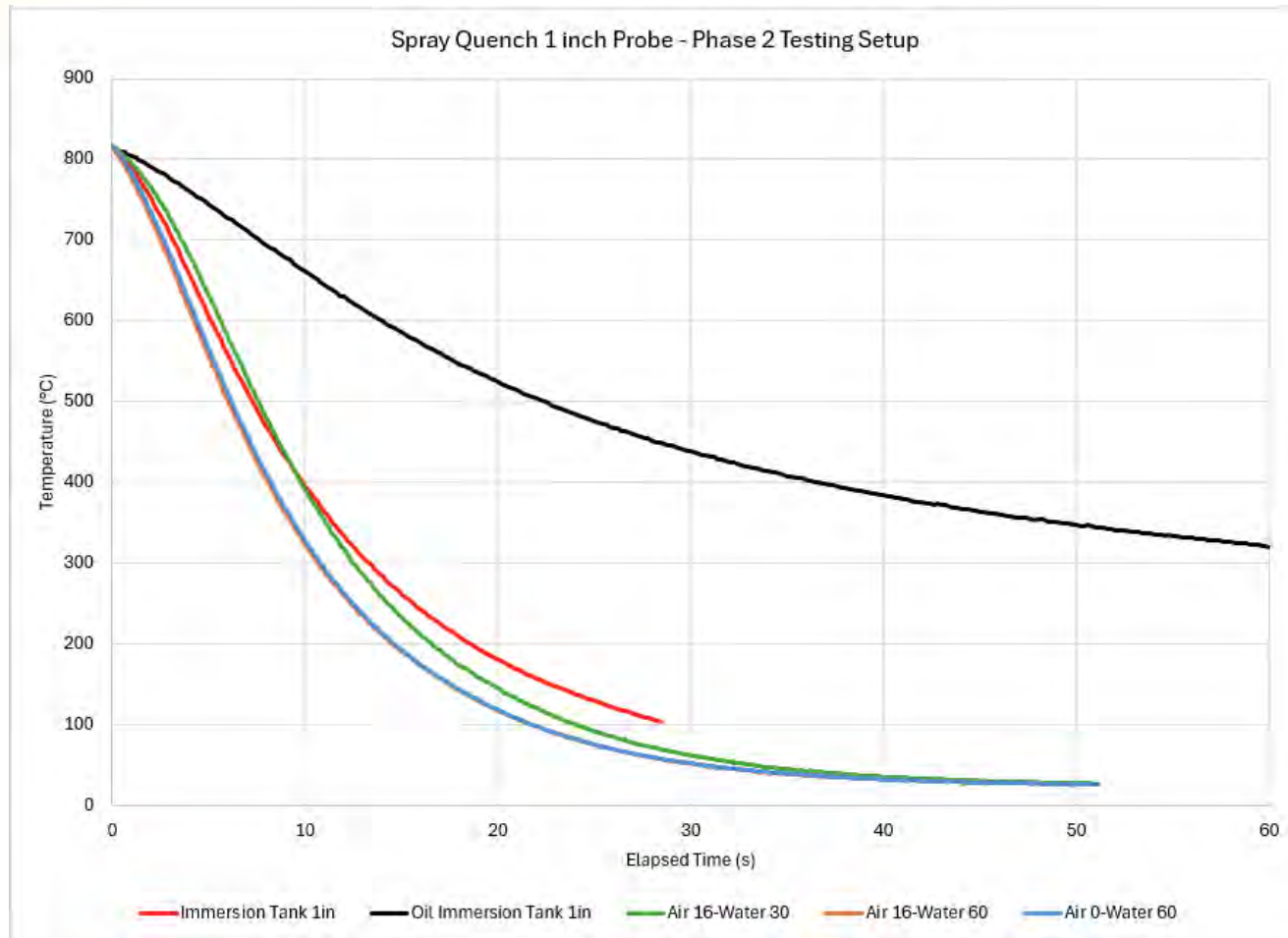
- The new setup was tested on the 1" probe at the previously used settings of 10 psi air and 30 psi water
- This was to verify the new setup worked
- The previous design achieved a quench rate of 40°C/s with the 1" probe and the new setup also achieved 40°C/s

Results and Parameters From New Setup 1"

Run	Probe Diam (in)	Actual Air Pressure (psi)	Actual Water Pressure (psi)	Spray Distance from Surface of Probe (in)	Time from 800 to 500°C (s)	Time from 1380 to 1220°F (s)	Quench Rate 800 to 500 (°C/s)	Quench Rate from 1380 to 1220 (°F/s)	Setup
1	1	12	32	5.5	7.6	2.1	39.5	76.2	SU43
2	1	10	32	5.5	7.4	2.1	40.5	76.2	SU43
3	1	11	32	5.5	7.3	2.0	41.1	80.0	SU43
4	1	18	62	5.5	6.0	1.6	50.0	100.0	SU43
5	1	17	61	5.5	6.2	1.7	48.4	94.1	SU43
6	1	17	62	5.5	6.0	1.7	50.0	94.1	SU43
7	1	13	62	5.5	6.1	1.6	49.2	100.0	SU43

- Runs 1-3 were the verification runs
- Runs 4-6 were done at 60 psi and achieved cooling rates greater than that of immersion quenching
- Run 7 was done with no air at all
 - The 13 psi is from the water back feeding to the transducer

Results From New Setup 1"

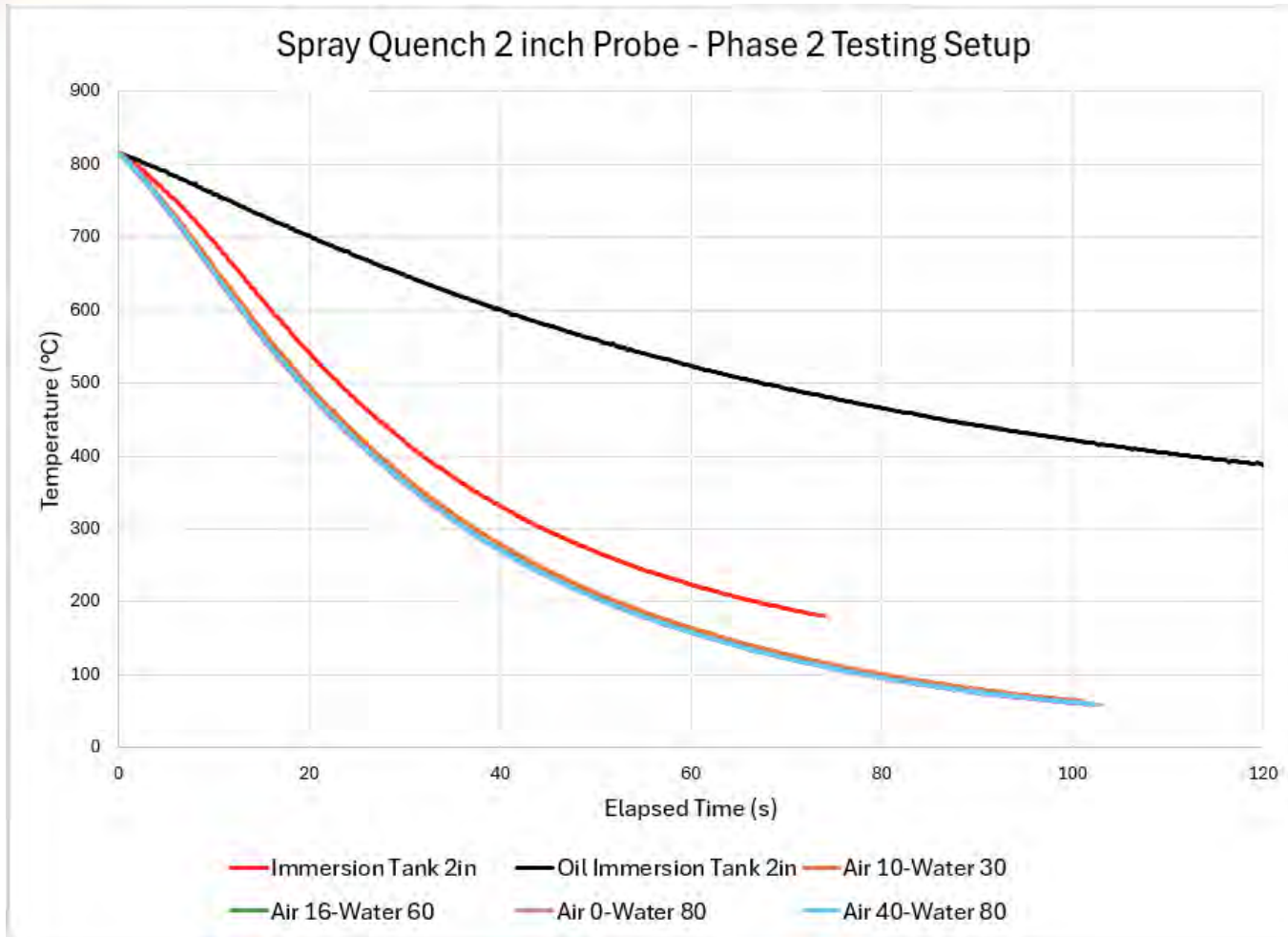


Results and Parameters From New Setup 2"

Run	Probe Diam (in)	Actual Air Pressure (psi)	Actual Water Pressure (psi)	Spray Distance from Surface of Probe (in)	Time from 800 to 500°C (s)	Time from 1380 to 1220°F (s)	Quench Rate 800 to 500 (°C/s)	Quench Rate from 1380 to 1220 (°F/s)	Setup
1	2	16	31	5	19.7	5.2	15.2	30.8	SU43
2	2	16	31	5	19.6	5.2	15.3	30.8	SU43
3	2	17	31	5	20.4	5.8	14.7	27.6	SU43
4	2	19	58	5	19.1	5.1	15.7	31.4	SU43
5	2	17	58	5	19.3	5.1	15.5	31.4	SU43
6	2	18	59	5	19.0	5.1	15.8	31.4	SU43
7	2	19	80	5	19.0	5.0	15.8	32.0	SU43
8	2	44	81	5	19.0	5.0	15.8	32.0	SU43

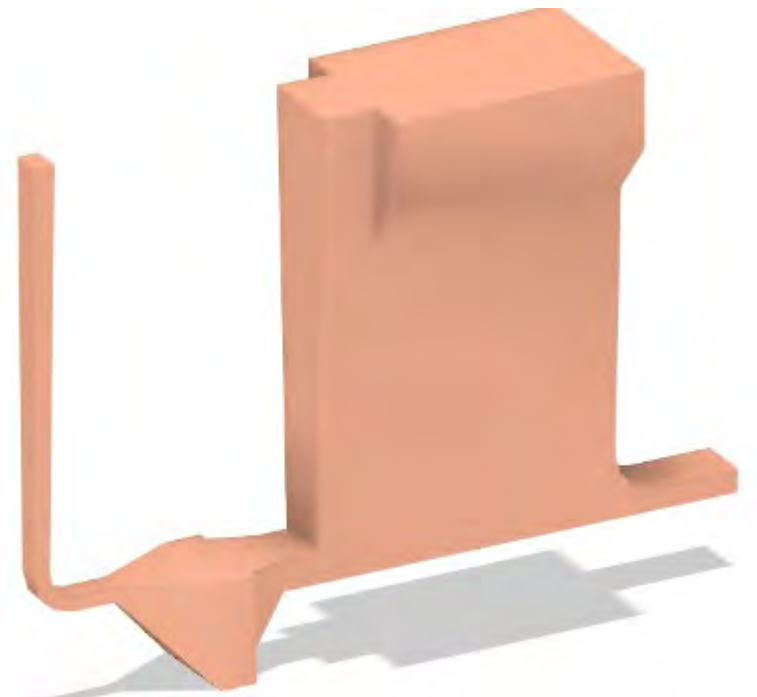
- Runs 1-3 were set at 10 psi air and 30 psi water which beat immersion quenching
- Runs 4-6 were set at 60 psi water which also beat immersion but achieved nearly identical results as 10 and 30
- Runs 7 and 8 were done at 80 psi to see if that would improve the quench rate, it did not
- We believe this plateau to be a result of the thermal conductivity of the stainless steel

Results and parameters from new setup 2"



Project Plans

- Cast 8630 wedges
- Fabricate spray quench rig for wedges
- Have a wedge immersion quenched at local facility
- Spray quench a wedge, section, measure hardness, and compare to immersion quenched wedge of same composition
- Goal is to obtain uniform properties in a non-uniform casting



Test Wedge Casting

Wedge ranges from ~1.5" to ~2" over 8"

Transition Plan

- Will provide data and results to foundries and heat treatment facilities
- Will present results to AMC Tech Review, SFSA Research Review, and annual SFSA T&O conference

Leveraging

- We are using the data that is being collected from the STAR-DoW as our baseline. So far, we have data from eighteen foundry/heat treat facilities and we will visit more facilities in the future
- We are using data collected from a DoW-DLA project where we measured mechanical and microstructural properties from a complex geometry steel casting poured and heat treated at a number of steel foundries and wedge castings poured at UAB
- Cost share will be provided on this project

Project Metrics

Description	Baseline	Threshold	Goal	How Measured	Target Date	Progress	How Demonstrated
Consistency in properties	30 ksi UTS difference in an 8630 steel	20% improvement in property consistency	30% improvement in property consistency	Testing to be done and properties to be measured on Pinson test part	2027	Properties will be measured after the quench unit is built	Testing results will be measured and presented

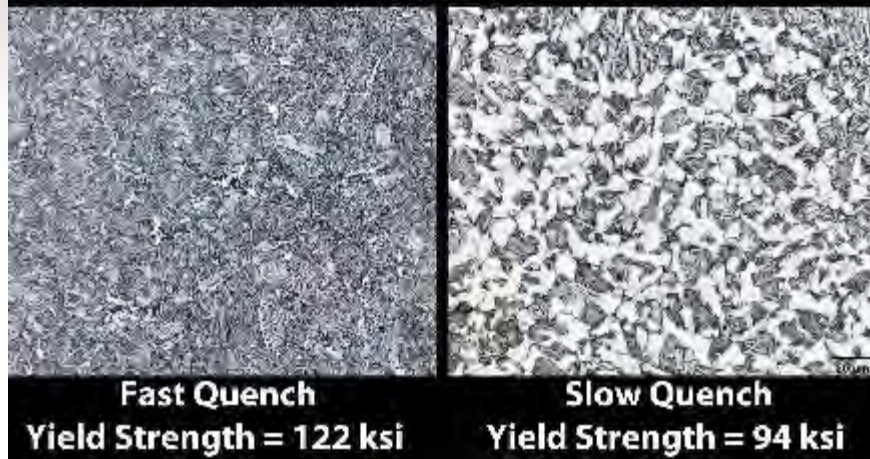
Acknowledgements

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Tankless Water Quenching of Production Steel Castings

DLA - POC: DLAR.DPR@dla.mil

8630 Steel



Problem

- Traditional immersion quench tanks do not easily allow tailoring of quench rates to challenging casting geometries.

Objectives

- Improve consistency in mechanical properties by 30%

Benefits to Warfighter

- This project can result in improved steel casting performance by improving tensile property consistency while producing an overall harder quench

Description of Project

This project will develop and implement an economically feasible tankless quenching system for foundries to be used on complex cast steel geometries, providing a new tool for the steel foundry industry.

Team: Steel Founders' Society of America, University of Alabama Birmingham, ATI



Milestones / Deliverables

- Design and build both a small and large tankless quench system
- Select test castings for both systems containing as many common geometric features as possible
- Develop data on spray parameters/thermal data/property data using the small chamber
- Conduct quench property tests using the larger system and larger test casting
- Finalize Best Practices Manual