



FLUXTROL[®]

Limitations of Standard Probes for the Measurement of Spray Quenching

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Spray Quenching

- Spray Quenching Is Commonly Used in Induction Heat Treating Applications
- Very Little Data Is Available on the Cooling Curves for These Quenchants
- Much Faster Cooling Rates than Typical for Immersion or Gas Quenching
 - Questionable Accuracy Using Standard Tools



Photo courtesy of Induction Tooling, Inc.
ASM Handbook Volume 4C
Design and Fabrication of Inductors for
Induction Heat Treating – Goldstein, Stuehr
and Black

Means of Quenchant Control/Monitoring in Practice

- Sampling of bath to monitor key variables
 - %Polymer Concentration
 - Bath Temperature
 - Cooling curves with standard system
- Measurement Quenchant Flow Rate and Temperature
- No Good Way to Monitor Characteristics of Flowing Quench



<https://www.ri.se/en/expertise-areas/services/ivf-smartquench-for-control-of-cooling-curve-measurement>

General Notes About Induction Spray Quenching Heads

- Quench heads typically built with a series of holes in parallel
 - Hole angle varied typically by row of quench
 - Holes staggered in different rows
 - Diameter of the hole also varies based upon the row
 - Baffling and multiple feeds often used to ensure uniform flow distribution
 - Goal is to hit the surface of the object and to have the quench then flow down the surface uniformly
 - Straight impact and deflection undesirable

General Notes About Induction Spray Quenchants

- Occasionally pure water spray quench is used
- More typically, water with a percentage of additives are typically used
 - 2 – 20% polymer covers the entire range
 - Most commonly in the 4-8% range of polymer
 - A number of different polymers used
 - Rust inhibitors also fairly common
 - Oftentimes, antimicrobials are added to the bath to prevent bacterial growth
- Often pick up machine oils and scale over time as they are recirculated and not entire part heated
 - Filtering strongly recommended

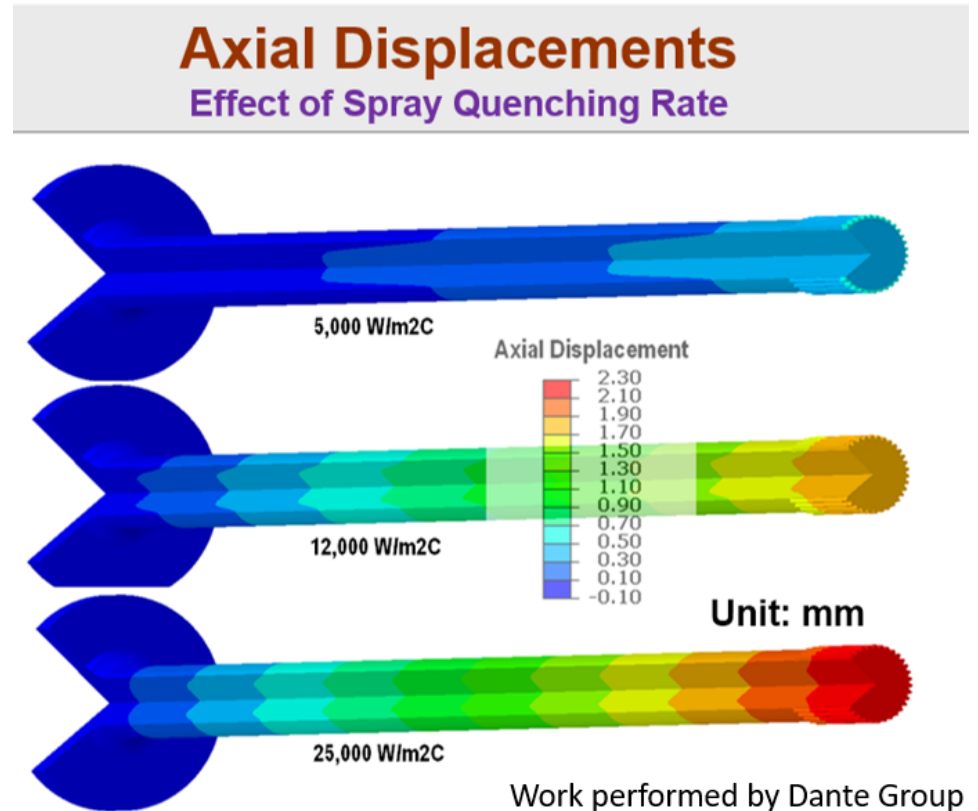
Common Probes

	Method				
	ISO 9950	AFNOR NFT 6077B	JIS K2242	Z8 E 45003	ASTM D6200
Country	International	France	Japan	China	USA
Probe Alloy	Inconel 600	Silver 99.999%	Silver 99.999%	Silver 99.999%	Inconel 600
Probe Dimensions, mm	12.5 x 60	16 x 48	10 x 30	10 x 30	12.5 x 60
Reference Fluid	Various	Various	Diocetyl Phthalate	Diocetyl Phthalate	Various
Vessel Dimensions, mm	115±5 dia.	138 dia. X 99 high	300 ml beaker	300 ml beaker	115±5 mm dia.
Oil Volume, ml	2000	800	250	250	2000
Oil Temperature °C	40 ± 2	50 ± 2	80, 120, 160	80 ± 2	40 ± 2
Probe Temperature, °C	850 ± 5	800 ± 5	810 ± 5	810 ± 5	850 ± 5

- Silver and Inconel 600 are the two main materials listed
- Size varies from 10 mm to 16 mm in diameter
- Volume of fluid and reference sample varies as well

Importance of Accurate Measurement of Cooling Rate

- It is known that cooling rate influences:
 - Cracking
 - Residual Stresses
 - Dimensional Movement
 - Component performance



Comparison of Non-Linear and Average Cooling Rates

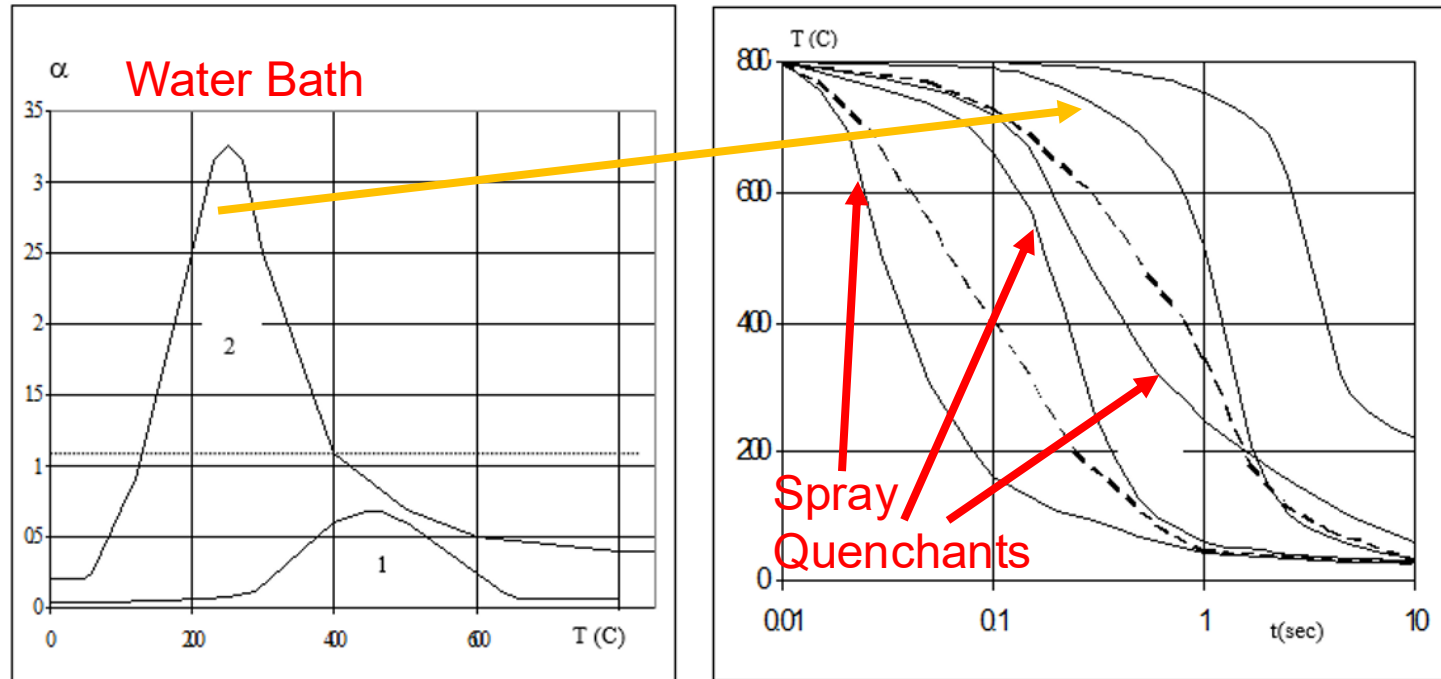


Figure 1 Non-linear heat transfer coefficients measurement with 8 mm silver probe and comparison with calculations using a mean heat transfer coefficient 1- Fast oil unagitated [11], where 2-Water unagitated; 3-Oil shower ($0.7 \text{ m}^3/(\text{s} \cdot \text{m}^2)$); 4-Water shower ($0.28 \text{ m}^3/(\text{s} \cdot \text{m}^2)$); 5-Water shower ($2 \text{ m}^3/(\text{s} \cdot \text{m}^2)$). ** Dashed lines represent simulation with mean value heat transfer coefficients for cases 2 and 4

[11] V. S. Nemkov, "Computer Simulation of Induction Heating and Quenching Processes," in *2nd International Conference on Quenching and Control of Distortion*, March 1999, Prague, Czech Republic, 1999.

Spray Quenchant Properties in ELTA Database

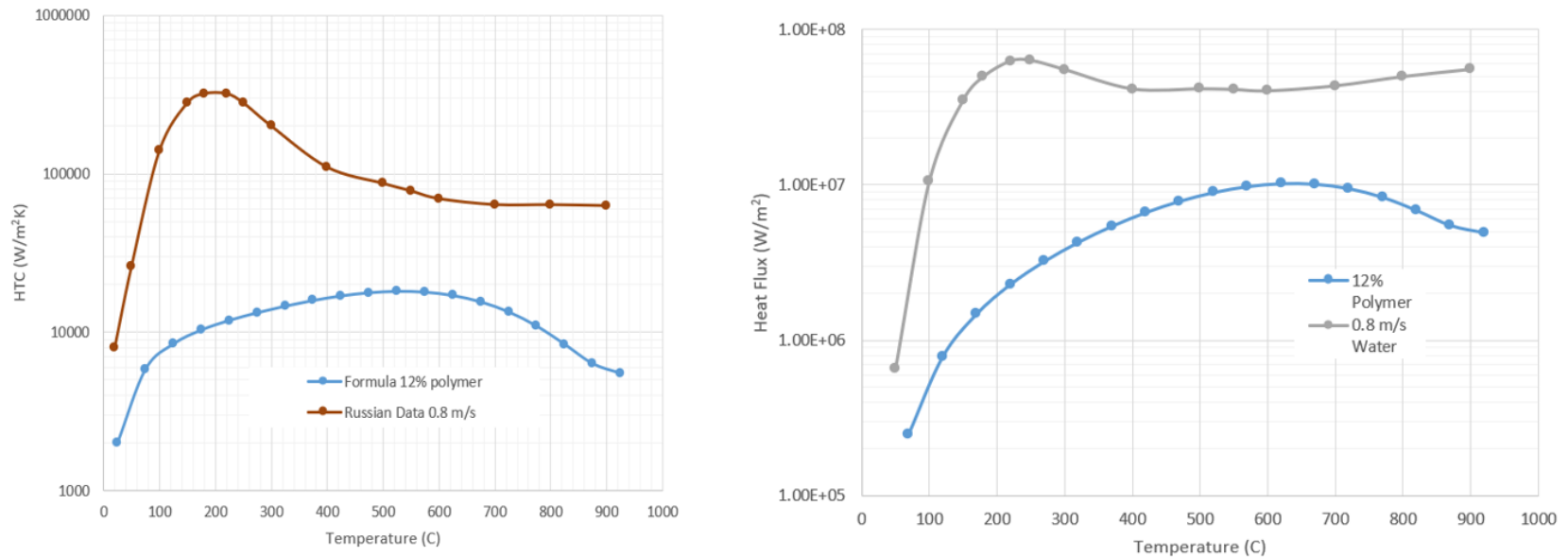


Figure 4. a) Heat transfer coefficient versus surface temperature for 12% polymer spray quench and 0.8 m/s spray quench from ELTA Database and b) resulting heat flux versus surface temperature.

Based upon “original experiments” in St. Petersburg, Russia, little else known by the authors.

Data Lined Up Well with Gleeble

Experimental Data taken at Colorado School of Mines by Whitely

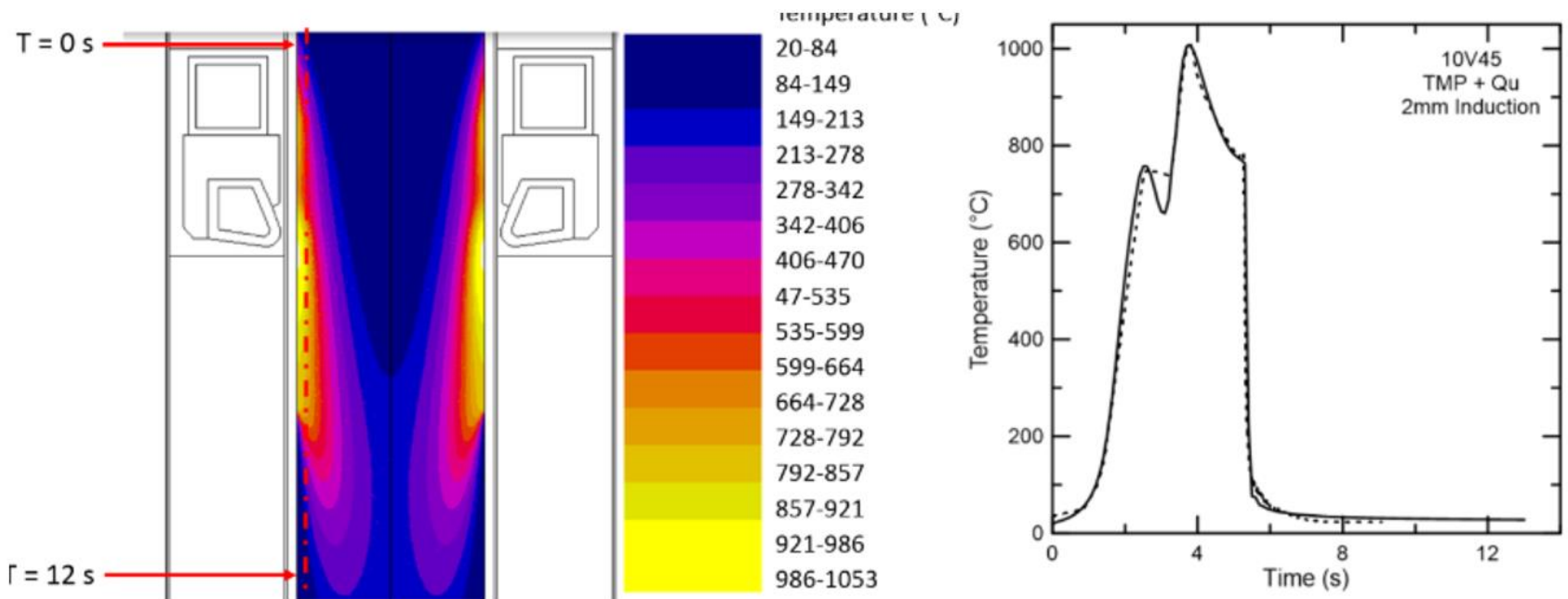


Figure 2 Modeling and experimental comparison between Gleeble simulation results using 0.8 m/s spray quench from ELTA database [14].

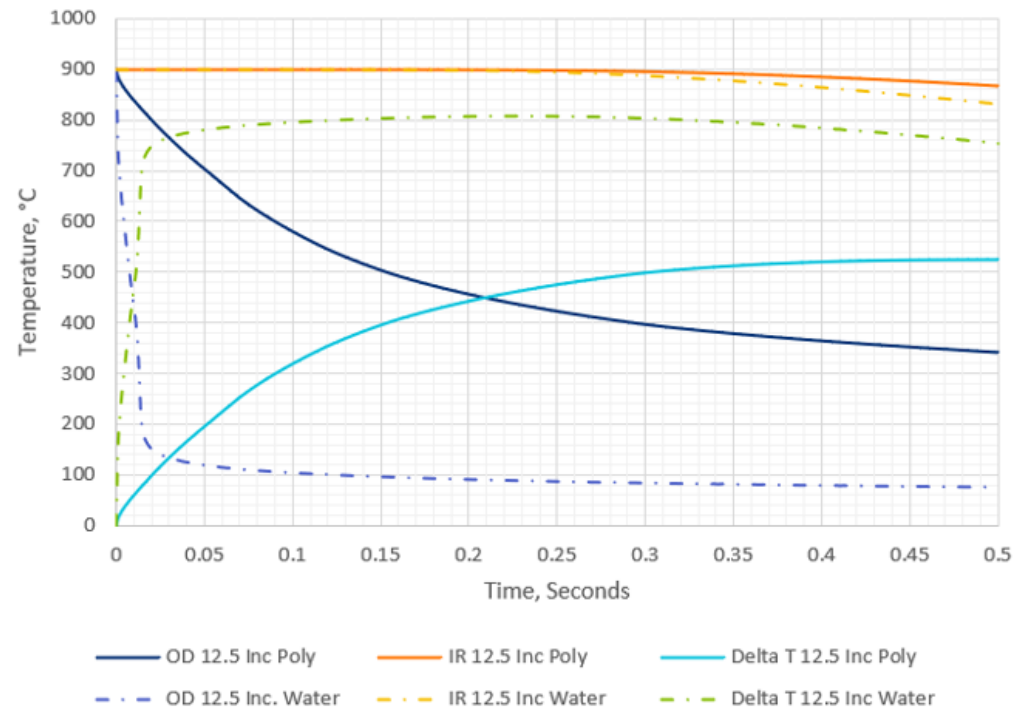
- [14] B. M. Whitley, J. G. Speer, R. L. Cryderman, K. O. Findley and D. K. Matlock, "Additions and Thermomechanical Processing on Austenite Grain Size Control in Induction-Hardenable Medium Carbon Steel Bar Rolling," *Mat. Sci. Forum*, vol. 879, no. International Conference on Processing & Manufacturing of Advanced Materials Processing, Fabrication, Properties & Applications (Thermec), pp. 2094-2099, 2016.

Quenchant Study Overview

- All calculations done virtually using ELTA
- 2 quenchants studied from ELTA database
 - 12% Polymer Spray Quenchant
 - 0.8 m/s Water Spray Quenchant
- Inconel and Silver Probes Considered with Central Temperature Measurement
 - Diameters 1.5, 3, 6 and 12.5 mm (standard Inconel 600 geometry used)
- Temperature Data Plotted every 1 ms for first 0.5 s of cooling

Standard Inconel Probe

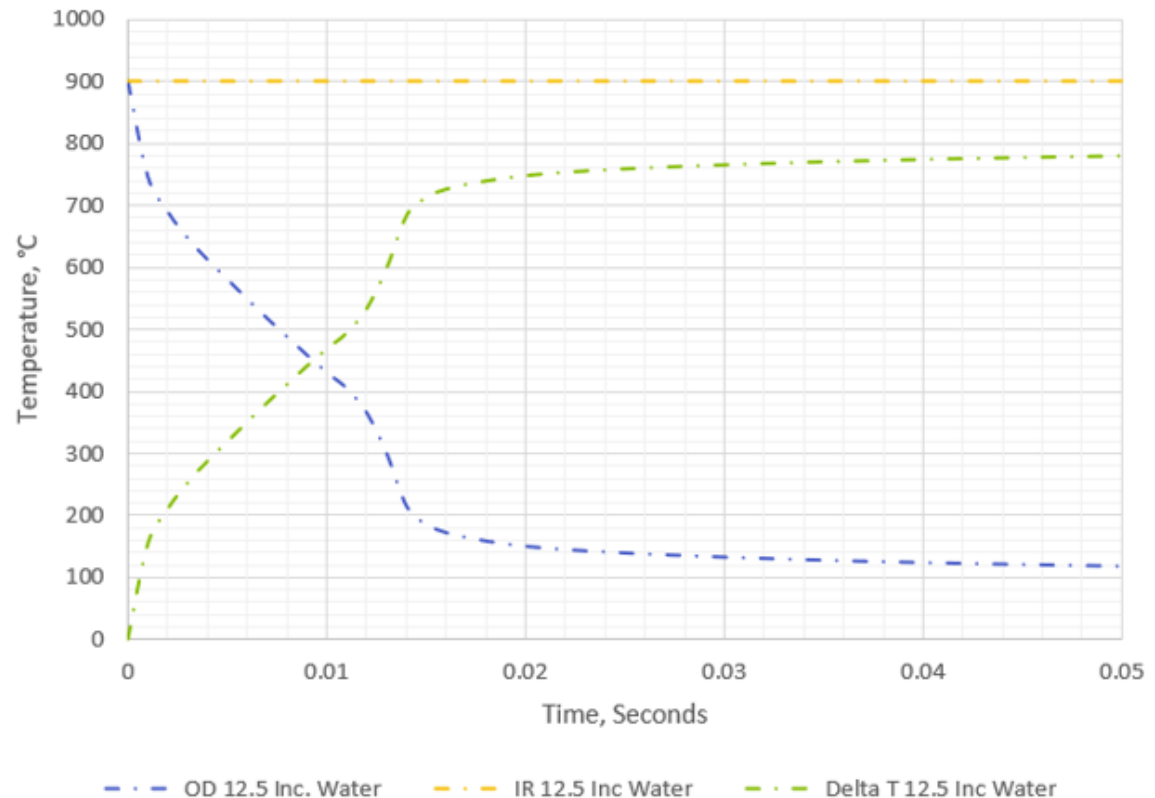
- For both quenchants, the ID Temperature barely moves in the first 0.5 s
- Meanwhile, the surface temperature has already passed through the Ms for many induction heat treatable steels
- Interestingly, in both cases, the surface temperature and delta T intersect around 450 C and beyond this point, delta T is larger than surface temperature



Clearly, the standard probe is too slow to measure these quenching rates

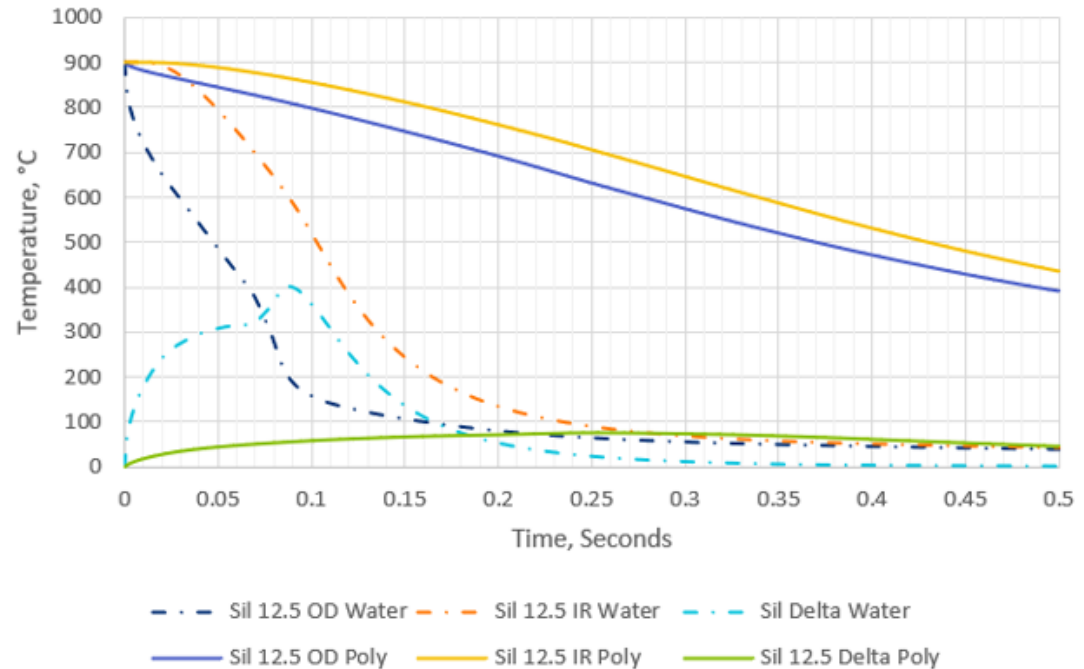
Standard Inconel Probe – 0.8 m/s Water Spray

- With the Water Spray, to see the non-linearities we need to shrink the time scale to 50 ms
- Inverse calculations will not be able to pick these up with the measurement lag



Silver Probe – 12.5 mm

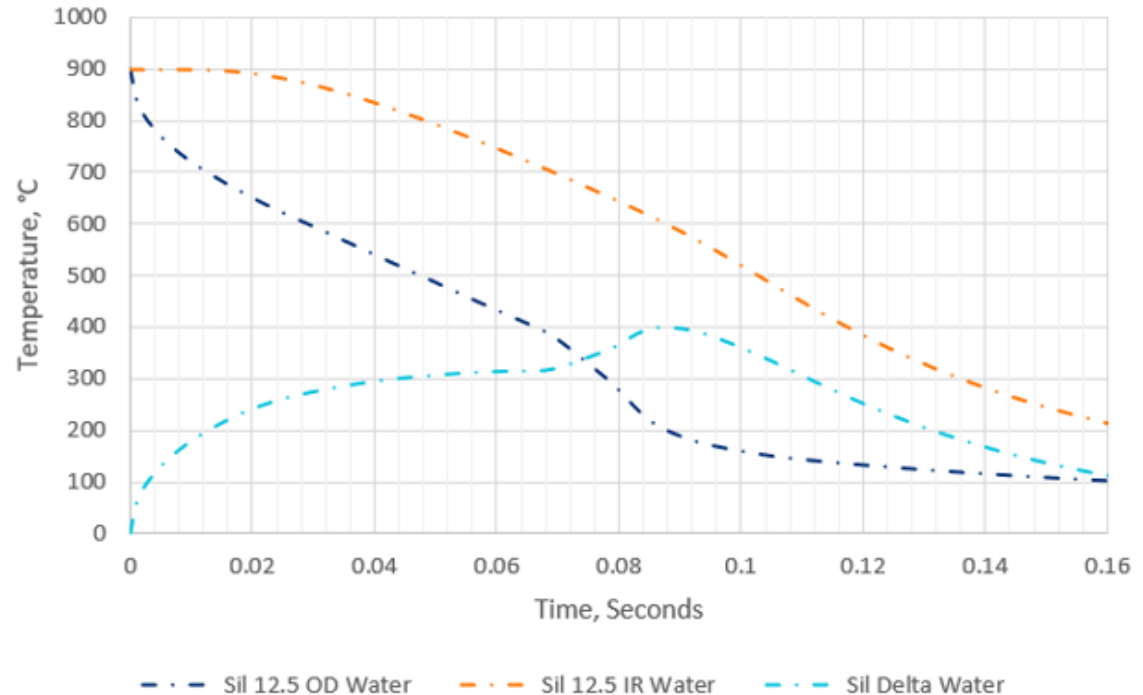
- Much Faster Response than With Inconel
- Shape of ID Curve and OD Curve Match Fairly Well for 12% Polymer Spray



Likely Adequate for Measuring 12% Polymer Spray Quench

Silver Probe 12.5 mm 0.8 m/s Water Spray

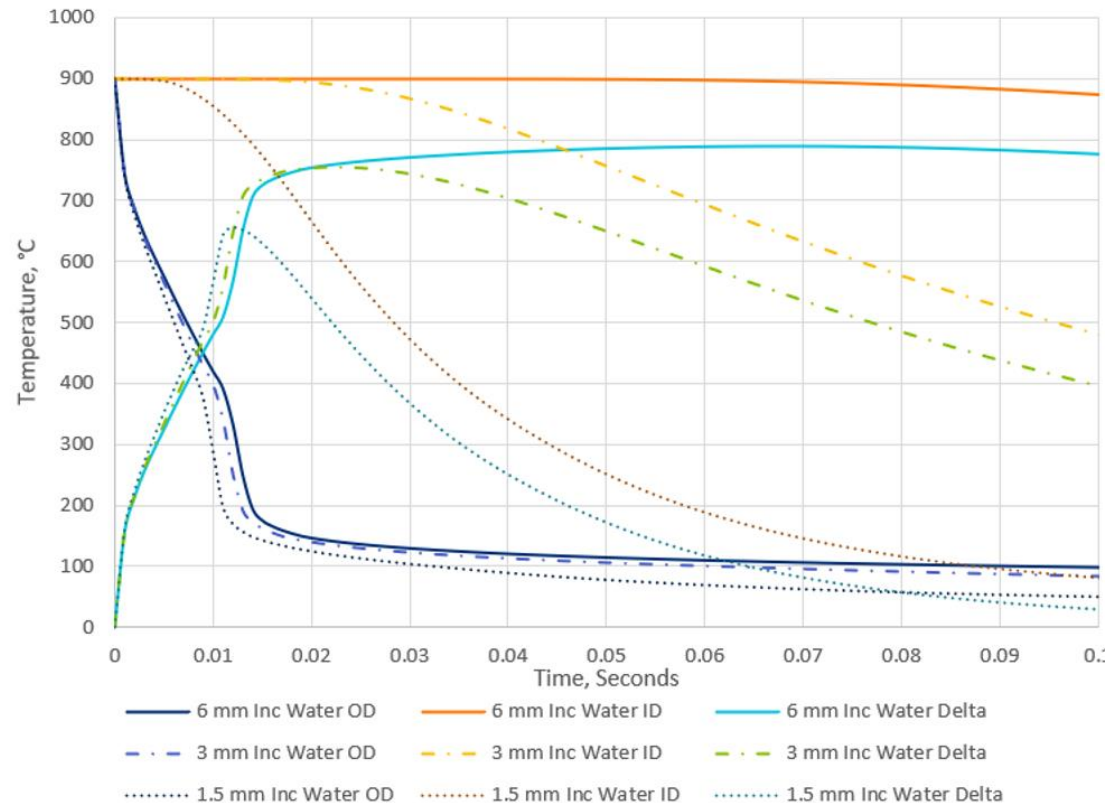
- For the 0.8 m/s Water Spray, the Shape of the OD and ID curve Does Not Match Nearly as Well



Clearly, the 12.5 mm Silver probe is too slow to measure these quenching rates

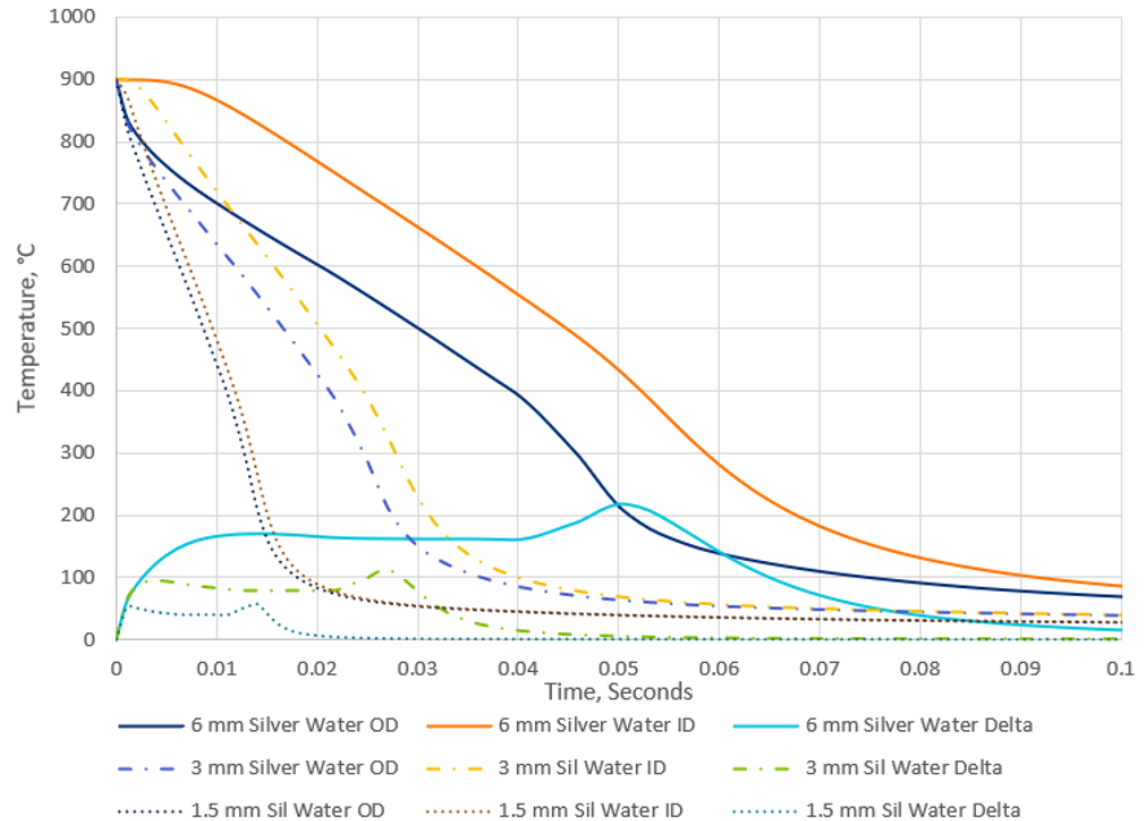
Influence of Diameter for Inconel 600 with 0.8 m/s Water

- Good curve matching not achieved
 - Even with 1.5 mm diameter probe, delta T reaches over 600 C and ID temperature curve is smooth and lacking similar contour to surface



Influence of Diameter for Silver with 0.8 m/s Water

- Reasonable curve matching achieved with smaller probes
 - 6 mm looks OK
 - 3 mm looks Good
 - 1.5 mm looks Very Good



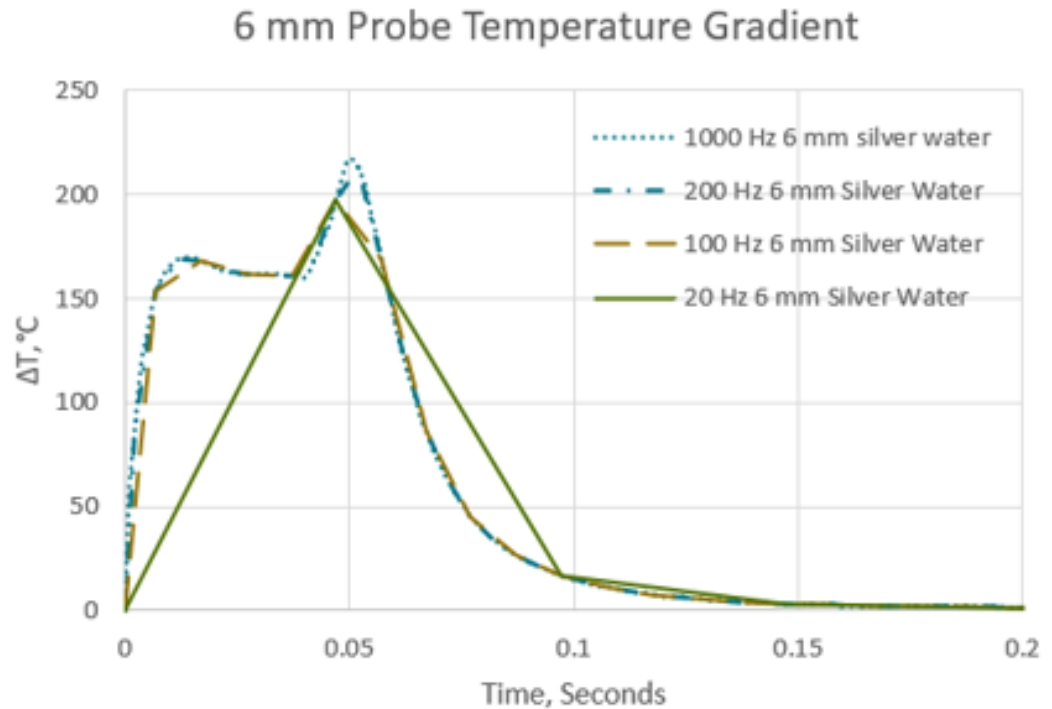
Keeping in mind, the practicality of measuring a spray quenchant with this size of probe, 3 or 6 mm may be better than the 1.5 mm probe

Summary

- Spray Quenchants Are Commonly Used in Induction Heat Treating Applications and Are Much Faster Than Immersion Quenchants
- There Is a Need for Improved Methods for Measurement and Characterization of Spray Quenchants for Induction Heat Treating
- A Virtual Study Was Performed Showing that Standard Quench Probes Were too Slow for Accurate Characterization of Faster Water Spray Quenchants
- Small Diameter Silver Probes Show Promise, but Consideration Needs to Be Made for the Practicality of Their Design

Effect of Data Sampling Rate on Temperature Gradient for 6 mm Probe

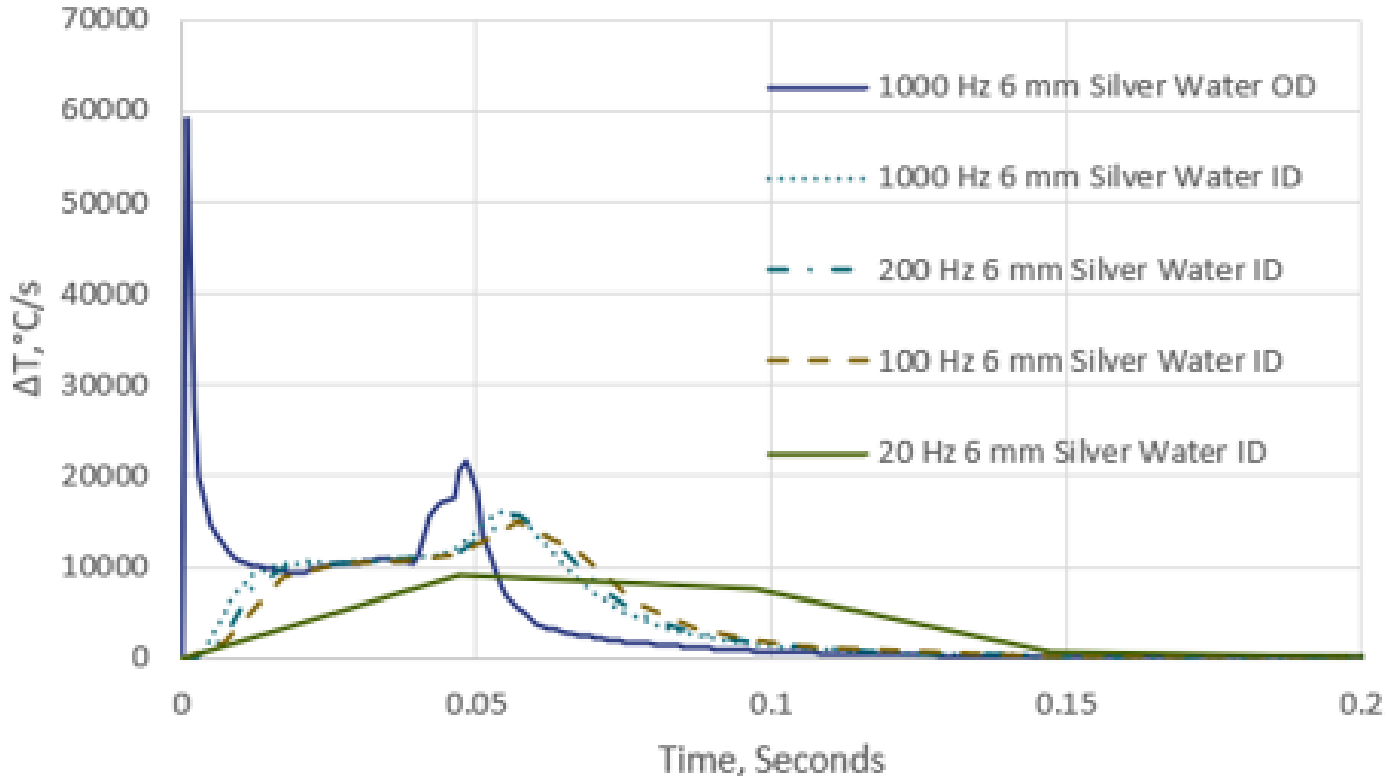
- Data sampling rate is also important
- With the 6 mm silver probe, 200 Hz sampling rate or Higher Should Be Used
 - 20 Hz typical with off the shelf equipment



Will Be Presented in Paper in Prague at ECHT 2025

Cooling Rate Comparison

6 mm Cooling Rate Measurement



Using this criteria, it is clear that 6 mm Silver Probe Is Too Slow as Well

Will Be Presented in Paper in Prague at ECHT 2025