Relative Humidity and Wet/Dry Transitions in Salt Spray Corrosion Tests

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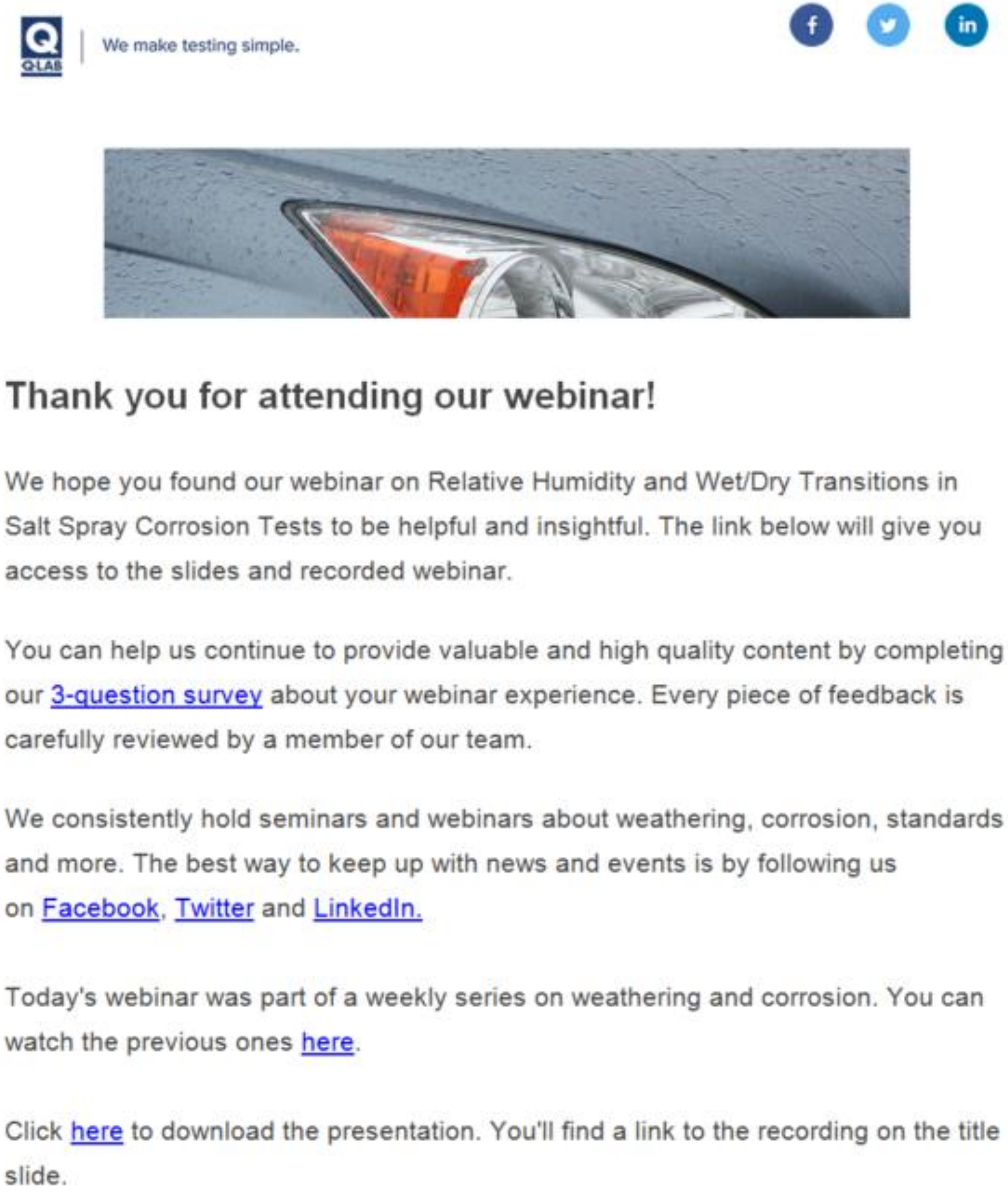

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Thank you for attending our webinar!

We hope you found our webinar on Relative Humidity and Wet/Dry Transitions in Salt Spray Corrosion Tests to be helpful and insightful. The link below will give you access to the slides and recorded webinar.

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We consistently hold seminars and webinars about weathering, corrosion, standards and more. The best way to keep up with news and events is by following us on Facebook, Twitter and LinkedIn.

Today's webinar was part of a weekly series on weathering and corrosion. You can watch the previous ones here.

Click here to download the presentation. You'll find a link to the recording on the title slide.

Discussion Topics

- Reproducibility and Deliquescence
- Theoretical effects of wet/dry transition times
- Case Studies
  - ASTM G85 Annex 5 (Prohesion)
  - SAE J2334: OEM Implementation
- How current standards handle moisture transitions

Corrosion Test Reproducibility

Wet/dry cyclic tests…

- Generally are more realistic than continuous salt spray
- Often have such poor reproducibility that many companies do not use them despite better realism

Salts in the Environment & TOW

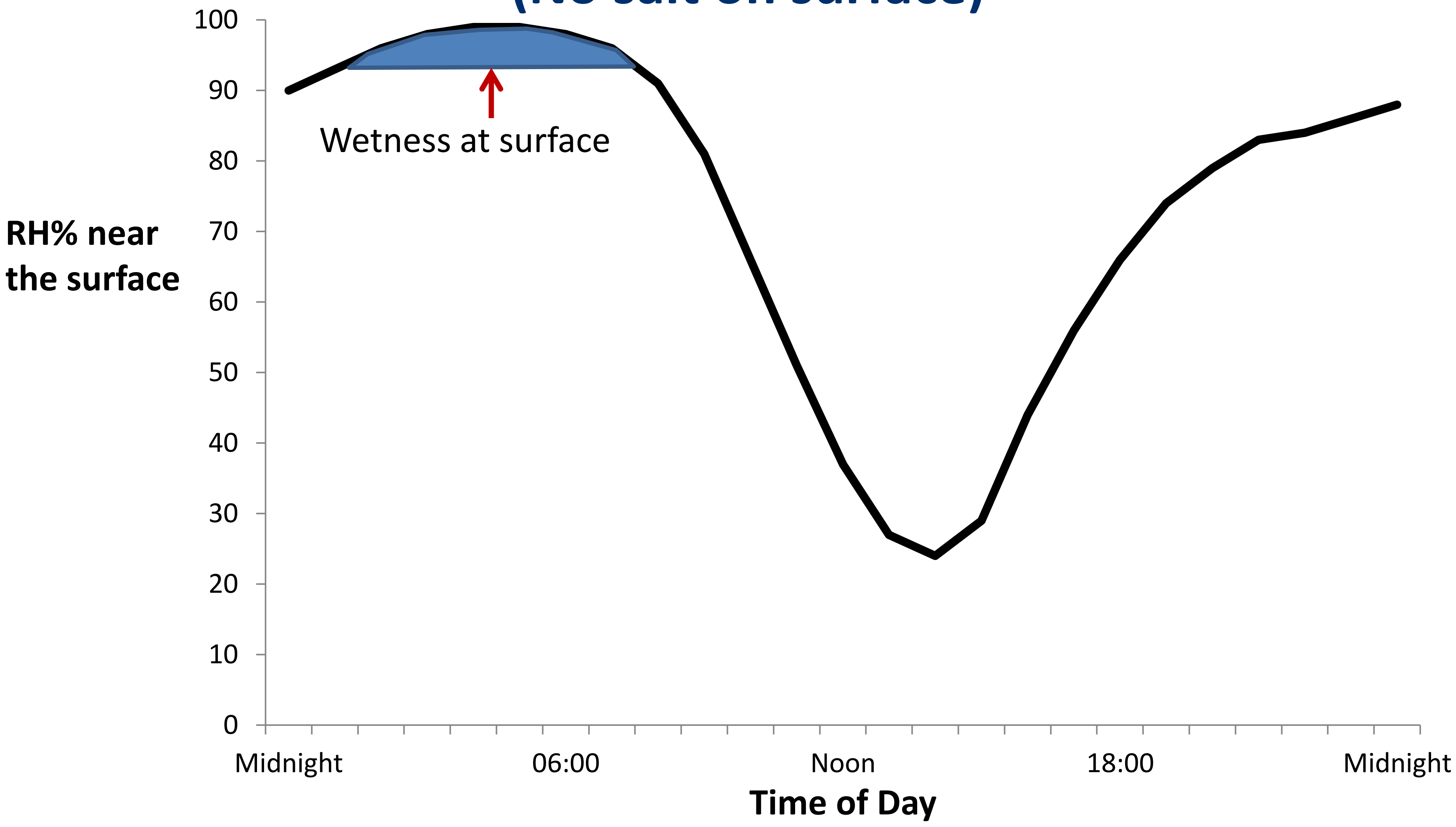
- Salts ***deliquesce*** - they absorb moisture from the atmosphere until they dissolve and form a solution.
- All soluble salts will liquefy for RH values <100%
- This leads to increased **time of wetness** and increased **corrosion**

Deliquescence Relative Humidity (DRH)

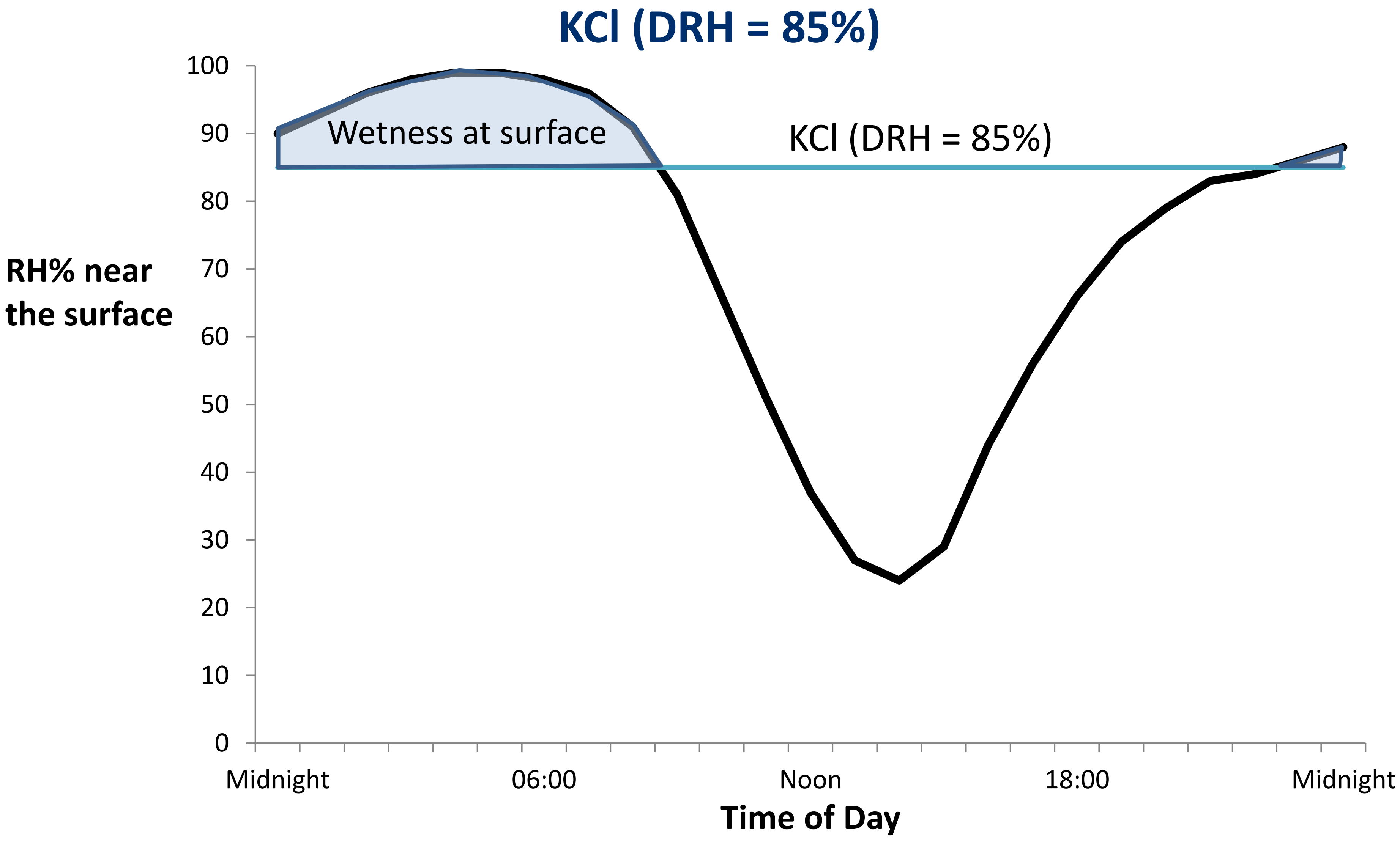
Salt	DRH
Potassium Chloride (KCl)	85%
Ammonium Sulfate $(NH_4)_2SO_4$	81%
Sodium Chloride (NaCl)	***76%***
Sodium Nitrate ($NaNO_3$)	74%
Magnesium Chloride ($MgCl_2$)	33%
Calcium Chloride ($CaCl_2$)	***31%***

if the environment is above this RH, a liquid salt solution will form

RH and Time of Wetness
(No salt on surface)

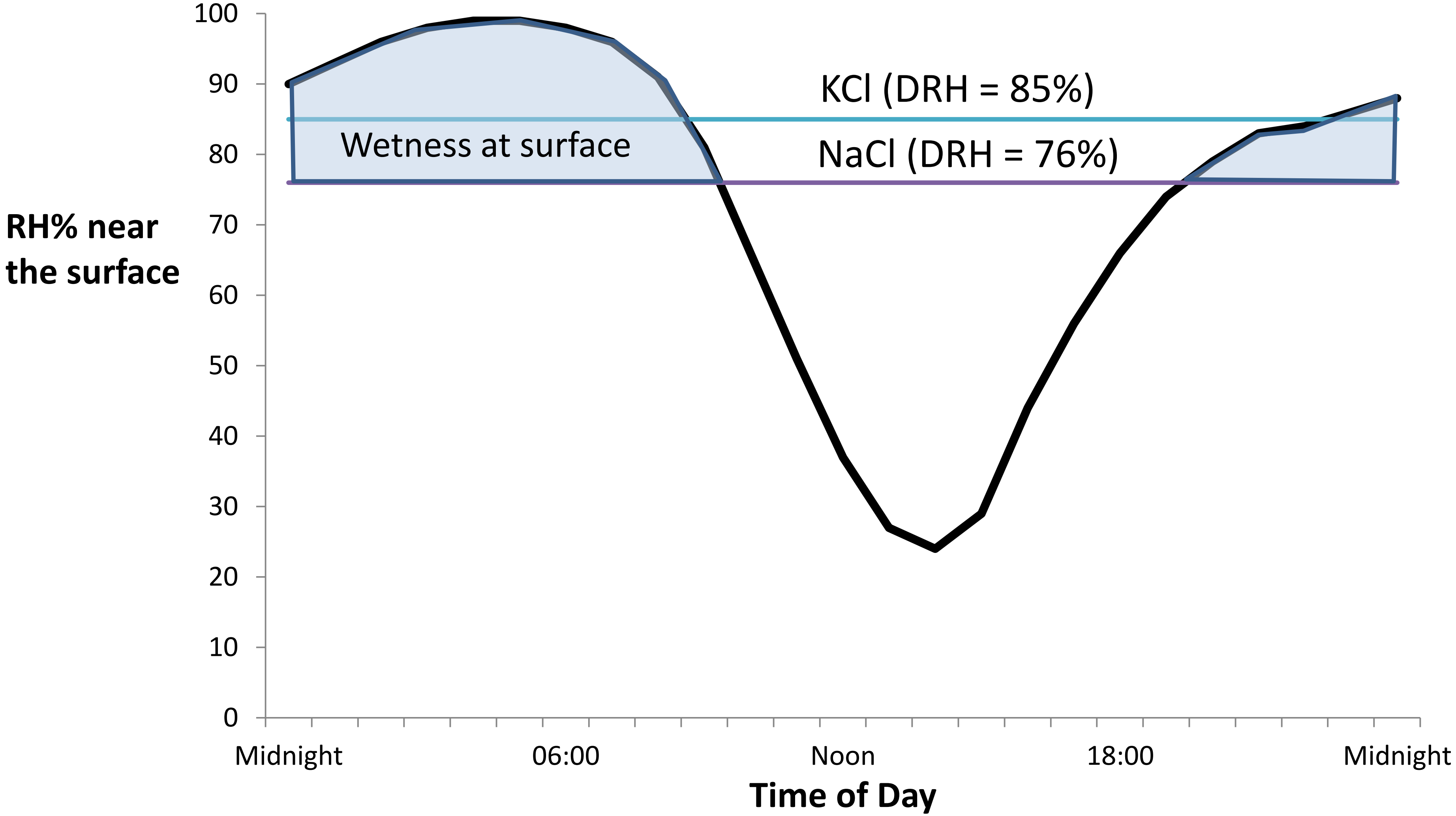


RH and Time of Wetness



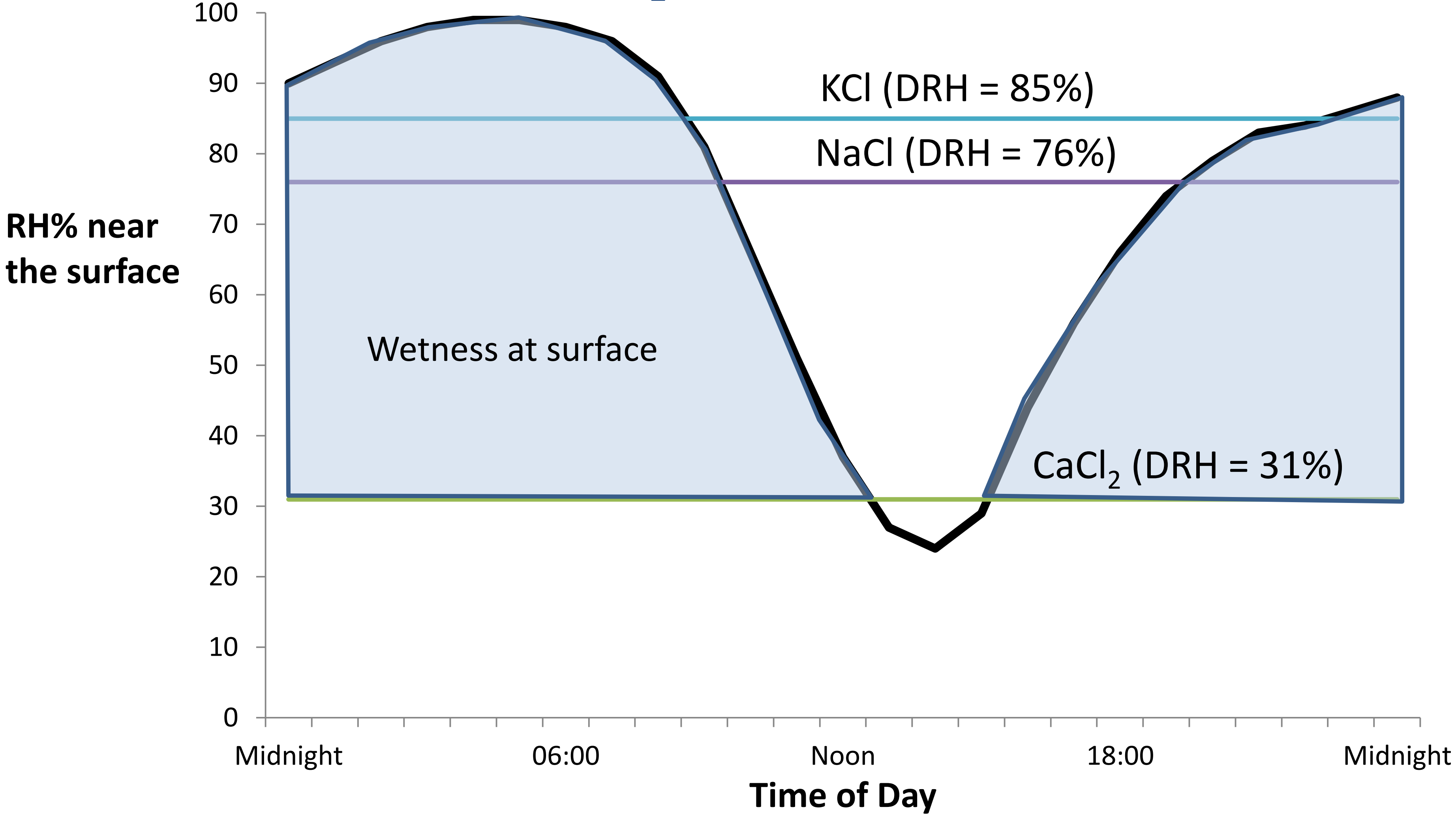
RH and Time of Wetness

NaCl (DRH = 76%)



RH and Time of Wetness

$CaCl_2$ (DRH = 31%)

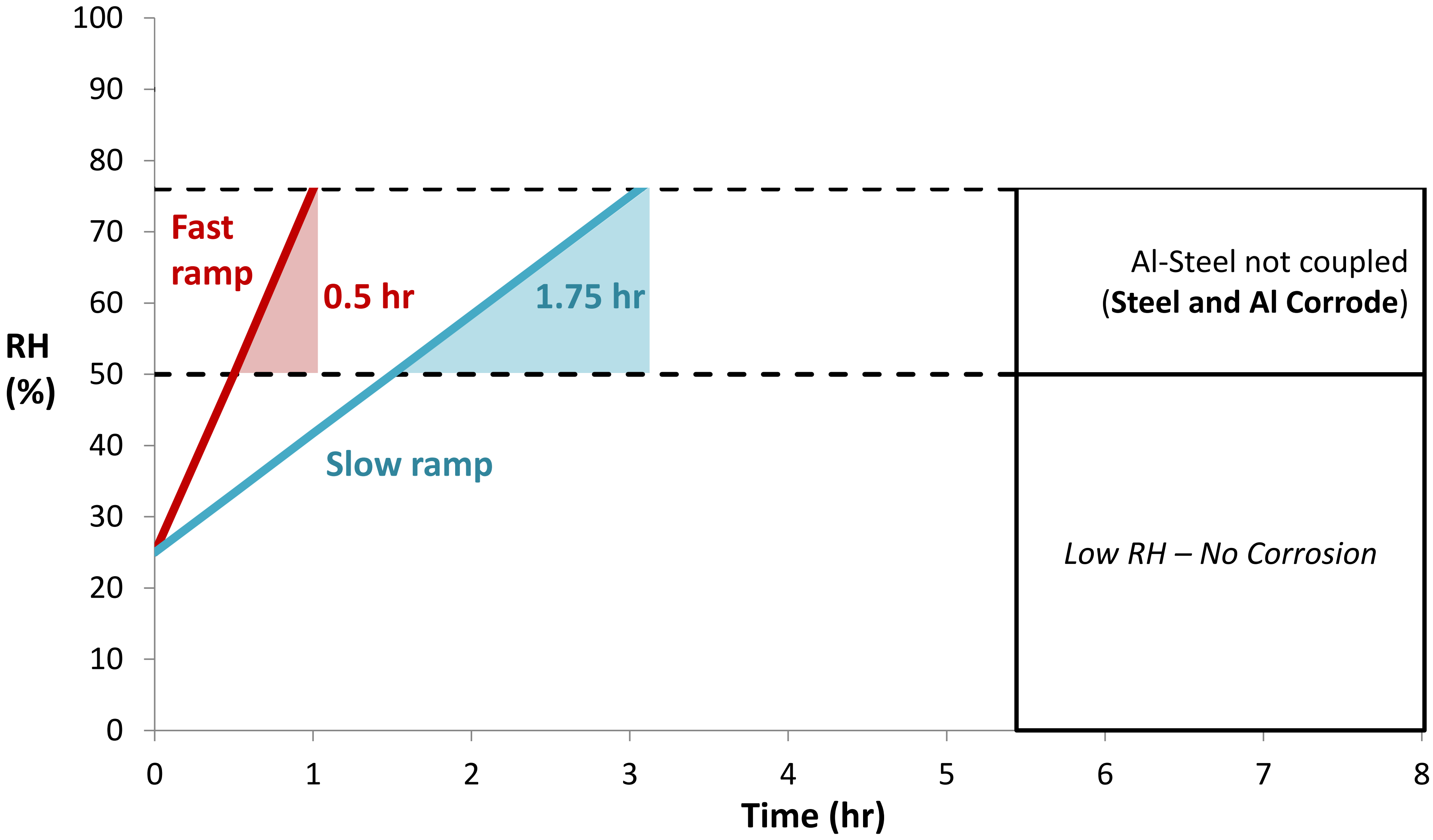


Relative Humidity and Corrosion

Condition	RH Range	Result
Dry	**≤ 50%**	Very little corrosion from NaCl
Electrolytic cells around salt crystals; film formation as RH increases	**50-76%**	• Corrosion of **steel** (maximum corroded area ~70% RH) and **aluminum** • AL-Steel galvanic couple broken
Uniform Electrolytic Film formation	**≥76%**	• Maximum cathode area for steel; deeper non-uniform corrosion • **Al corrosion** in galvanic couple with steel

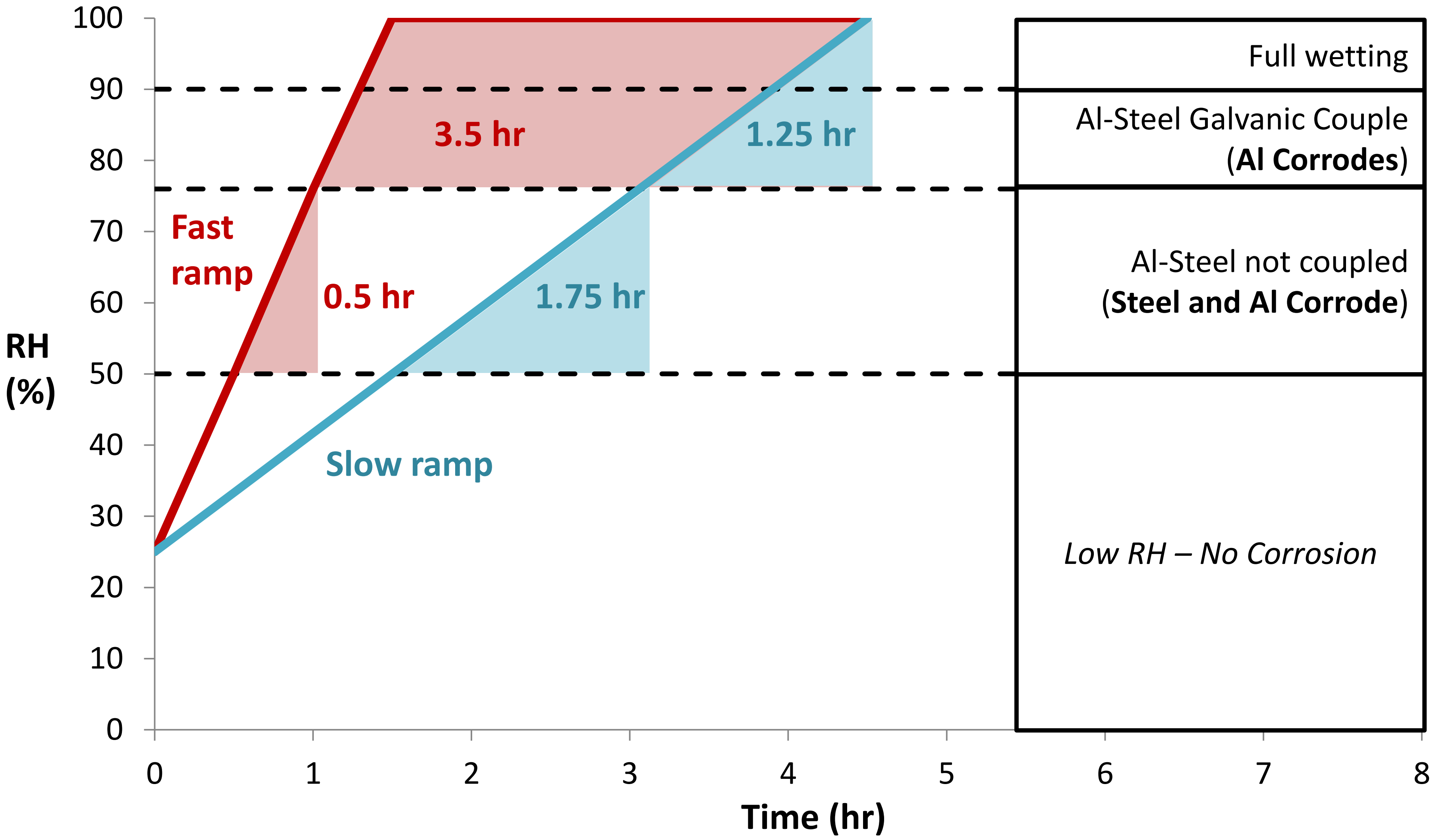
Galvanic corrosion during ramping

50% < RH < 76%



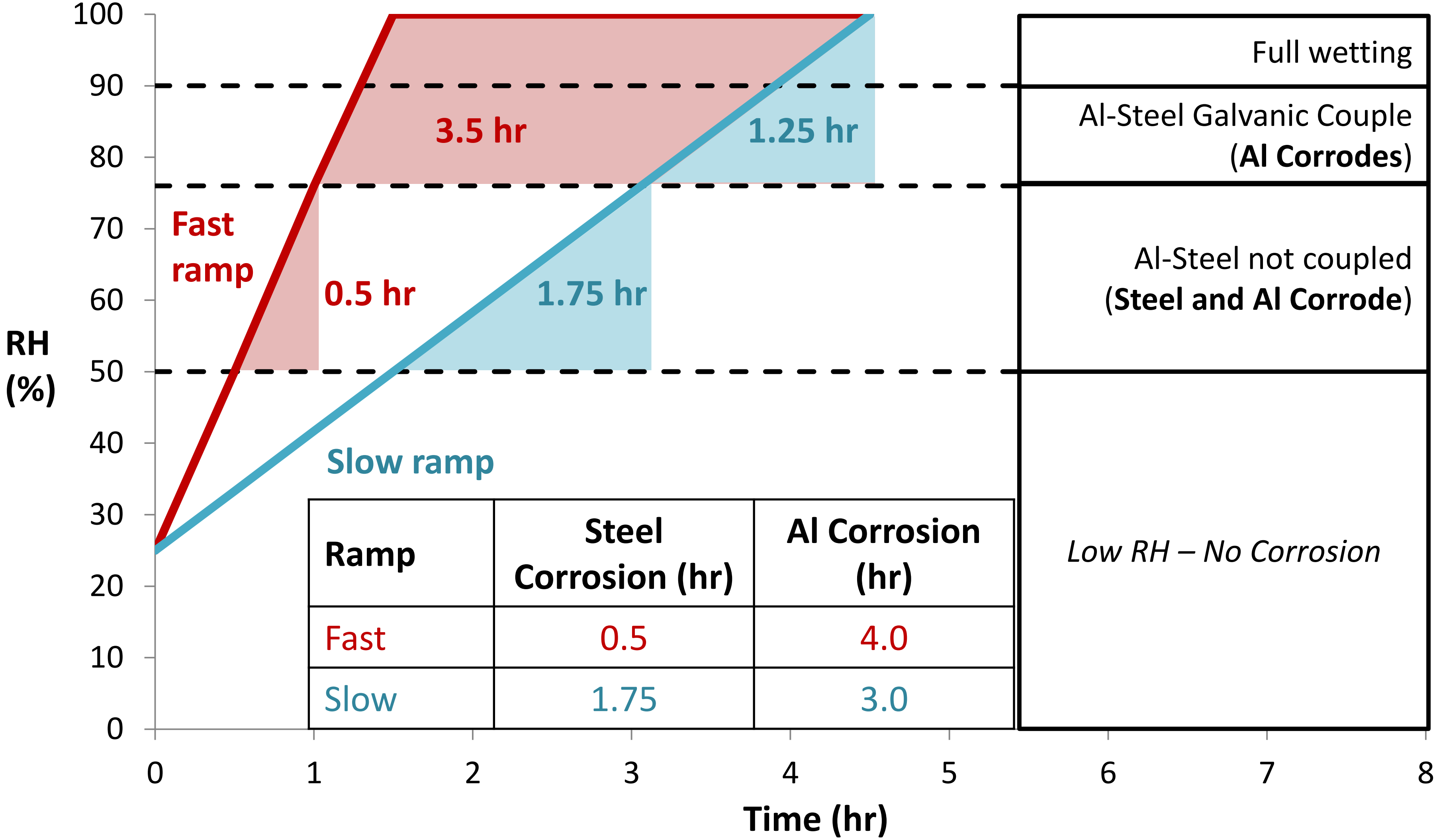
Galvanic corrosion during ramping

High RH > 76%



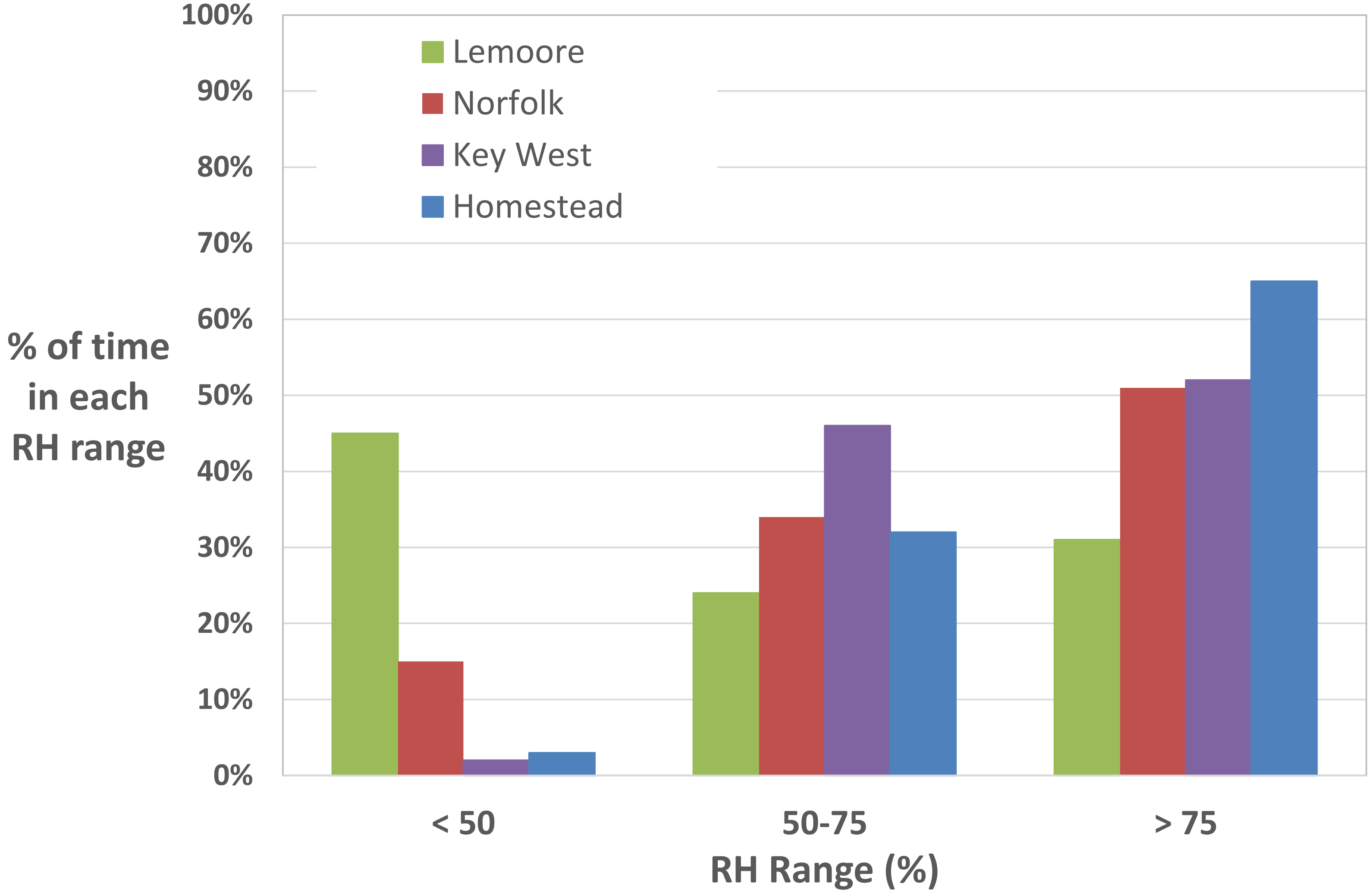
Galvanic corrosion during ramping

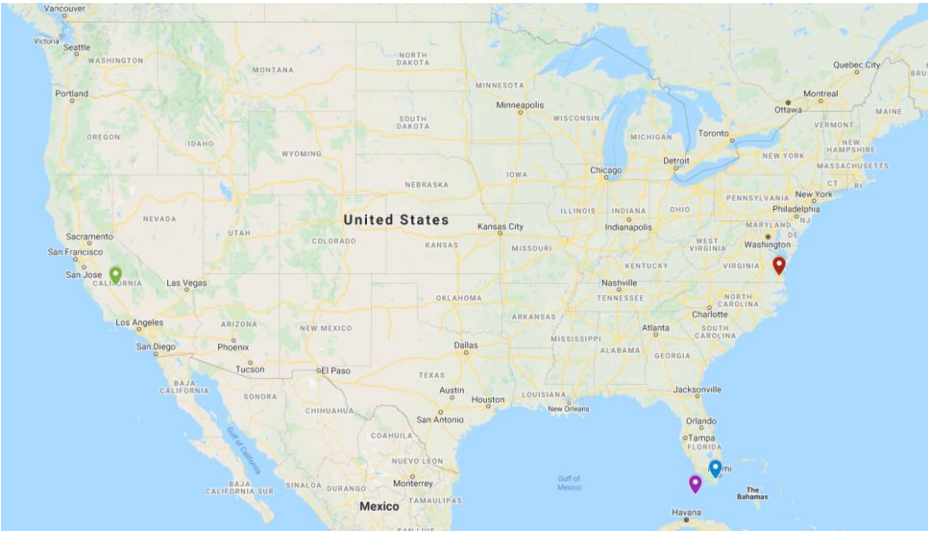
High RH > 76%



Ramp	Steel Corrosion (hr)	Al Corrosion (hr)
Fast	0.5	4.0
Slow	1.75	3.0

RH Conditions in the Natural Environment





Reproducibility Case Studies

- ASTM G85 Annex 5 (Prohesion)
- SAE J2334

ASTM G85 Annex 5 (Prohesion)

1 Hour fog at "ambient" temperature
1 hour dry-off 35°C

Solution: 0.05% NaCl
0.35% $(NH_4)_2SO_4$
pH: 5.0 - 5.4

ASTM G85 Annex 5 (Prohesion)

- How dry is dry?
- How long does it take to achieve a “dry” condition?

Answers are in the non-mandatory appendix: “within ¾ hour all visible moisture is dried off the specimens”

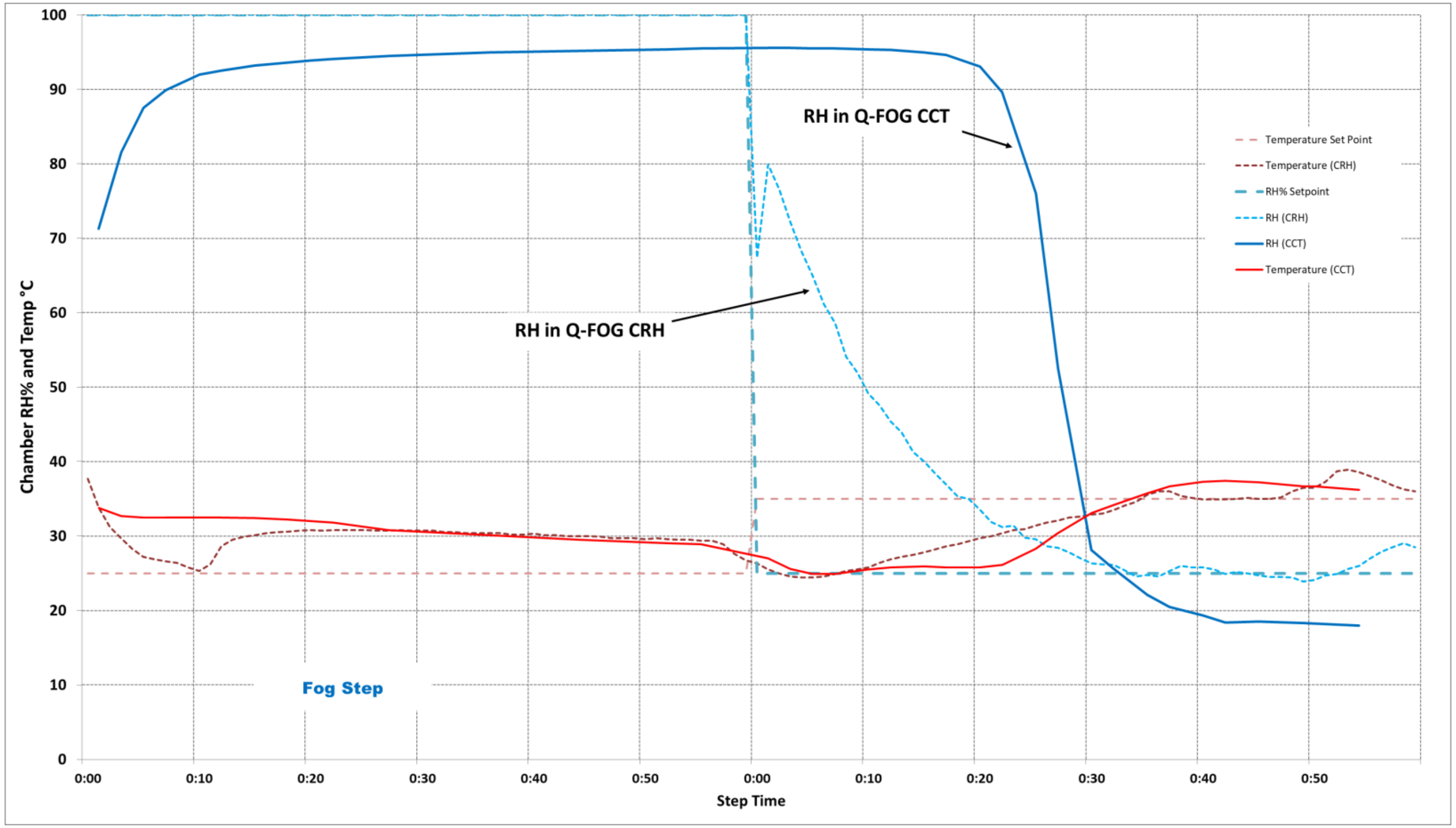
Problem Statement

My new chamber isn't as severe as my old one

After 1000 hours of Prohesion, new chamber produced less severe results on a coatings test

Q-FOG CCT *Q-FOG CRH*

Prohesion RH Profile in Two Chambers



Q-FOG CCT Cycle:

Step 1: Fog 24°C 1:00

Step 2: Dry 35°C 1:00

Step 3: Go to Step 1

Q-FOG CRH Cycle:

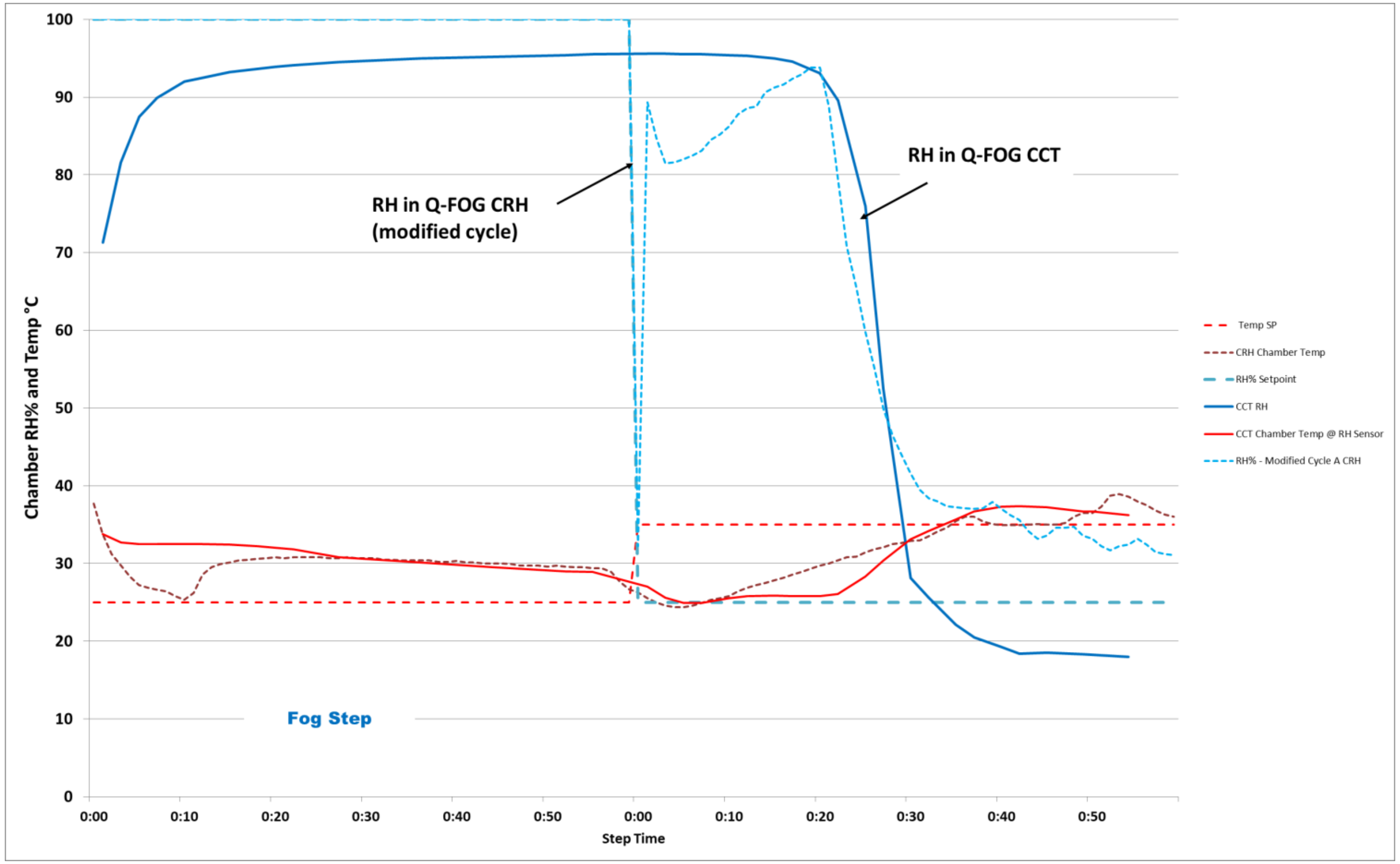
Step 1: Fog 24°C 1:00

Step 2: RH 35°C, 25% RH 1:00

Auto transition

Step 3: Go to Step 1

Modified CRH Prohesion Cycle



Modified Prohesion Cycle:

Step 1: FOG 24°C 1:00

Step 2: RH 35°C, 95%RH 0:30

Auto transition

Step 3: RH 35°C, 25% RH 0:30

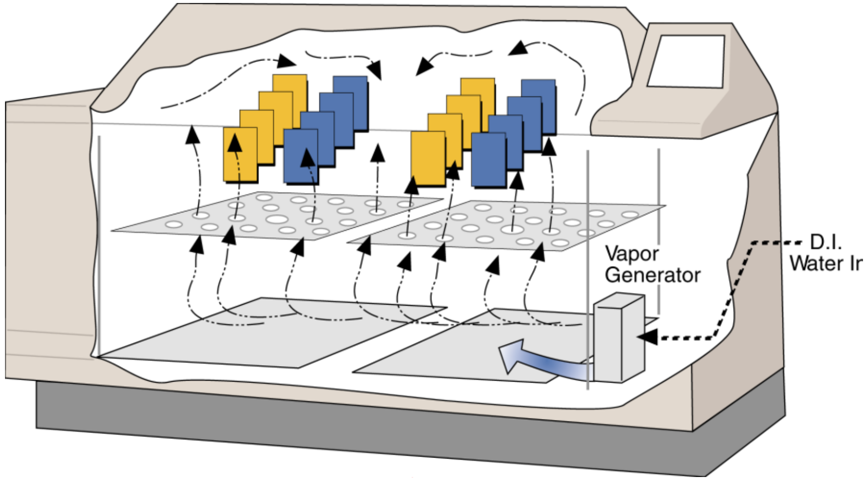
Auto transition

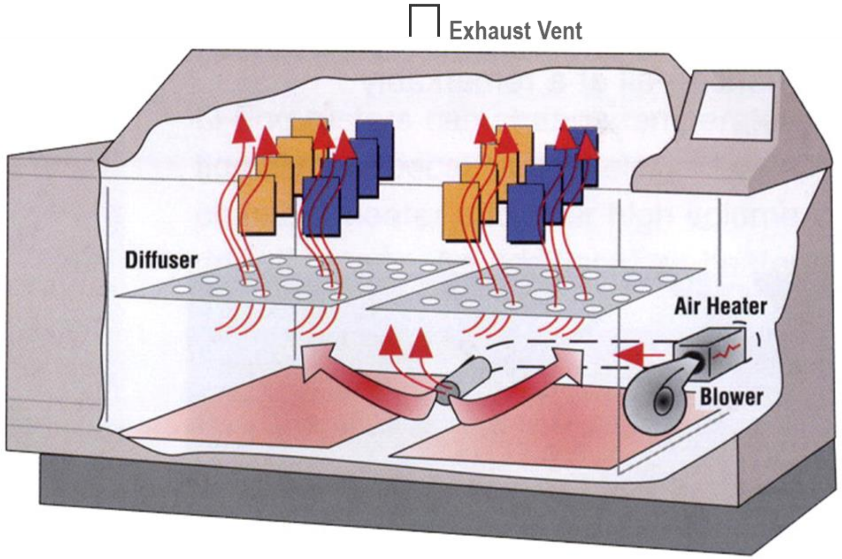
Step 4: Go to Step 1

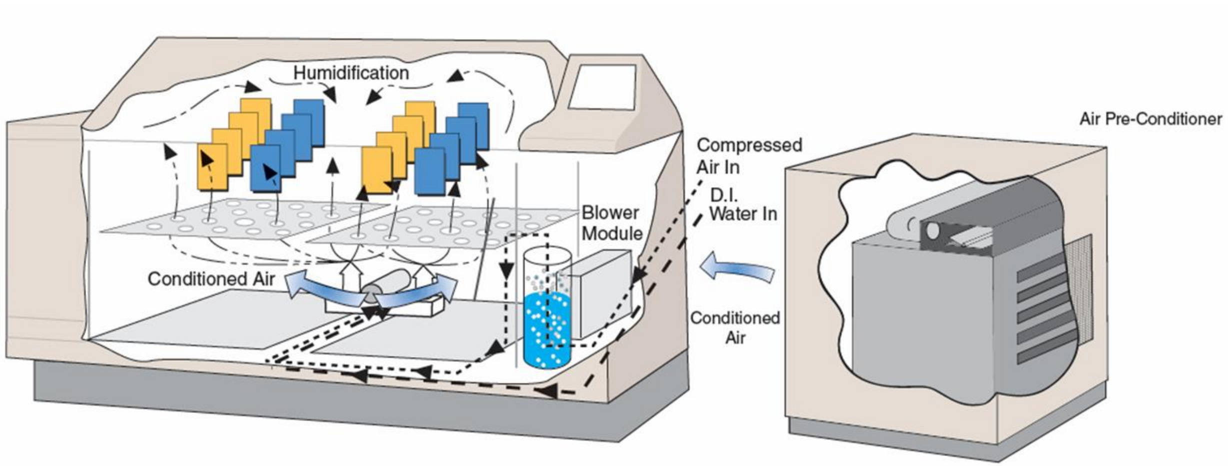
Q-FOG CCT *Q-FOG CRH (modified cycle)*

Q-FOG CCT vs CRH

Q-FOG CCT has simple humidity generation without air flow and dry-off by blown heated air through chamber

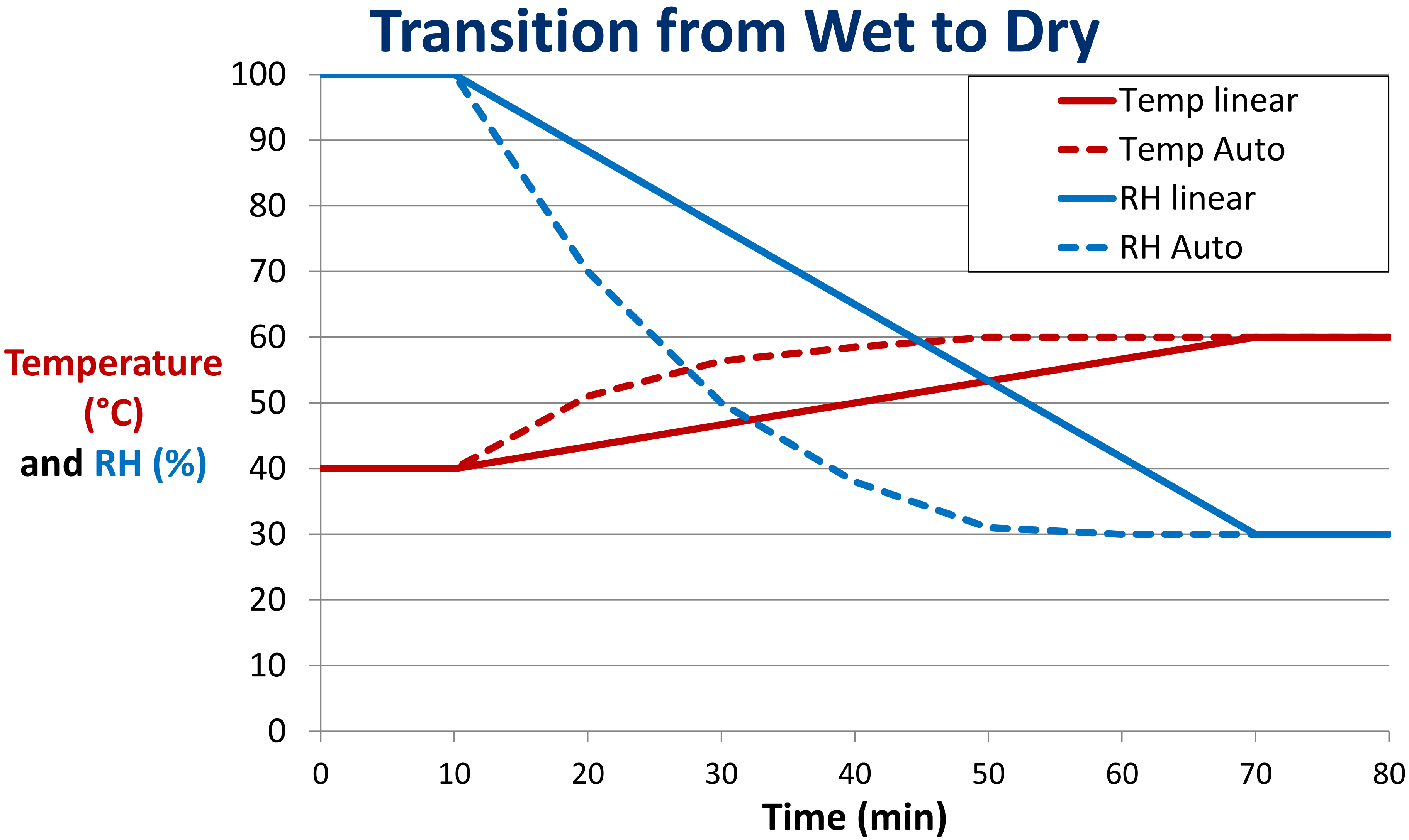






Q-FOG CRH has atomizing humidification nozzles, an air drier (chiller), and a recirculation system with damper to regulate moist and dry air streams

Q-FOG CRH Linear and Auto Ramping



SAE J2334

Test Solution

0.5% NaCl

0.1% $CaCl_2$

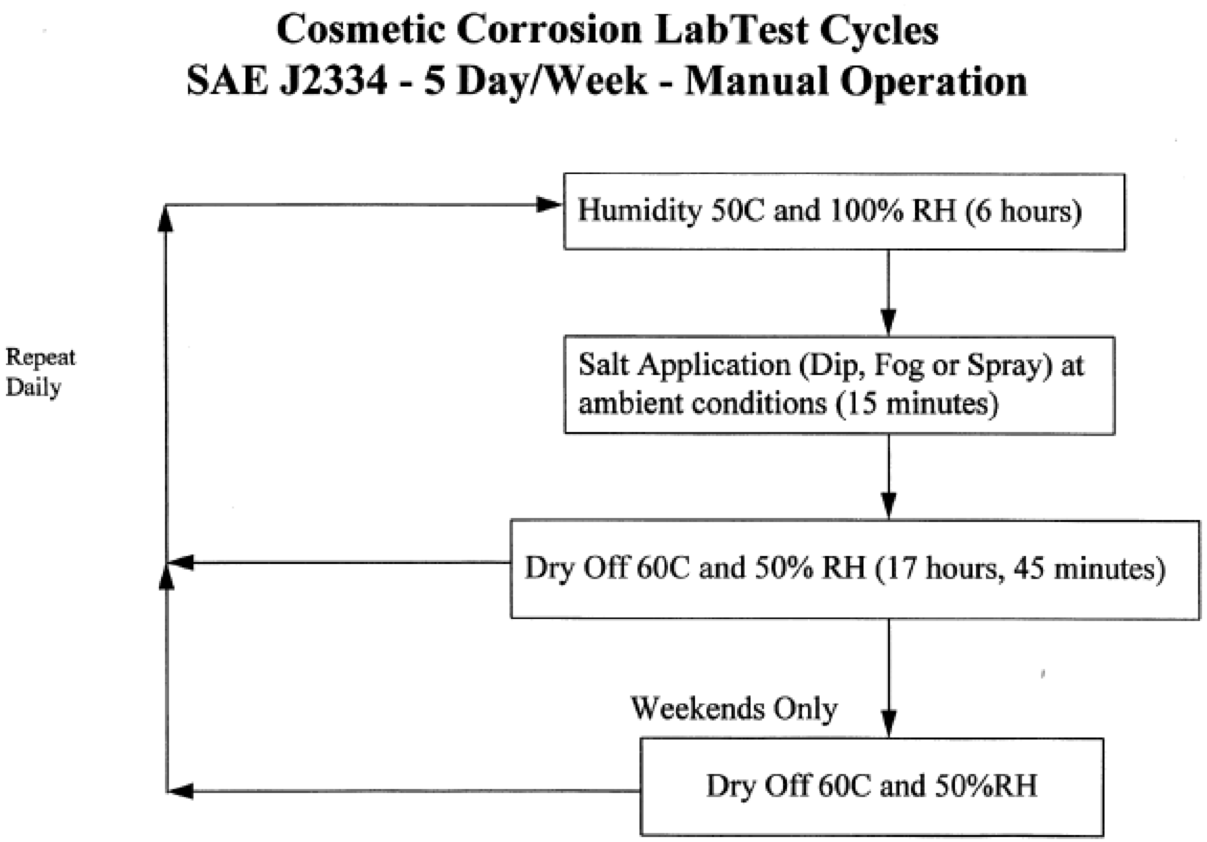
0.075% $NaHCO_3$

This is the same as GM 9540P and GMW 14872

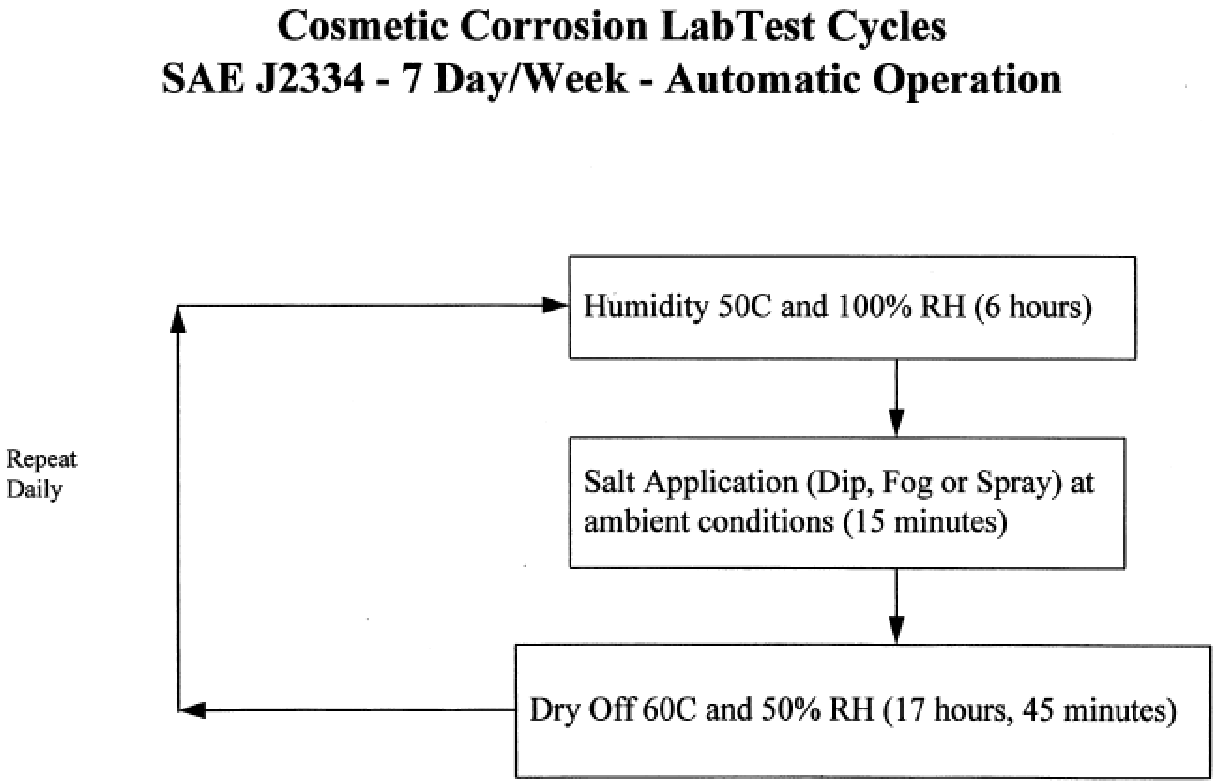
Salt solution applied by

- *Immersion (used to develop method)*
- *Fog (may not deposit much salt on specimens)*
- *Shower (most common today)*

SAE J2334



Cosmetic Corrosion LabTest Cycles
SAE J2334 - 5 Day/Week - Manual Operation
Humidity 50C and 100% RH (6 hours)
Repeat Daily
Salt Application (Dip, Fog or Spray) at ambient conditions (15 minutes)
Dry Off 60C and 50% RH (17 hours, 45 minutes)
Weekends Only
Dry Off 60C and 50%RH

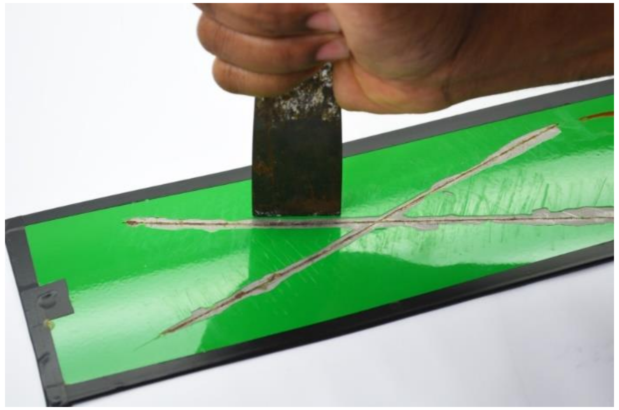


Cosmetic Corrosion LabTest Cycles
SAE J2334 - 7 Day/Week - Automatic Operation
Humidity 50C and 100% RH (6 hours)
Repeat Daily
Salt Application (Dip, Fog or Spray) at ambient conditions (15 minutes)
Dry Off 60C and 50% RH (17 hours, 45 minutes)

OEM Implementation of J2334

Added mass loss requirement after 20 cycles: 1.3 – 3.0 g

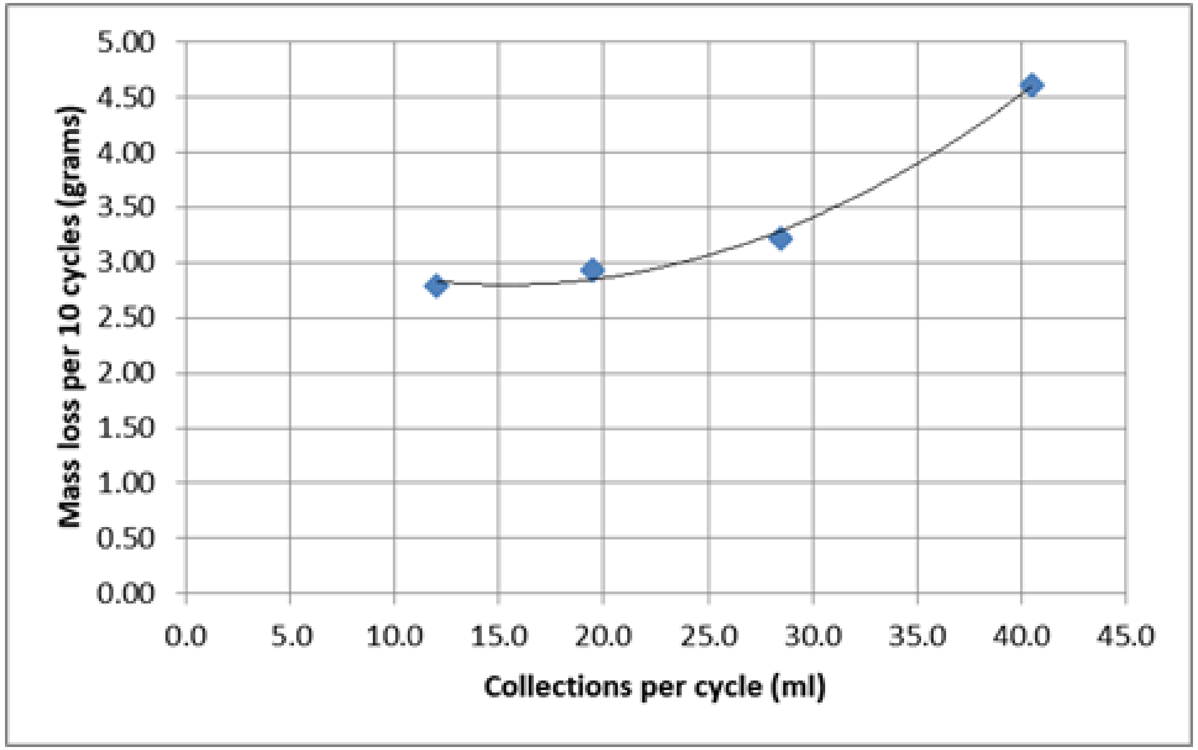
Topcoat specification: Rust “Creepback Value Before Scraping” Average: 4, maximum 6.5



The Problem

- U.S. lab "passed" a formulation (average CVBS < 3)
- European lab "failed" same formulation (average CVBS > 6)
- Formulation was a proven durable system (used as a test control)
- European lab coupon mass loss too high (~5 g after 20 cycles—3 g is max allowed)

Experiment 1: Salt Shower Quantification



- Amount of collections correlated with mass loss (previously known from GMW 14872 testing)
- Adjusted spray on/off time to reduce spray (10ml/cycle)
- Mass loss remained high!

What about chamber conditions?

- Wet to dry transitions were programmed differently in U.S. lab (other chamber) and European lab (Q-FOG CRH)
  - 20 minute transition step added to U.S. chamber to speed up RH reduction (a common practice)

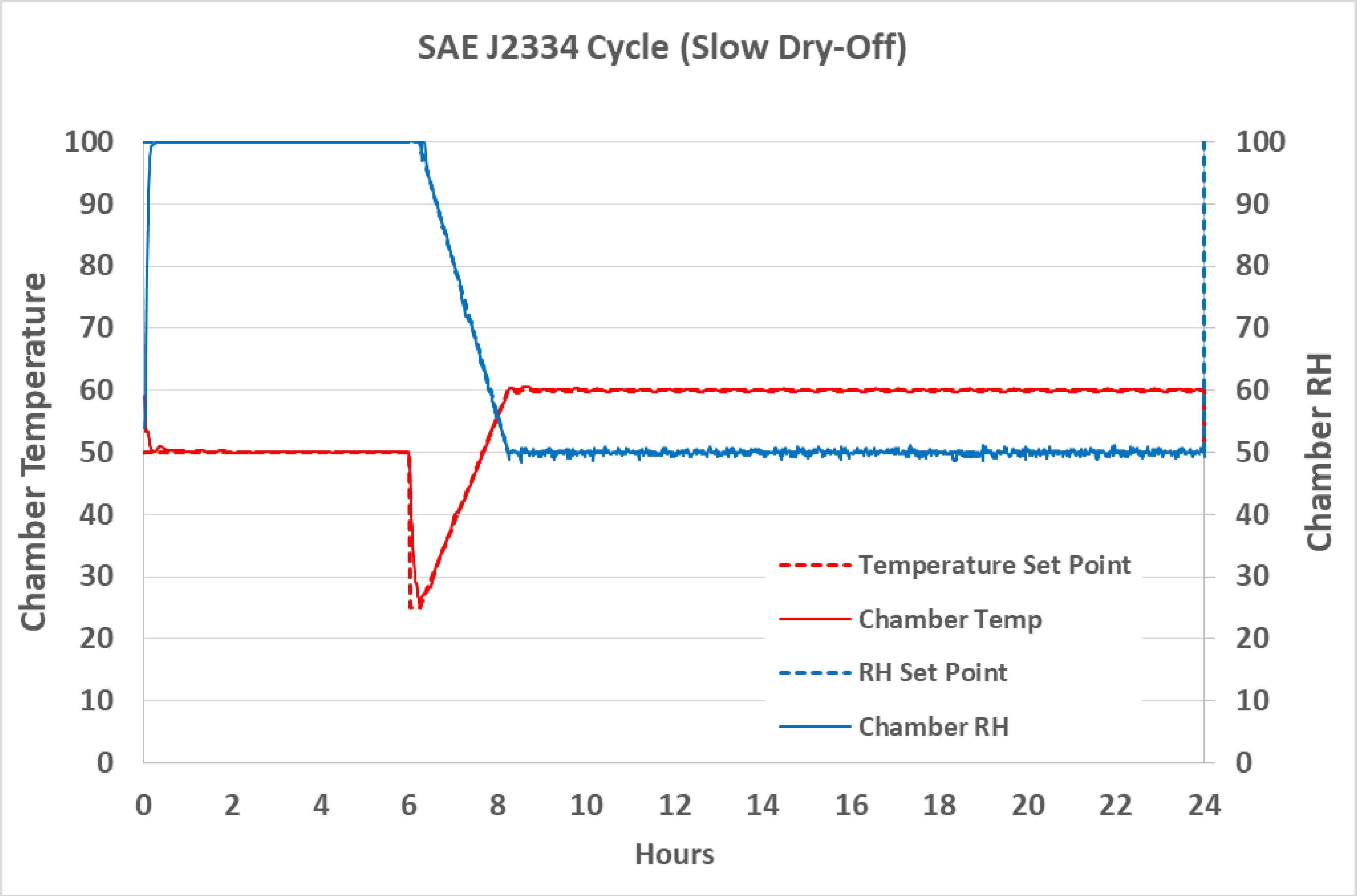
Experiment 2: Rapid and Slow Dry Times

- Test original default SAE J2334 cycle in Q-FOG and another cycle designed to achieve faster dry-off time

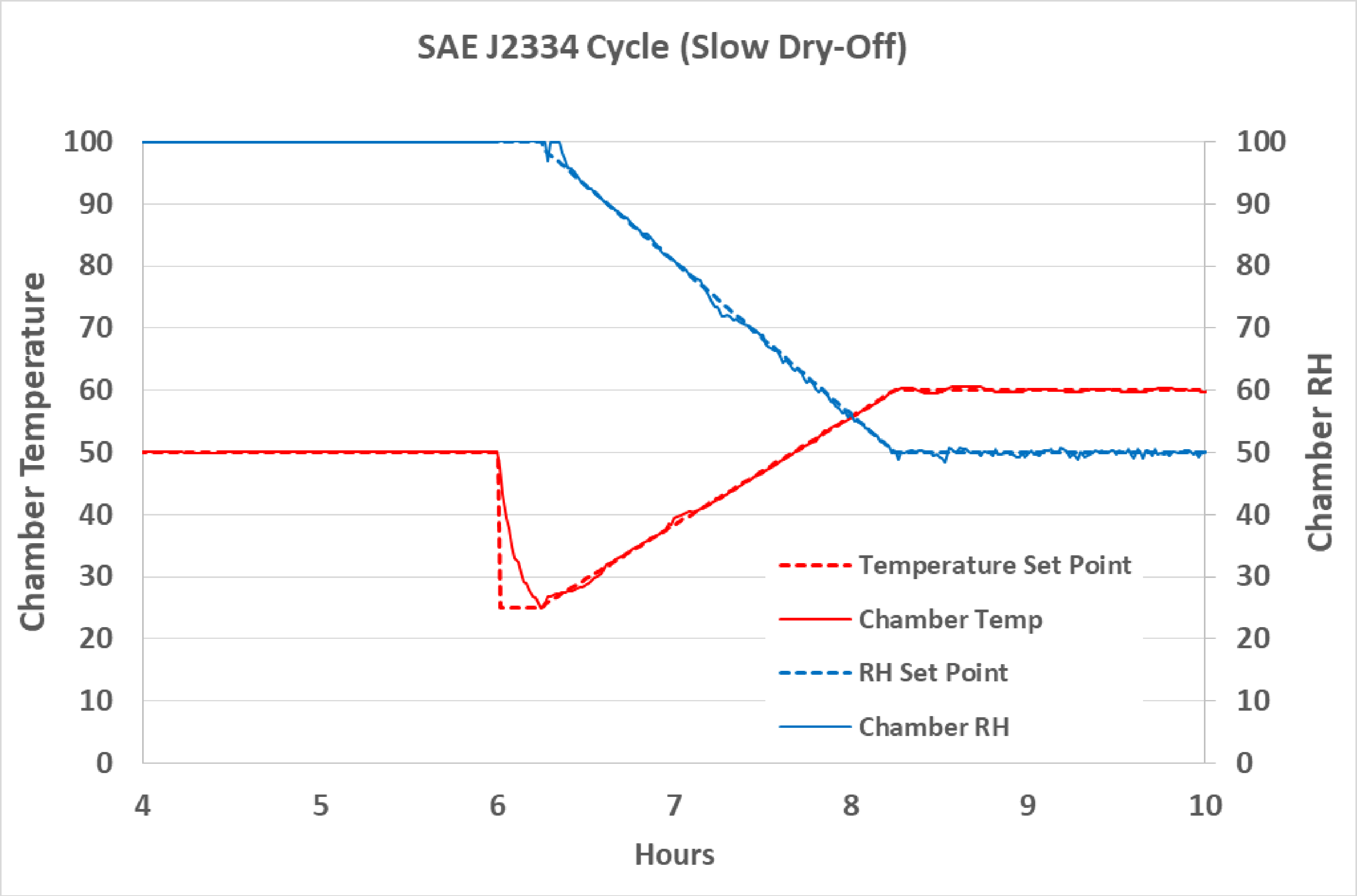
Slow Dry Programming Cycle

Long Dry-Off Time

Step	Function	Chamber Air Temp (ºC)	RH (%)	Step Time (hh:mm)	Ramp
1	RH	50	100%	6:00	Auto
2	SHOWER	25		0:15	
3	RH	60	50%	17:45	Linear (2:00)
4	Final Step - Go To Step 1				



This version of the test was Q-Lab's default program for J2334 Linear transition after spray



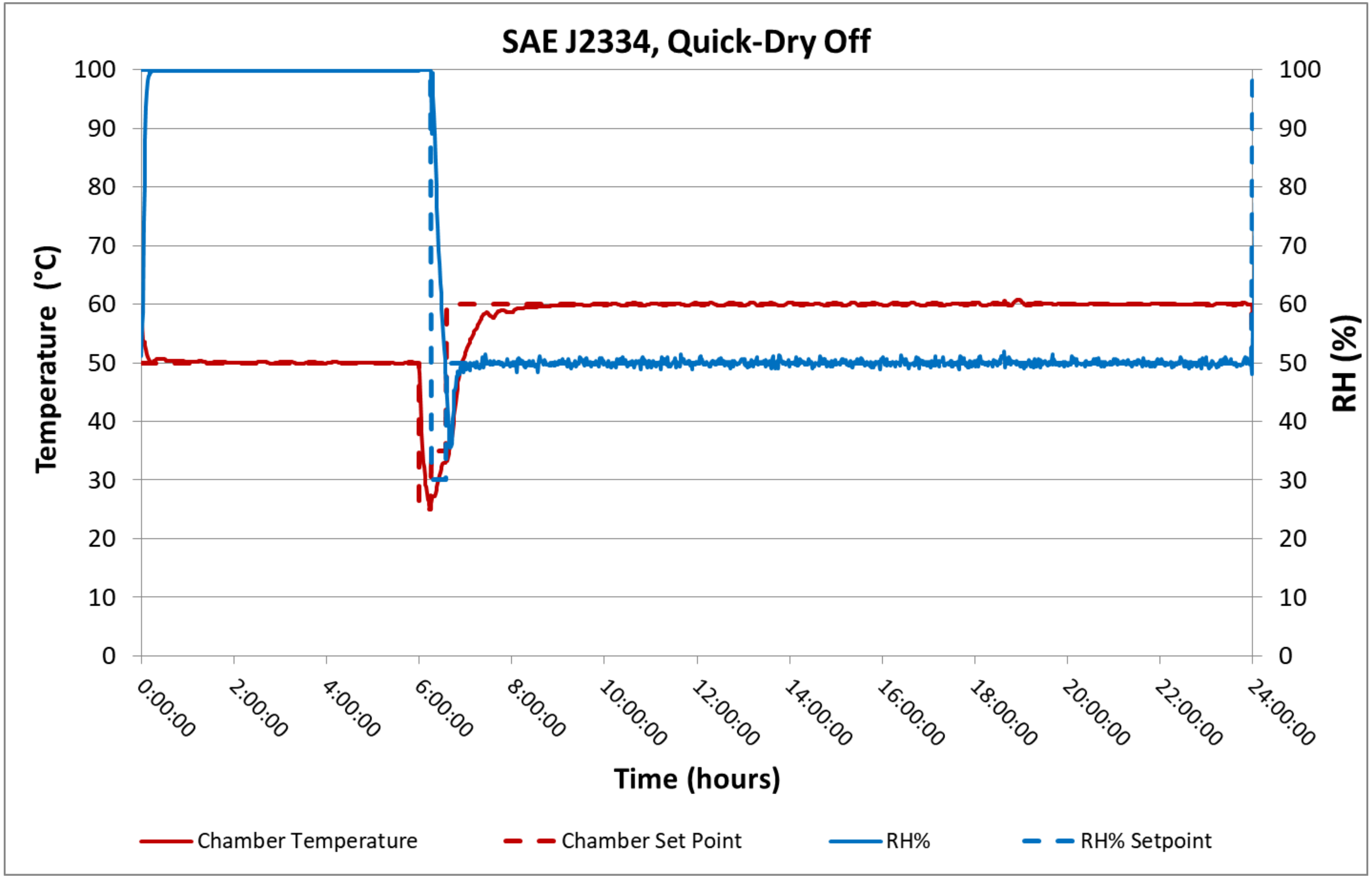
Zoomed in view of the transition

During the transition, the time above the Deliquescence RH of NaCl is about 1 hour

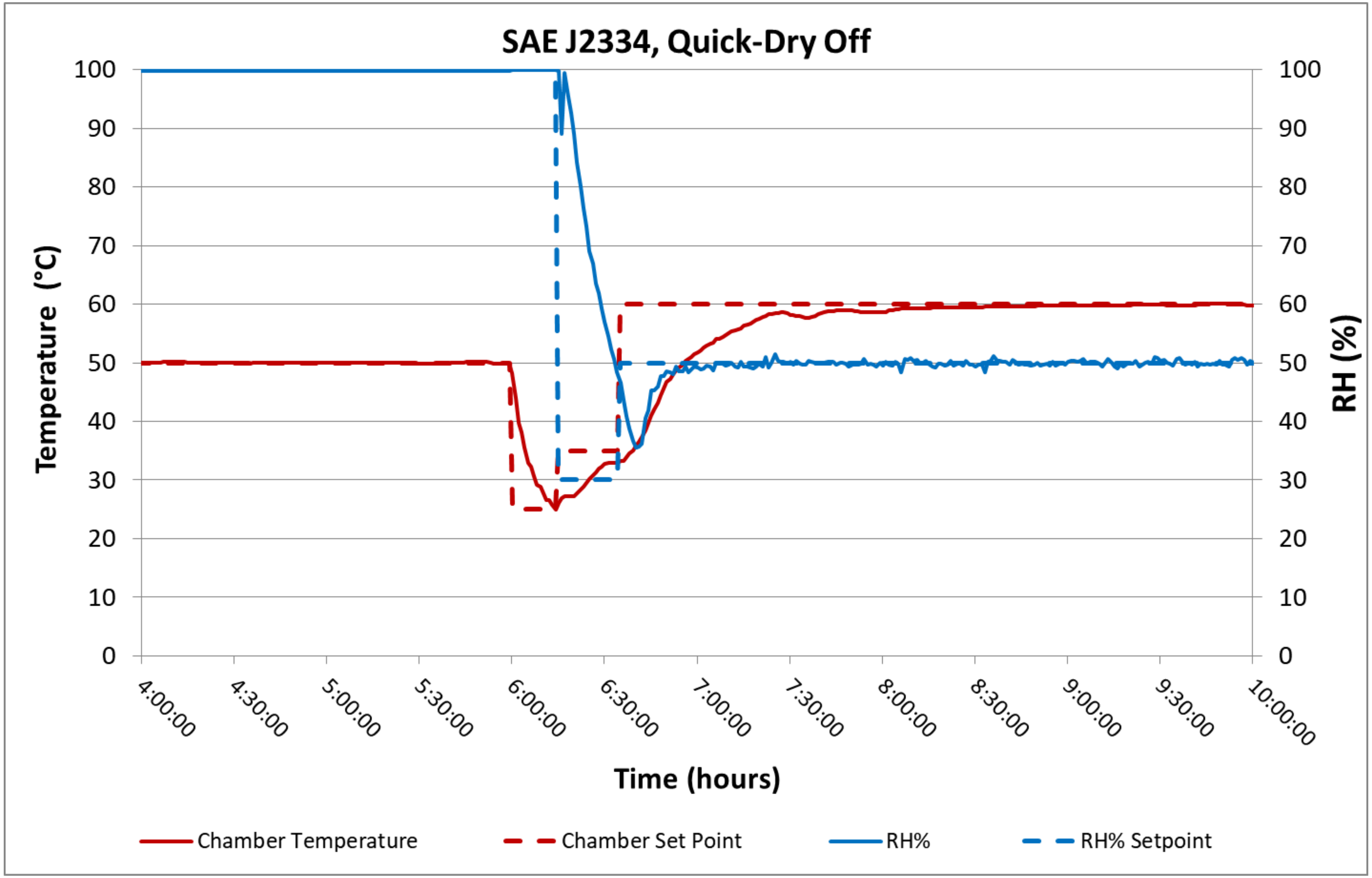
Rapid Dry Programming Cycle

Rapid Dry-Off Time

Step	Function	Chamber Air Temp (ºC)	RH (%)	Step Time (hh:mm)	Ramp
1	RH	50	100%	6:00	Auto
2	SHOWER	25		0:15	
3	**RH**	**35**	**30%**	**0:20**	
4	RH	60	50%	17:25	Auto
5	Final Step - Go To Step 1				



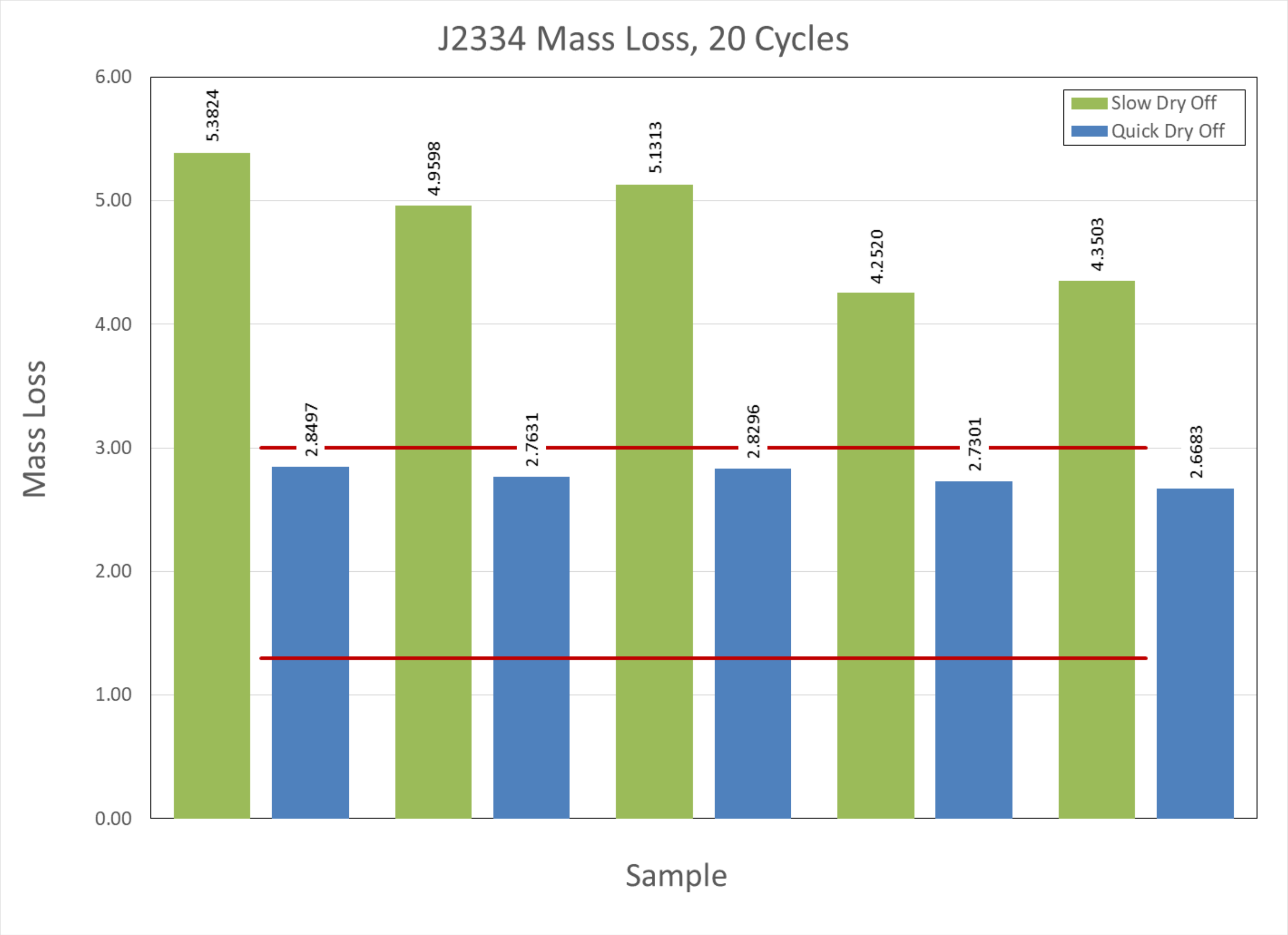
This version of the test cycle is programmed to be similar to customer's U.S. laboratory (in a different chamber)



Zoomed in view of the transition

During the transition the time above the Deliquescence RH of NaCl is about 10 minutes

Corrosion Coupon Mass Loss



Green bars represent test under slow dry-off conditions

Blue bars represent test under rapid dry-off conditions

Red lines represent tolerance of OEM standard

Under the rapid dry test, the coated panels once again passed the test

Case Study Conclusions

- Reproducibility issues largely due to RH transitions
- The longer the test, the bigger the difference between chambers
- Amount of spray not a major contributor to reproducibility (but it contributes some)

Environmental Transitions in Today's Standards: Two Approaches

Rapid (e.g. <30 minutes wet to dry)

- Japanese Car Companies
- CCT I, II, IV, JASO M609
- Renault ECC1

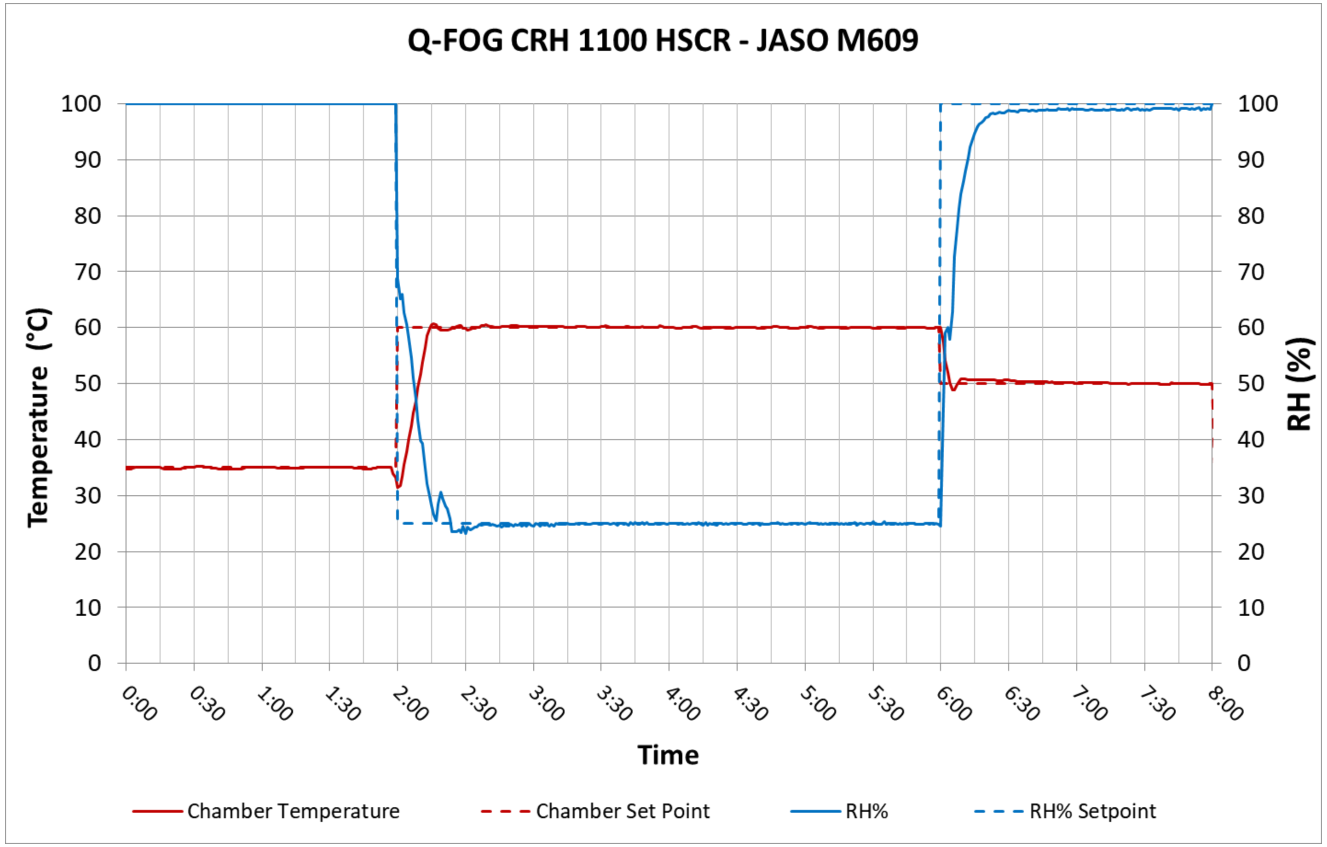
Controlled/Linear

- Volvo ACT1
- Volvo ACT2/Ford L-467
- GMW 14872
- Renault ECC1
- VDA 233-102

JASO M609 (ISO 14993, 11997-1)

- Chamber Volume – 1100 l
- Chamber Load – 240 x 4” x 6” Steel Panels
- Laboratory Room Temperature – 28-30 °C

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	FOG	35		2:00	< 0:30
2	RH	60	25	4:00	< 0:30
3	RH	50	100	2:00	< 0:15
4	Final Step – Go To Step 1				



JASO M609

Transition times for JASO M609 in full Q-FOG CRH 1100 HSCR Chamber.

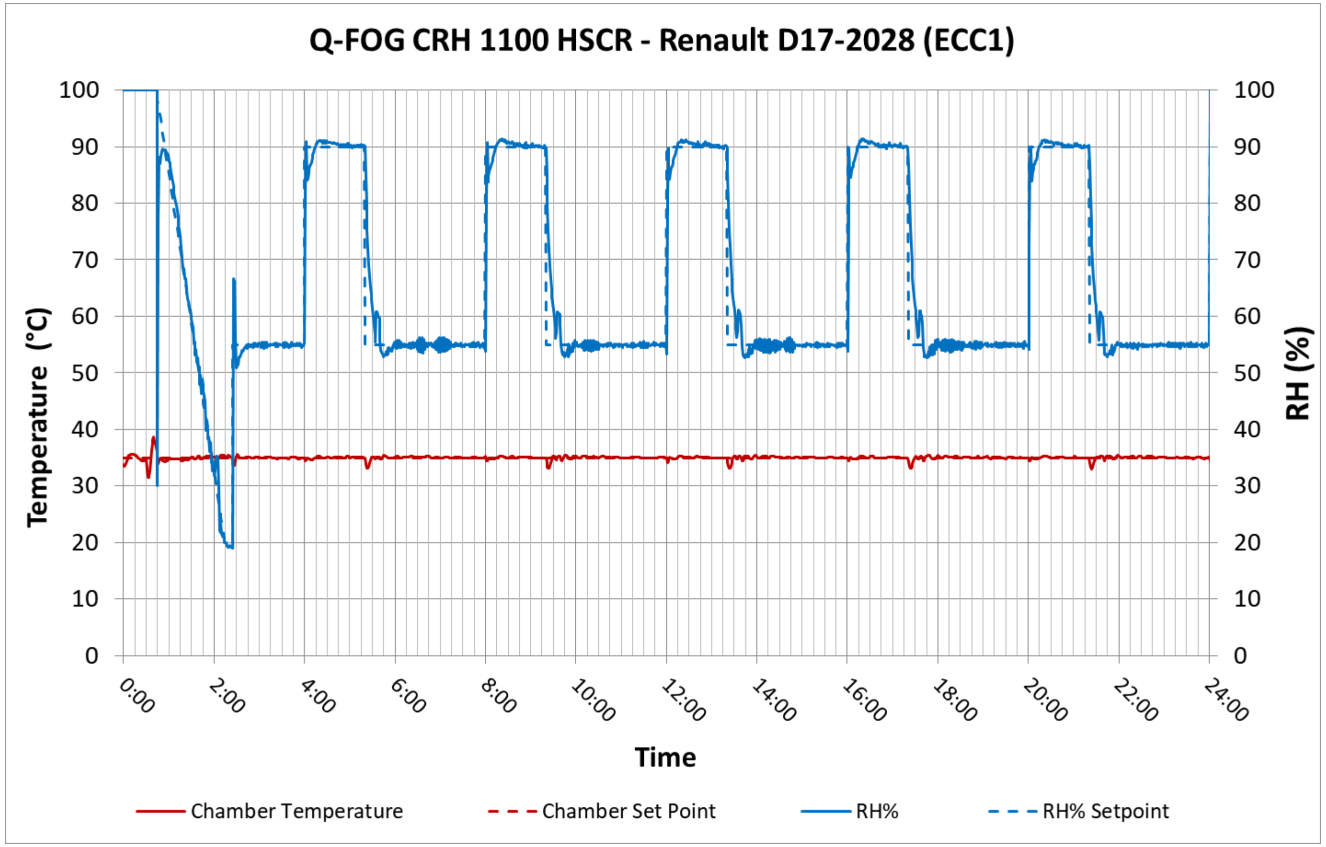
			Transition Requirement	Time for Temperature to reach requirement	Time for Relative Humidity to reach requirement
JASO M609	Fog to Dry	35 °C ➔ 60 ± 1 °C / 20 - 30% RH	< 0:30	0:13	0:14
	Dry to Wet	60 ± 1 °C / 20 - 30% RH ➔ 50 ± 1 °C / > 95% RH	< 0:15	0:04	0:15
	Wet to Fog	50 ± 1 °C / > 95% RH ➔ 35 °C	< 0:30	0:06	

Renault D17-2028 (ECC1)

- Chamber Volume – 1100 l
- Chamber Load – 240 x 4” x 6” Steel Panels
- Laboratory Room Temperature – 26-28 °C

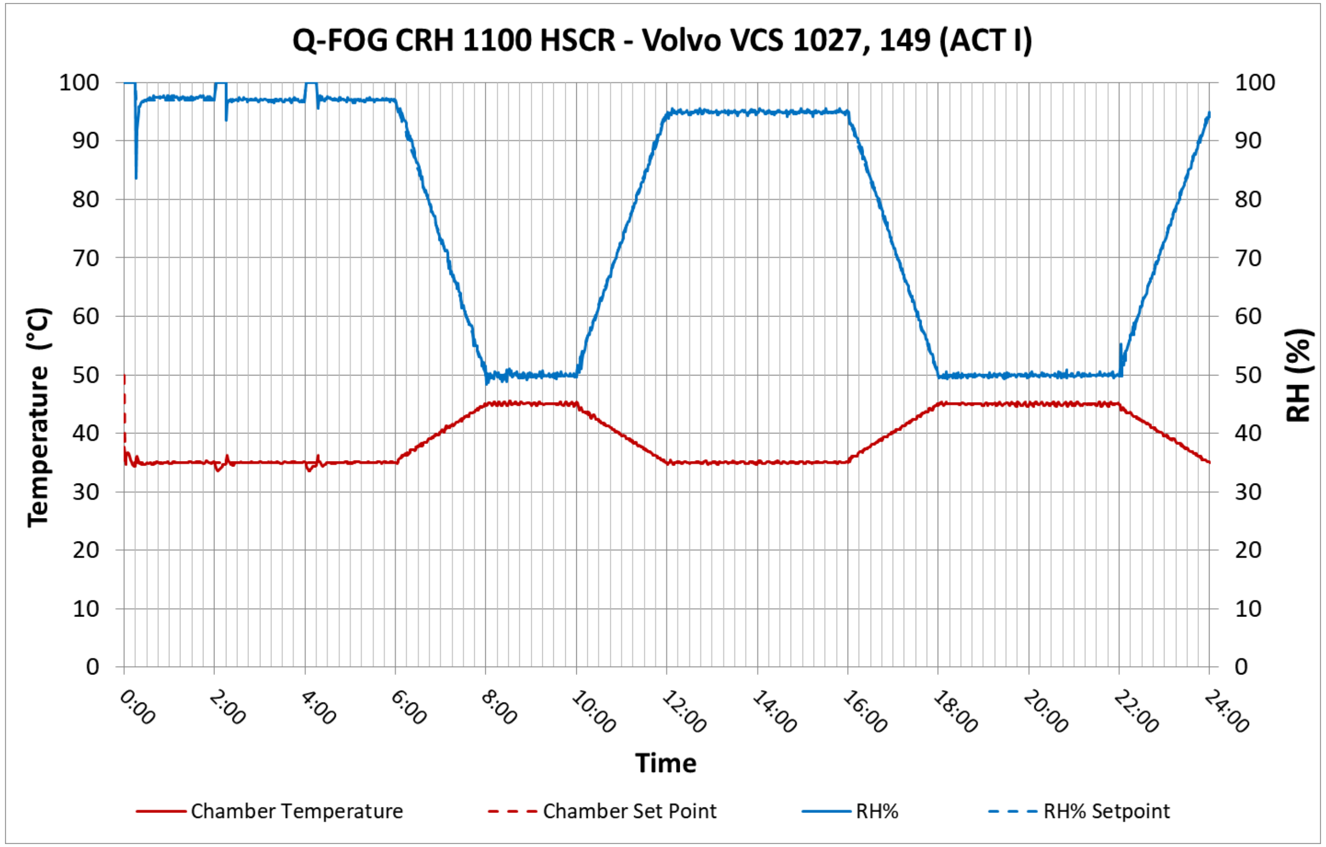
Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	FOG	35		0:35	
2	RINSE	35		0:05	
3	FOG	35		0:05	
4	RH	35	20	1:40	Linear 1:30
5	RH	35	55	1:35	Auto
6	Subcycle*				
7	RH	35	90	1:20	Auto
8	RH	35	55	2:40	Auto
9	Final Step – Go To Step 1				

*Step 6: Subcycle Repeat Steps 7-8 5x



Volvo VCS 1027, 149 (ACT I)

- Chamber Volume – 1100 l
- Chamber Load – Empty
- Laboratory Room Temperature – 22-25 °C



Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	Subcyle*				
2	SHOWER	35		0:15	
3	RH	35	97	1:45	Auto
4	RH	45	50	4:00	Linear 2:00
5	RH	35	95	2:00	Linear 2:00
6	Subcyle**				
7	RH	35	95	4:00	
8	RH	45	50	6:00	Linear 2:00
9	RH	35	95	2:00	Linear 2:00
10	Final Step – Go To Step 1				

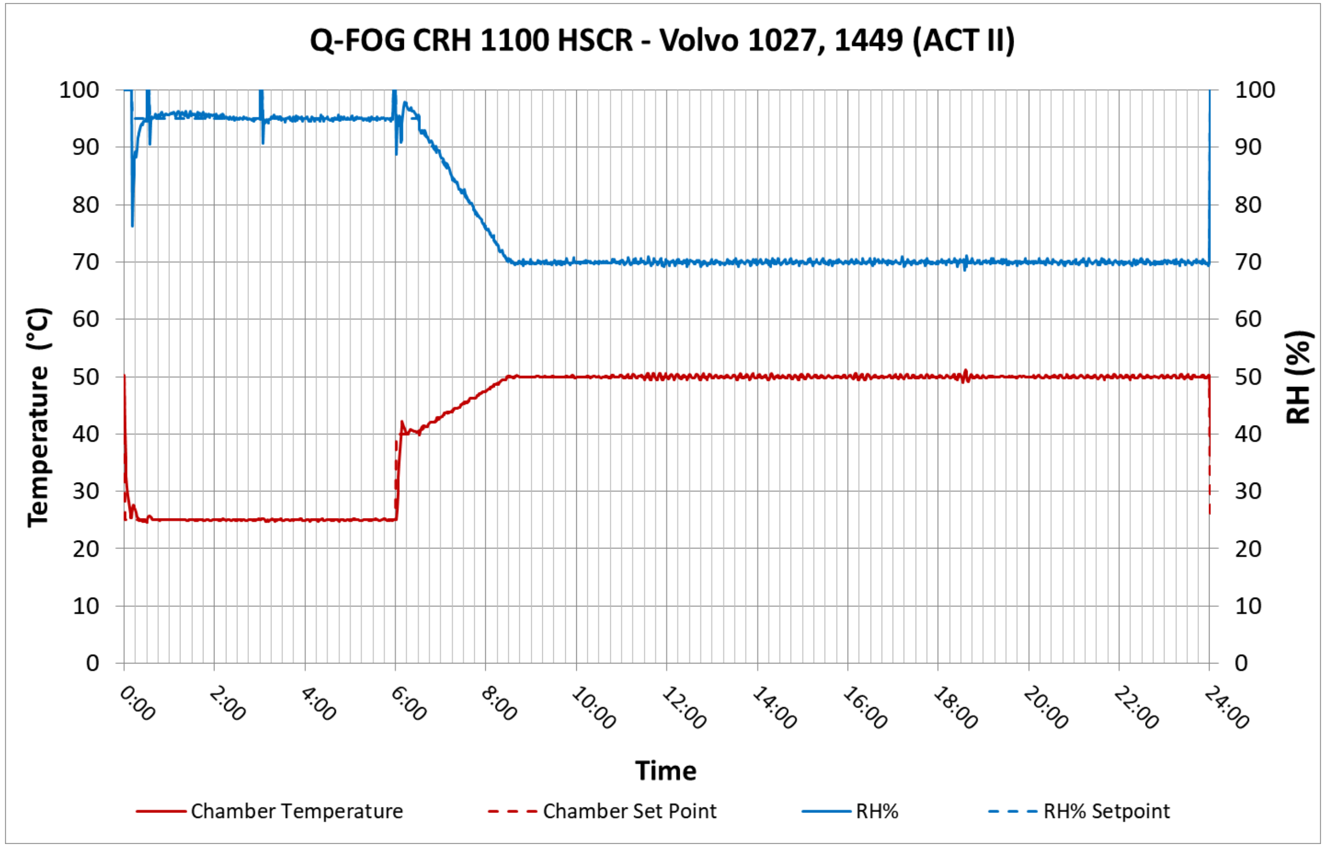
*Step 1: Subcycle Repeat Steps 2-3 3x
**Step 6: Subcycle Repeat Steps 7-9 7x

Volvo VCS 1027, 1449 (ACT-II)/Ford L-467

- Chamber Volume – 1100 l
- Chamber Load – Empty
- Laboratory Room Temperature – 22-25 °C

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	Subcyle*				
2	SHOWER	25		0:10	
3	RH	25	95	0:20	Auto
4	SHOWER	25		0:03	
5	RH	25	95	2:27	Auto
6	SHOWER	25		0:03	
7	RH	25	95	2:54	Auto
8	SHOWER	25		0:03	
9	RH	40	95	0:30	< 0:30
10	RH	50	70	17:30	Linear 2:00
11	RH	50	70	48:00	Auto
12	Final Step – Go To Step 1				

*Step 1: Subcyle Repeat Steps 2-10 5x

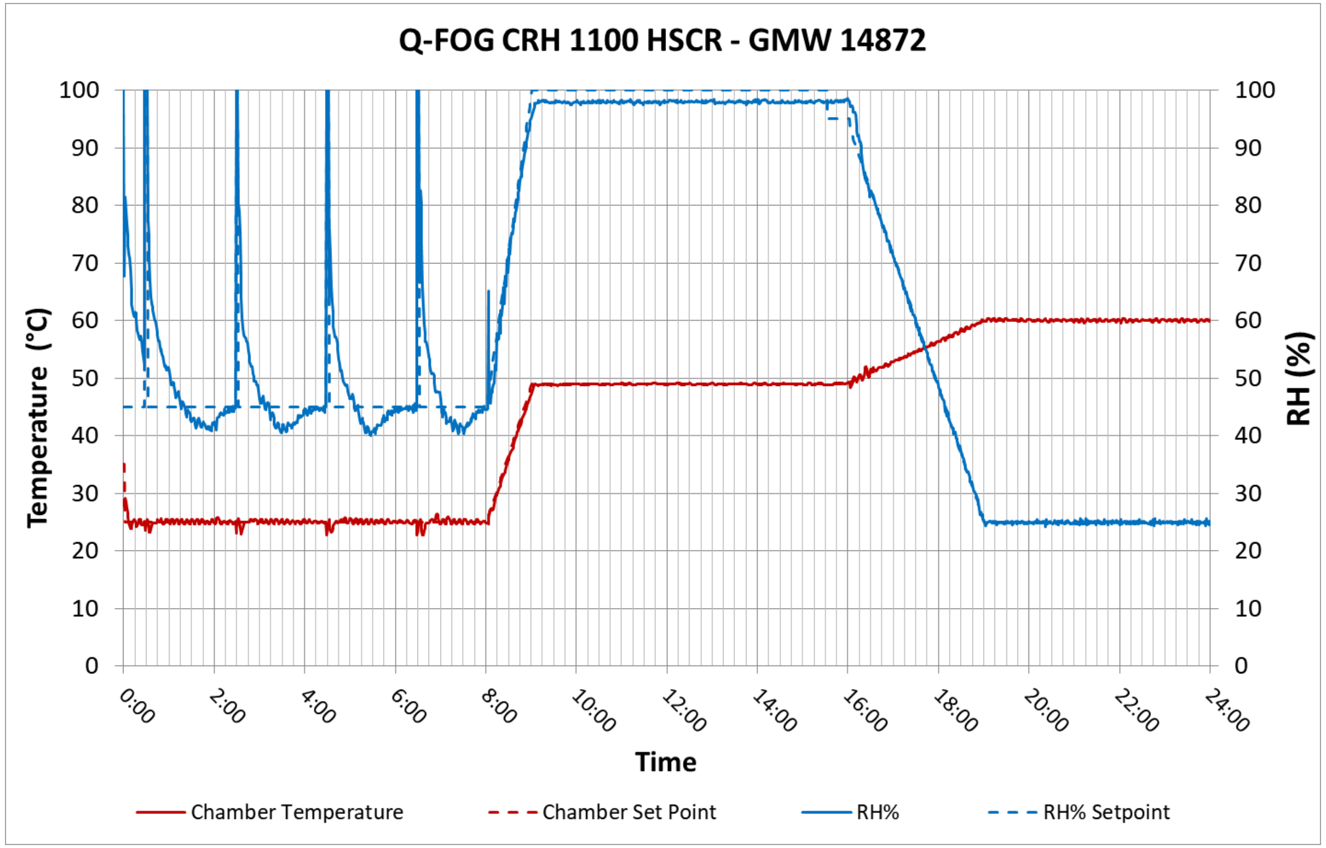


GMW 14872

- Chamber Volume – 1100 l
- Chamber Load – Empty
- Laboratory Room Temperature – 22-25°C

Step	Function	Chamber Air Temp (°C)	RH (%)	Step Time (hh:mm)	Ramp
1	Subcycle*				
2	RH	25	45	0:27	Auto
3	SHOWER	25		0:03	
4	RH	25	45	1:30	Auto
5	RH	49	100	7:30	Linear 1:00
6	RH	49	95	0:30	Auto
7	RH	60	25	8:00	Linear 3:00
8	Final Step – Go To Step 1				

*Step 1: Subcycle Repeat Steps 2-4 4x



Thank you for your attention!

Questions?

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