Specifying and testing CUI protective coating systems

Engineer's Specification Guide for CUI Coatings

Bart Martens | NACE JUBAIL Technical Workshop Corrosion Under Insulation

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PPG Protective & Marine Coatings
Bringing innovation to the surface.™

Presentation outline

Three items from the invitation will be addressed:

KEY SESSIONS AND TOPICS

- CUI Design Parameters and Key Factors.
- Insulation Materials and Selection Criteria.
- Best Practices in Maintenance to enhance Material Life-cycle and minimize corrosion.
- CUI Advance Inspection Technologies.
- Non-Destructive Testing Methodologies and Techniques.
- CUI Mechanisms and Causes.
- Advanced Coating System for CUI protection.

Presentation outline

Design parameters

- Coating system for hot exposure: how hot is hot?

Coating systems

- Testing and choosing a protective coating system

Maintenance

- Substrate condition

Design parameters

Coating system for hot exposure: how hot is hot?

Maximum temperatures

- Vary with coating chemistry
- Are not the only selection criteria

Maximum exposure

Traditional coating systems: atmospheric/under insulation Ŧ

Epoxy/PU atmospheric systems	<80-120°C	*
Some epoxy coatings/linings	<150°C	@
Special alkyd systems	<175°C	
Some (phenolic) epoxy	<200°C	@
Special phenolic epoxy	<230°C	@
Silicone acrylic	<350°C	**
Zinc silicate	<400°C	***
Silicone aluminium	<540°C	**

Notes:

- * Sometimes requested/specified as 150°C (without PU topcoat)
- ** With or without zinc silicate primer
- *** Without a topcoat
- @ under insulation only for approved systems

NACE SP 0198-2010

Typical Protective Coating Systems for Carbon Steels Under Thermal Insulation and Fireproofing					
System Number	Temperature Range (A)(B)	Surface Preparation	Surface Profile, µm (mil) (c)	Prime Coat, µm (mil) (D)	Finish Coat, µm (mil) (D)
CS-1, CS-2, CS-3	Epoxy, Fusion Bonded Epoxy, Epoxy Phenolic minus 110° to 302°F [minus 45° to 150°C]				
CS-4	-45° to 205°C (-50 to 400°F)	NACE No. 2 / SSPC-SP 10	50-75 (2-3)	Epoxy novolac or silicone hybrid, 100-200 (4-8)	Epoxy novolac or silicone hybrid, 100-200 (4-8)
CS-5	-45° to 595°C (-50 to 1100°F)	NACE No. 1 / SSPC-SP 5[15]	50-100 (2-4)	TSA, 250-375 (10-15) with minimum of 99% aluminum	Optional: Sealer with either a thinned epoxy-based or silicone coating (depending on maximum service temperature) at approximately 40 (1.5) thickness
CS-6	-45° to 650°C (-50 to 1200°F)	NACE No. 2 / SSPC-SP 10	40-65 (1.5-2.5)	Inorganic coplymer or coatings with an inert multipolymeric matrix, 100-150 (4-6)	Inorganic coplymer or coatings with an inert multipolymeric matrix, 100-150 (4-6)
CS-7	Petroleum wax primer; ambient to 140°F [60°C]				
CS-8	Shop primers and topcoats for inorganic zinc (IOZ) minus 110° to 750°F [minus 45° to 400°C] Novolac, phenolic, inorganic copolymer and inert polymeric matrix				

Cyclic Service

No clear definition

Frequency: number of cycles per

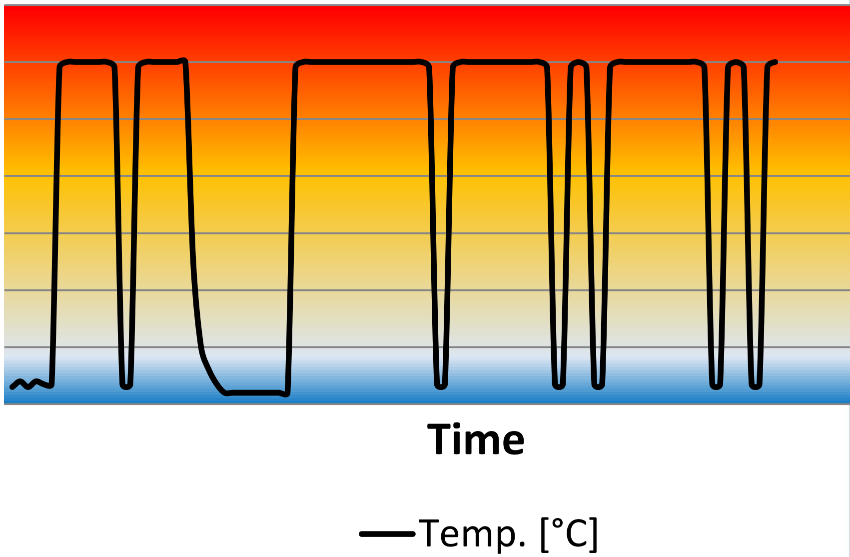
- Day / Week
- Month / Year

Regularity

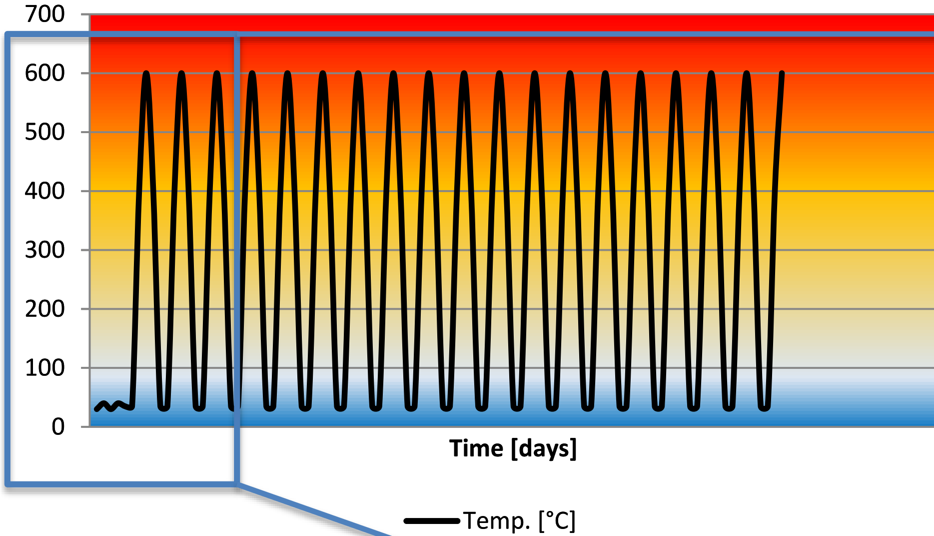
- Always the same hot and cold periods?
- Duration of hot and cold periods.
- Lowest and peak temperatures.

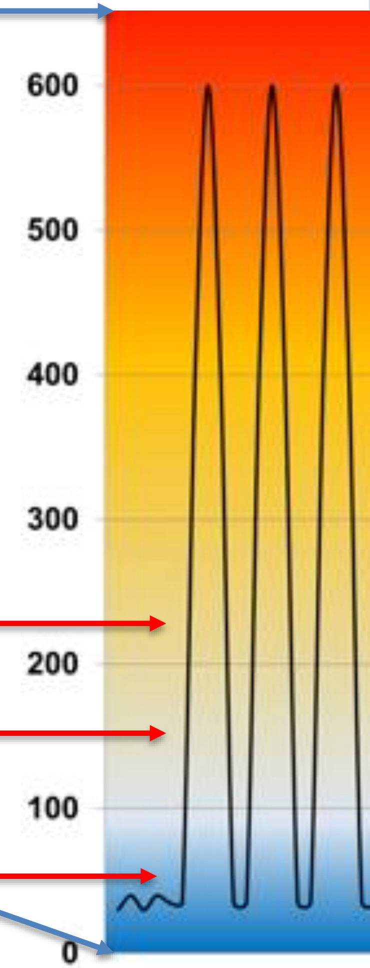
Gradients

- How quickly does the temperature go up and down?



Different heat cycles



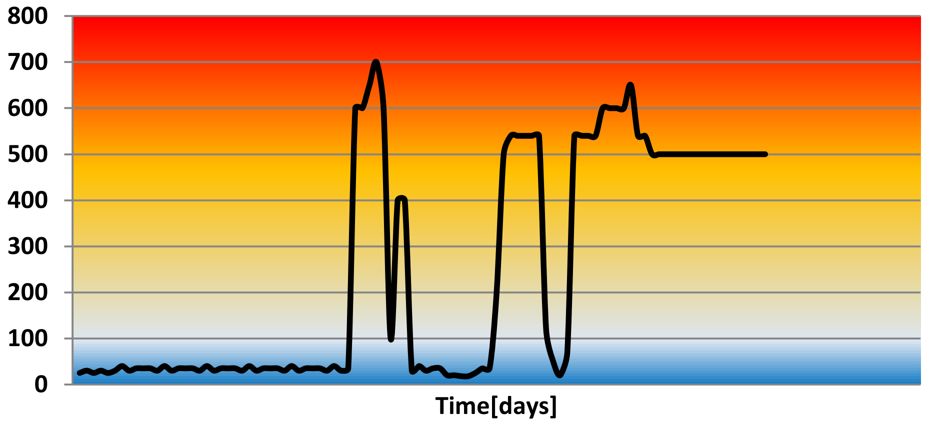


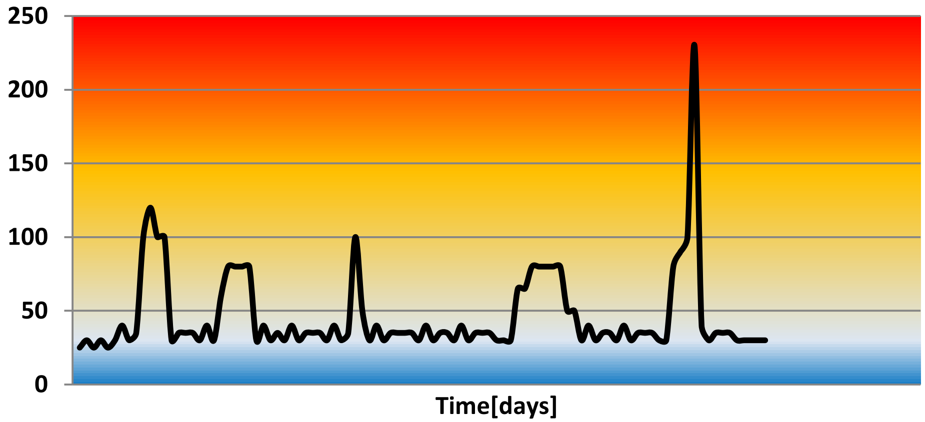
Dry (low corrosion pressure)

Evaporation/Steam (especially under insulation)

Ambient: Condensation/Wet
May be limited to and X days per cycle and <10% of the time for certain products

Less regular cycles





Peak

- >>230°C and peaks >540°C
- Inorganic co-polymer /multi-polymeric matrix

Initial ambient phase

- Long: low DFT system may not be suitable
- early corrosion.
- Extra DFT (barrier) to be considered if possible

Cycle

- Less frequent cycle
- Longer hot periods vs cold

Peak

- Varying temperatures
- >200°C
- Only some (phenolic) epoxy systems

Cycle

- Less frequent
- More time at ambient than hot
- Higher DFT system preferred.
- Chemical resistance

Corrosion protection (barrier effect)

- Blasting profile of 50µm: Peaks covered?
- Barrier against moisture, impact and abrasion?
- Active galvanic protection.

<u>Silicone (acrylic)</u>

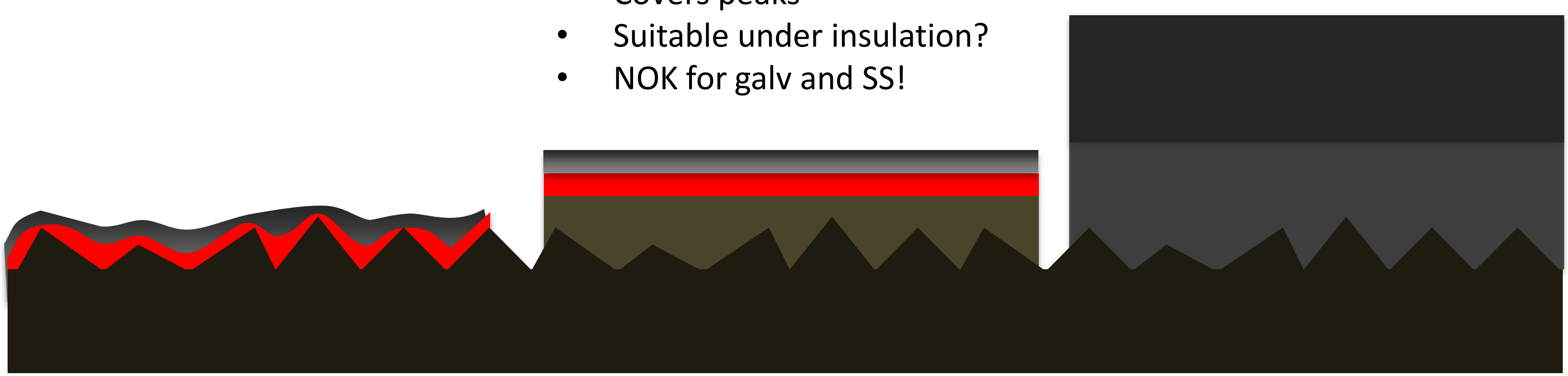
- 2 coats of 25µm
- Total DFT = 50µm
- Barely covers peaks
- Suitable under insulation?
- OK for galv and SS?

<u>Zinc & Silicone (acrylic)</u>

- 75µm zinc primer
- 2 coats of 25µm
- Total DFT = 125µm
- Galvanic protection (sacrificial, sealed)
- Covers peaks
- Suitable under insulation?
- NOK for galv and SS!

<u>Phenolic or multipolymeric matrix</u>

- 2 coats of 125µm = 250µm
- Covers peaks + 200µm
- Extra barrier in 3 coats possible
- OK under insulation.
- OK for galv and SS!



What about cryogenic?

Atmospheric corrosion pressure is low below 0°C

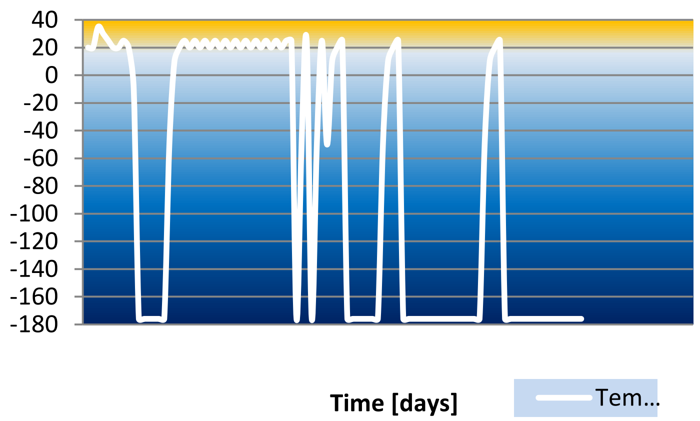
- No liquid water
- Lower temperatures means slower chemical reactions

Ice and condensation

- Ice: potential mechanical stress
- Condensation: semi immersed situation, not pure atmospheric
  may affect the recoat window of some primers

All coatings become brittle when cooled to cryogenic temperatures

- Far below their glass transition temperature, Tg
- Most epoxies/PU systems perform well until -40°C
  Winter exposure in countries like Canada, Russia etc.
- Strength / flexibility will be needed at lower temperatures
- especially in combination with (rapid) cycling



Selecting coating systems: Physical Performance

Wide choice of protective coating systems

- NACE SP0198-2010

CUI is often the most severe corrosion

- entrapment of chlorides and sulfides
- rapid spread of corrosion to other areas

Coating chemistries

Testing standards for CUI coating systems will be discussed

Design Criteria of CUI Coatings

Physical and resistance properties

- **Resistance to thermal shock & cycling**
- **Resistance to thermal aging**
- **Chemical resistance**
- **Intermittent hot & boiling water immersion**
- **Flexibility and toughness to handle varying thermal gradients**
- **Matched CTE over temperature range**

Classification of CUI Coatings

- **Metallic Coatings; TSA, TSZ, Galvanized, Aluminized**
- **Inorganic ceramic composites**
- **High Build Aluminium, Titania Siloxane Composites**
- **Modified epoxies phenolic / novolac, MIO / glass filled**

Metallic Coatings - TSA

Thermal Spray Aluminum Ambient to 1200° F [650°C]

- **TSA coatings form a mechanical bond to the substrate**
- **SSPC-SP 10 “Near White Blast” for surface preparation is critical**
  - Limited suitability for maintenance.
- **Coefficient of Thermal Expansion not matched to the substrate**
  - Thermal cyclic conditions will affect TSA: internal stresses
- **Good permeability resistance under non-insulated isothermal conditions at lower temperature range up to 392°F [200°C]**
- **Limited chemical resistance**
- **TSA can lose on average one mil [25 microns] or more per year based on recent case studies**

Chemical Attack of Aluminium

Reaction of aluminum with halogens

- Aluminum metal reacts vigorously with all halogens. It reacts with chlorine, Cl_2, bromine, Br_2, and iodine, I_2
  - $2Al(s) + 3Cl_2(l) \rightarrow 2AlCl_3(s)$
  - $2Al(s) + 3Br_2(l) \rightarrow Al_2Br_6(s)$

Reaction of aluminum with acids

- Aluminum metal dissolves readily in dilute sulfuric and hydrochloric acid to form solutions containing aquated aluminum species.
  - $2Al(s) + 3H_2SO_4(aq) \rightarrow 2Al^{3+}(aq) + 2SO_4^{2-}(aq) + 3H_2(g)$
  - $2Al(s) + 6HCl(aq) \rightarrow 2Al^{3+}(aq) + 6Cl^-(aq) + 3H_2(g)$

Reaction of aluminum with bases

- Aluminum dissolves in sodium hydroxide with the evolution of hydrogen gas, H_2, and the formation of aluminates of the type $[Al(OH)_4]^-$.
  - $2Al(s) + 2NaOH(aq) + 6H_2O \rightarrow 2Na^+(aq) + 2[Al(OH)_4]^- + 3H_2(g)$

Inorganic Ceramic Inert High Build Coatings

302°-1200°F [150°-650°C]

- **Chemical bonding to the substrate (covalent)**
- **Surface tolerant with minimum substrate preparation**
- **CTE near match to substrate**
    - Excellent thermal cyclic resistance to include cryogenic service
- **High build capability up to 18 mils [450 um]**
- **Open recoat window / single component**
- **Good chemical resistance**

Metallic High Build Universal Coatings

Aluminum & TiO_2 Ambient to 840°F [450°C]

- **Metallic, inorganic co-polymer coatings form a mechanical / interfacial polar bond to the substrate**
- **SSPC-SP 10 “Near White Blast” for surface preparation is critical**
- **Severe thermal cyclic conditions will affect metallic coatings over time due to internal stresses**
- **Good permeability resistance under isothermal conditions**
- **Poor chemical resistance**

Epoxy Phenolic / Novolac

Ambient to 400°F [204°C]

- **Interfacial polar to polar hydrogen bonding to the substrate**
- **Organic composition limits temperature window**
  - Reinforced and specialized formulations peak > generically similar types
    - Generic pure epoxy 120-150°C
    - Some glass or mio versions withstand 200°C
- **Good permeability resistance**
- **Cyclic resistant**
- **Short overcoat window**
- **Good chemical resistance**
- **Application up to 150°C substrate possible for some products**

Typical Test Methods for Elevated Temperature Coatings

- **ASTM B-117:**
  - Salt Fog Chamber 3500–4500 hours
- **ASTM 2485:**
  - This test ensures adhesion based on CTE after severe thermal shock
- **ASTM 2402:**
  - Mass loss is critical in determining the porosity and longevity of a coating
- **EIS Testing:**
  - Electrical Impedance Spectroscopy, permeability before and after thermal exposure

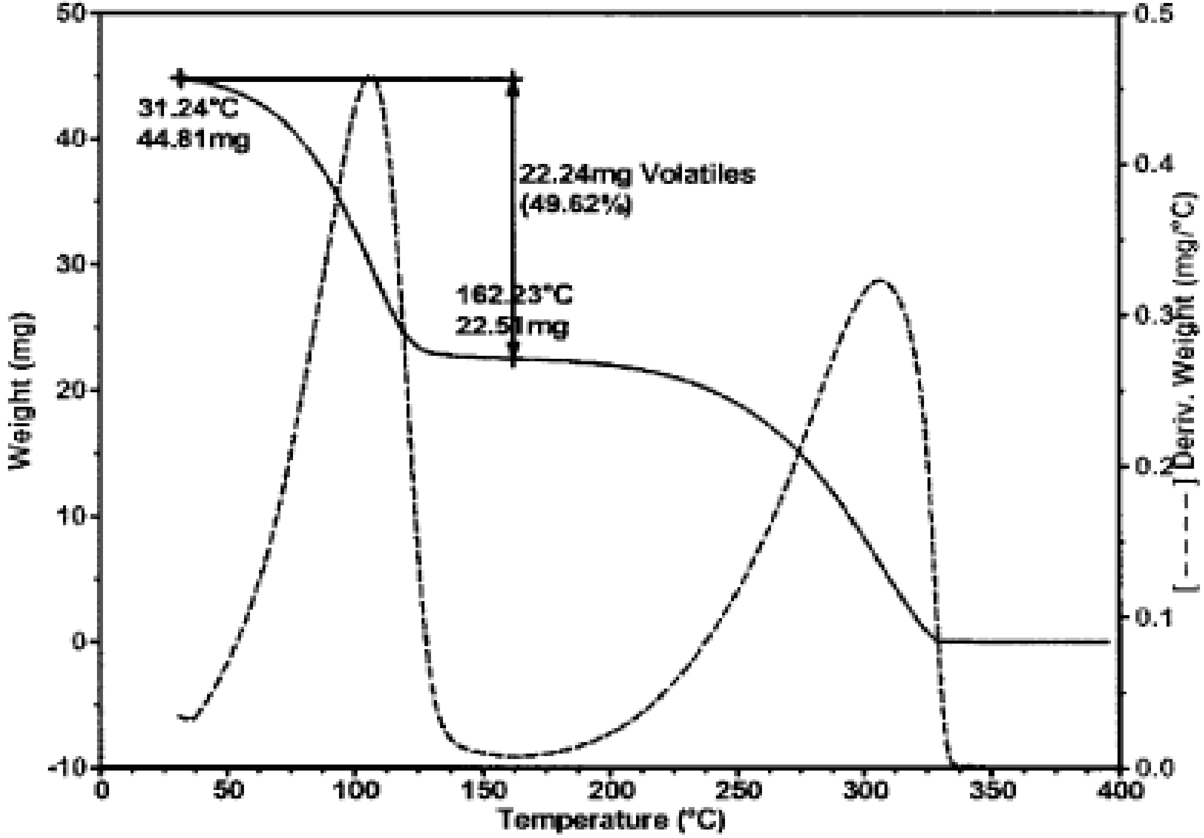
ASTM D 2485

Typical Procedure

- Coated finished panels are placed in a muffle furnace with the following schedule:

205˚C (400˚F)	-	8 hours	– quench
260˚C (500˚F)	-	16 hours	– quench
315˚C (600˚F)	-	8 hours	– quench
370˚C (700˚F)	-	16 hours	– quench
425˚C (800˚F)	-	8 hours	– quench
538ºC (1000ºF)	-	16 hours	– quench

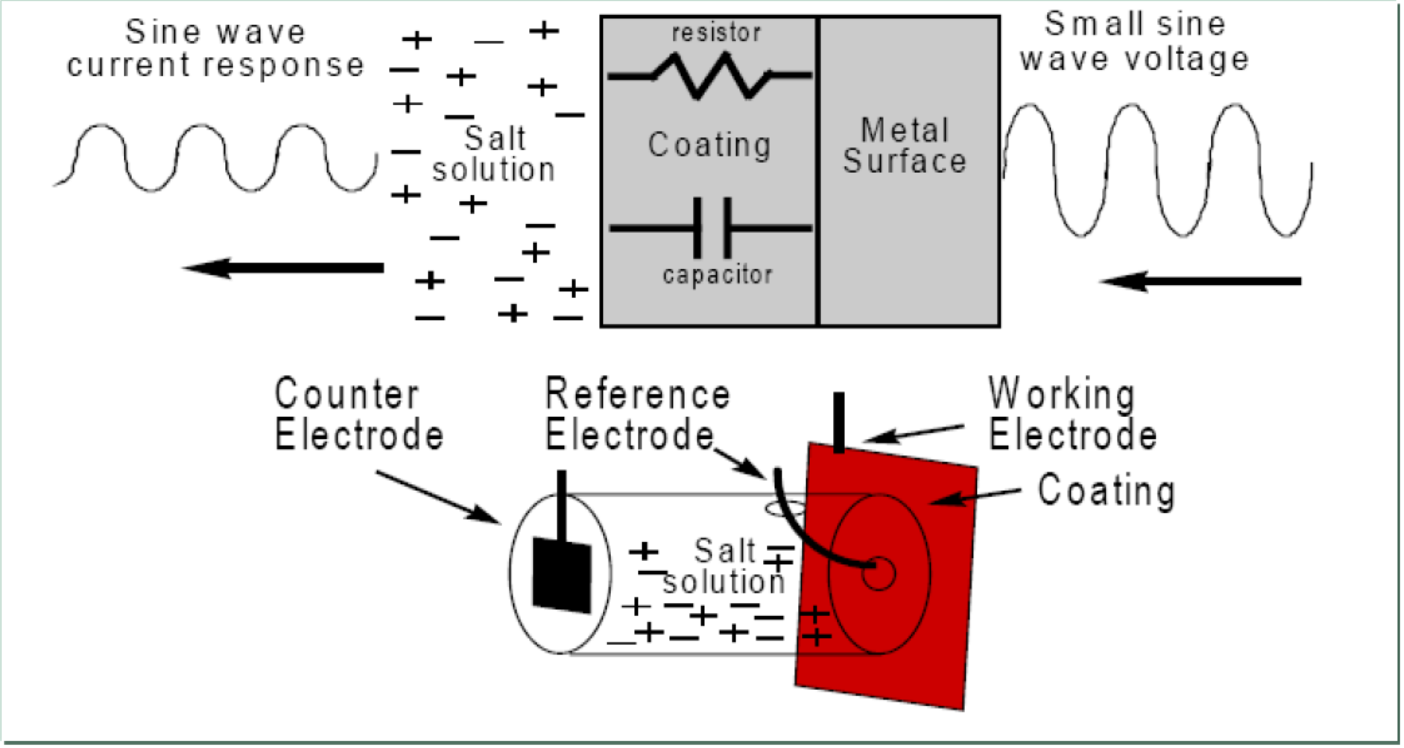
ASTM E2402 Mass Loss



Mass Loss Test Data

ASTM 2402 Mass Loss Comparison				
Product	Weight Loss (in percent)			
	400°F 204°C	600°F 316°C	800°F 427°C	1000°F 538°C
Inorganic Ceramic	1.0	3.2	7.3	9.6
High Build Cold Spray Aluminum	1.5	5.1	11.7	21.2
Inorganic Co-Polymer / Aluminum Titania Siloxane	1.8	5.3	10.9	16.7
Glass Filled or MIO Filled Phenolic Novolac Epoxy	2.0	6.0	NA	NA

EIS Test Method



Permeability is minimized as impedance is increased.

Values of > 10^6 ohms*cm^2 indicate good barrier effect / corrosion protection.

Specific CUI Test Methods

- **Shell Test; Cyclic Wet / Dry Immersion Testing 16 weeks**
- **Steam Bypass Test 90 days**
- **Modified Houston Pipe Test 21-30 days**
- **ASTM G189**
- **PPG HTC CUI Chamber Test (1008 hours, 252 cycles)**

Other tests only focus on dry exposure and/or thermal shock.

Shell CUI Cyclic Test 2001 - 2002

Test protocol:

Week days (5 days)

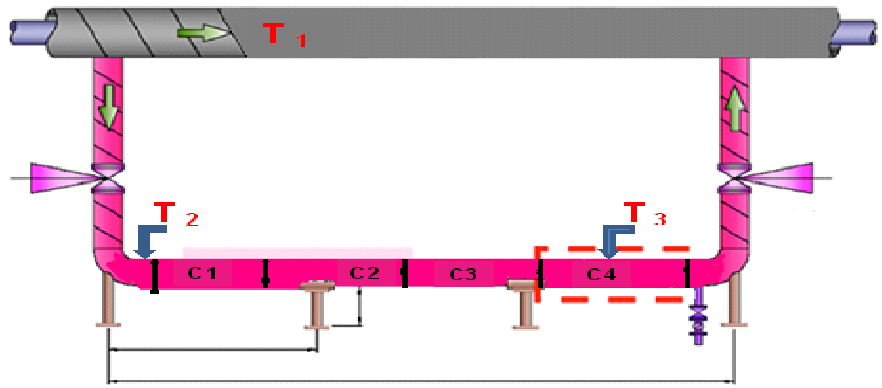
- Dry heat exposure at 400°F [208°C] for 16 hours, then quenched in cold water
- Immersion and steam-out exposure at 210°F [99°C] for 8 hours

Weekend (2 days)

- dry heat exposure in an oven at 400°F [204°C]

TOTAL TEST DURATION	**16 weeks**
• Total Heat Exposure	2240 hours
• Number of Thermal Quenches	80
• Total Time of Immersion in 210°F [99°C]	640 hours

CUI Steam Bypass Test 2011



T_1 - 160°C, T_2 - 155°C, T_3 - 140°C

- Cyclic Profile
  90% Continuous
  10% Downtime
- Solution of 100ppm NaCl + 100ppm Sulfur
- C1 through C4 – Various coatings
- Spray Application – Surface prep SSPC-6 Blast

This is a typical on-site test, not accelerated or controlled

Modified Houston Pipe Test 2010

Cycle description:

- Add 1 liter water (1% NaCl)
- Heat for 8 hours to produce a thermal gradient
- Add 1 more liter of salt water
- Allow to cool to ambient for 16 hours

After 30 cycles the pipe is removed from test and the coating evaluated.

Vertical steam-out/dry simulation
70+% of CUI occurs in the horizontal plane
Not accelerated cyclic immersion test

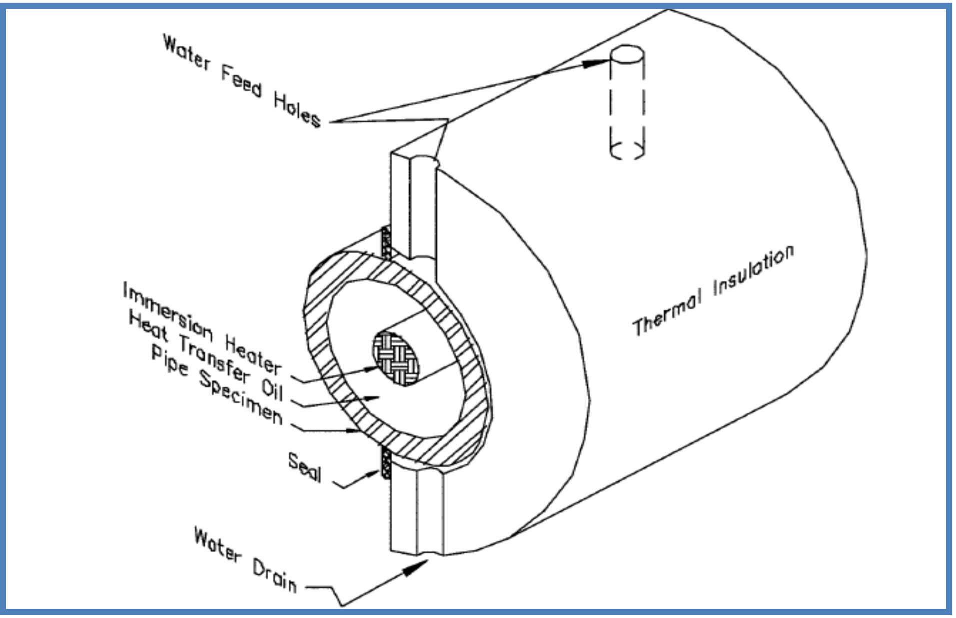
ASTM G189 - 2007

Simulation of CUI

- Iso-thermal or Cyclic
- Wet / Dry

Can be used to test

- CUI effect on substrate materia
- Insulation material
- Coatings

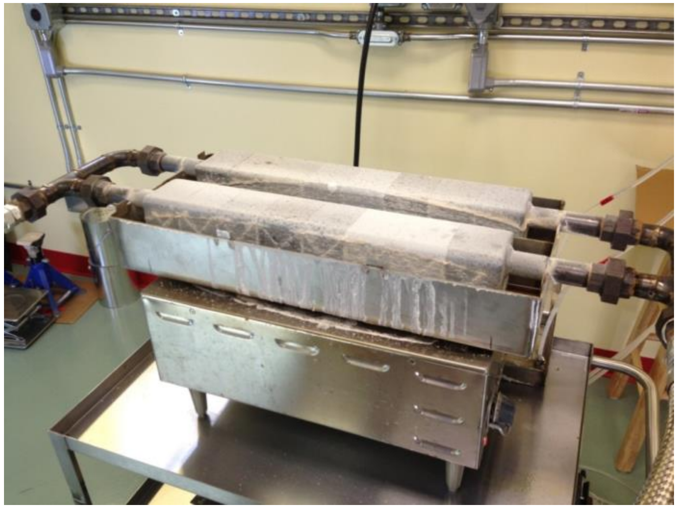


CUI Chamber Test 2008

Uses ASTM G189 as a model

- For simplicity the insulation is omitted
- Temperature control: ambient to 250°C
- Consistent and repeatable results.
- The chamber environment can be totally controlled

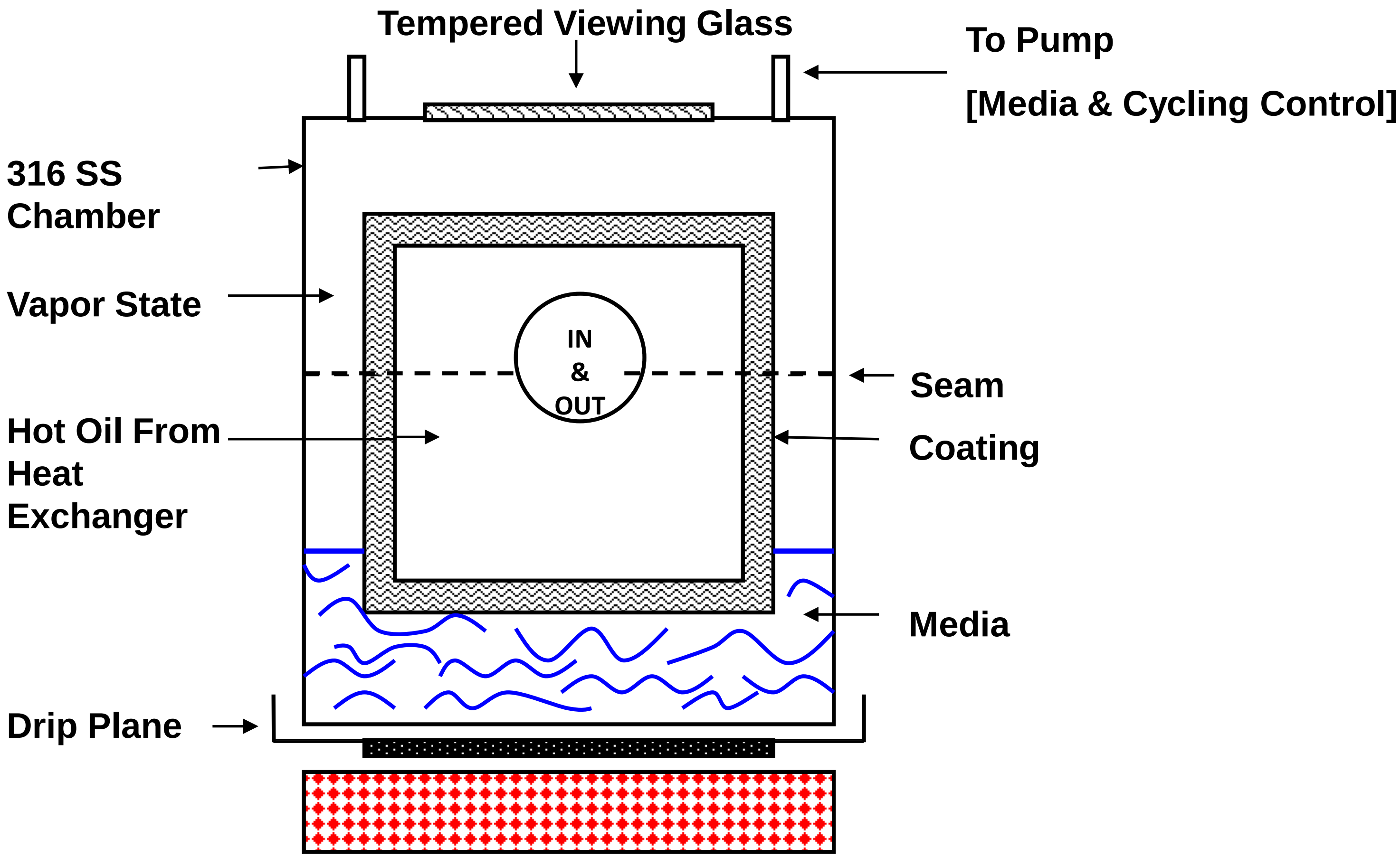
Approvals: Shell Oil 2008, Aramco 2010



Method B:

- 5% NaCl solution
- Set wet/dry cycle time [4 hours]
- 42 day duration [252 cycles] 1008 hours
- Internal temp 350°F [179°C]
- Steam-out immersion temp 212°F [100°C]

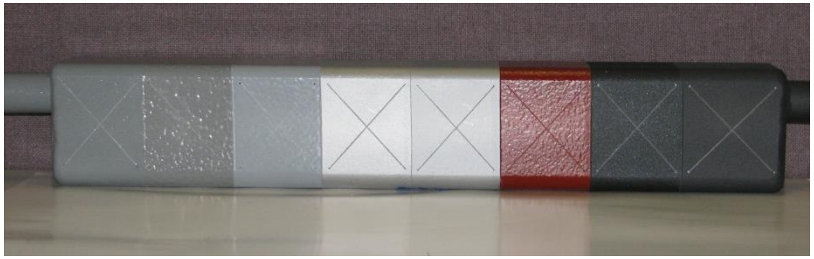
Chamber Cross Section



D.Betzig 2010

Hot Plate Temp Range: 20˚-250˚ C

CUI Test Examples



Before Test

After 6 Weeks Front View

After 6 Weeks Bottom View

Maintenance

Substrate condition

Review

- Type of substrate
  - Coated: coating condition?
  - Carbon steel or stainless steel
- Corrosion
  - Review causes
  - Wall thickness review: still in spec?
  - Remove rust (adhesion issue) to agreed standard Sa2 or Sa2½, St2, St3
- Roughness
  - Pitting corrosion: review material thickness
  - Review coating suitability and required thickness
- Contaminants
  - Sources of osmotic blistering (during ambient phase)

Maintenance

Substrate condition

Surface cleanliness

- Is achievable standard acceptable for the type of coating?
  - Zinc silicate primers and phenolic epoxy require Sa2½
  - Some products can be applied on solvent or detergent cleaned stainless

In service application: substrate temperature

- In maintenance substrate temperature may be elevated or increase shortly after application.
- Some epoxy products are suitable for 90-150°C substrate at application.
- Inorganic ceramic inert (multi-polymeric) coatings are available for application on substrates up to 316°C/600F.
- Application technique may be slightly different: building up thickness in multiple passes to allow solvents to evaporate or coating to "set".
- Safety of solvent based material in a "hot" environment: flash point vs. self ignition temperature.

Product selection: ease of use

Flexibility in specifying and application

- **Single component**
  - Open recoat window
  - No mix-volume measuring for smaller applications
- **Surface & application tolerant**
  - Spray, brush or roll
  - Adherent to welds
  - Easily repaired at ambient or on hot surfaces
  - Field repairs and tie-ins with limited surface preparation
  - Field repairs and tie-ins with same coating system
- **Cost effective**
  - Requiring minimal surface preparation
- **High DFT**
  - Extended CUI protection (for extended ambient exposure)
  - Crack resistance
- **"Constructability"**
  - Robust enough to transport / lay down / erect with minimal repair
  - Minimal damage from insulation and cladding installation

Conclusions

Coating vs CUI Requirements

Coating must withstand:

- the process temperatures (design and operational range e.g. 200° to 500°C)
- the actual exposure scenario
  (cyclic, iso-thermal, wet/dry/immersion exposure, thermal shock, steam-out)
- the most corrosive temperature range of 150° to 180°C
- chlorides, halides and sulfides and intermittent pH in the range of 5 to 10
- accelerated CUI Test

And must:

- be compatible with the specified substrate: carbon, duplex and austenitic stainless steels
- be suitable for insulated and non-insulated service
- have chemical resistance to have good (chemical) bonding to substrate
- have CTE designed to minimize surface tension
- Meet application requirements:
  - New construction
  - Maintenance

Conclusions

State of the Art CUI coating technology - 150° to 650°C

Inorganic ceramic inert coatings offer the best overall performance for high temperature cyclic and isothermal conditions

- CTE is matched closely to the substrate
- Limited mass loss: <8% at 400°C
- Chemical bonding to the substrate and good overall chemical resistance (intermittent pH 5-10)

These coatings are single component and user friendly, with open recoat windows allowing ease of maintenance and extended life

Questions