Assessing the Need for 50% Relative Humidity During Tank Painting

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EXECUTIVE SUMMARY

There is a disagreement between some shipyards and the Navy on the importance of maintaining 50% relative humidity in tanks during painting. A previous NSRP panel project has identified the requirement to maintain the relative humidity in a tank or void space at a maximum of 50% from the start of surface preparation to cure of the topcoat as one of the most expensive in Navy Standard Item (NSI) 009-32. Because of this, the NSRP has requested that the Navy amend 009-32 to allow tank painting at manufacturers recommended conditions (commonly 85% relative humidity). The Navy believes that achieving and maintaining 50% relative humidity during coating application and curing will ensure "maximum coating performance and life while minimizing schedule risks associated with the application of coatings."[1] Our review of the history suggests three main criteria are used to justify maintaining the 50% maximum relative humidity requirement:

- Inhibit the formation of "rust back"
- Allow the blast to be "held" in a Near White condition indefinitely
- Provide optimum environmental conditions for epoxy coatings to cure, virtually eliminating the potential for inter-coat delamination due to amine-bloom.

This project explored both sides of the argument and developed proposals for intermediate solutions which address the Navy concern regarding risk reduction without increasing costs as drastically as the current requirement. As a direct result of the project, the Navy has approved changes to NSI 009-32 which will reduce the burden and costs associated with maintaining 50% relative humidity by relaxing the requirement in low risk or high cost situations. Specifically, the following changes will be made in the FY011 version of 009-32:

- The coating tables will be modified to allow 85% relative humidity in chain lockers and CHT tanks
- Note (26) and (29A) will be modified to clarify that the 50% relative humidity condition only needs to be maintained from surface preparation G-point acceptance until the "cure to recoat" time for the final touch-up has been reached. During the remaining cure to immersion, 85% relative humidity shall be adequate.
- Components such as pipe hangars, access cuts, stiffeners, plate and hatches which are painted in the shop may be preserved at 85% RH.
- 85% relative humidity may be maintained for new and disturbed areas[2] of individual areas 2 sq ft or less totaling less than 0.03 percent of the total surface area. 3.6.2.4 states that the requirements of Notes (26) and (29A) do not apply to these areas.

This report presents a technical discussion of the issues, presents the proposed changes based on the cost-risk tradeoff analysis and presents a go-forward strategy if the Navy shipbuilding community wants to build a body of evidence on the overall cost effectiveness of the requirement.

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[1] Brinkerhoff, NAVSEA 05M1 White Paper, 50% Relative Humidity Requirement for US Navy Shipboard Critical Coated Areas, December 2005

[2] "disturbed surfaces" are defined in FY-11 NSI 009-32, paragraph 4.6.3

ACKNOWLEDGMENTS

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CONCLUSIONS

1. The literature review did not reveal any quantitative data on the performance of coatings applied at various levels of relative humidity in the range of interest (i.e., 50% to 85%)

2. Based on our review of the literature, the requirement for 50% relative humidity during tank coating can be traced to a 1995 program to improve the service life of Navy tank coatings. Specifically, the requirement was intended to:

   - Inhibit the formation of "rust back"
   - Allow the blast to be "held" in a Near White condition indefinitely
   - Provide optimum environmental conditions for epoxy coatings to cure, virtually eliminating the potential for inter-coat delamination due to amine-bloom.

3. A principal objective of the lower humidity requirement is to ensure that no part of the tank experiences surface condensation on the steel prior to coating or on freshly applied paint during the cure cycle. In situations such as complex tanks where a few surface temperature measurements may not be representative of the entire structure, a lower relative humidity decreases the risk of condensation occurring.

4. The risk associated with rustback, losing a white metal blast condition, and sub-optimal curing conditions may be acceptable in many situations. "Risk" considers the technical risk of the unfavorable event occurring, the process risk of the unfavorable event not being detected and remedied, the schedule risk associated with rework as a result of the unfavorable event, and performance risk associated with coatings applied under the unfavorable conditions.

5. The cost to maintain 50% relative humidity (viz 85%) can be high in certain situations yet low in others. The real cost issue is whether humidity control is necessary to achieve the desired condition. To achieve 50% relative humidity in most US shipbuilding environments will require some form of humidity control for the majority of the time. However, in many of those same environments 85% relative humidity can be achieved the majority of the time without humidity control equipment. Of course, an uncontrolled environment adds another element of schedule risk to the project which may or may not be significant depending on the local environment, time of year, specific location of the work and other factors.

6. Dehumidification is an effective way to minimize the chances of rustback and maximize the likelihood of proper cure in situations when ambient conditions might dictate its use. The decision whether to use dehumidification equipment must balance the cost of dehumidification with the possibility of incurring costs and delays associated with rework.

7. Relaxing the 50% relative humidity requirement in low risk-high cost situations has the potential to create real savings for the Navy without incurring substantial risk. Specifically identified low risk-high cost situations include:

Situation	**Low Risk**	**High Cost**
Small tanks should be allowed to reach 85% relative humidity.	In these tanks, the steel surface can be blasted and painted in a short time, thus shortening atmospheric exposure of the white metal surface and lowering the risk of rust-back. In addition, the chance of unpredictable weather impacting such jobs (i.e., creating an excursion beyond 85%) is considerably reduced because of the shorter job duration.	For such jobs, the mobilization and demobilization of equipment dominates cost; thus the cost to dehumidify is proportionally higher.
Steel painted in a shop should be allowed to reach 85% relative humidity.	Shop environments are more predictable and easier to control so there is a lower likelihood of an excursion beyond the proposed 85% requirement.	Shop environments generally encompass large spaces which can be considerably more expensive to dehumidify.
Allow 85% relative humidity after the cure to touch time is reached (viz full cure).	The risk of amine blush and other curing problems is significantly reduced after the coating is cured to touch.	The cost associated with operating equipment can be reduced. The equipment can be moved to another tank, potentially shortening the availability.
Allow 85% relative humidity during touch up.	Touch up impacts a very small percentage of the tank. Touch up can be planned around unsatisfactory weather conditions when necessary.	Relative to the surface area being preserved, the cost will be extremely high, especially is equipment must be mobilized for the touch up work.

RECOMMENDATIONS

1. Implement proposals submitted to SSRAC into Navy Standard Item 009-32. Use the guide in APPENDIX A of the report to disseminate the information to those involved with Navy tank painting.

2. Perform testing outlined in this report to develop the quantitative data necessary to quantify any coating performance benefit associated with application and cure at 50% relative humidity. Test protocol considerations are outlined in Appendix B.

3. Evaluate tank assessment data from US Navy ships to determine if there is a significant difference in performance of tanks painted before and after the 50% relative humidity requirement was institutionalized. Note that any such analysis would be difficult as it would have to correct for myriad other changes to Navy tank painting practices over the years.

4. Regardless of the relative humidity requirement, condensation should not be allowed during the surface preparation and coating cycle. Proper airflow should be maintained during coating application and cure.

PROJECT OBJECTIVES AND METHODOLOGY

There is a disagreement between US shipyards and the Navy on the importance of maintaining 50% relative humidity in tanks during painting. A previous NSRP panel project has identified this issue (i.e., the requirement to maintain the relative humidity in a tank or void space at a maximum of 50% from the start of surface preparation to cure of the topcoat) as one of the most expensive requirements in NSI 009-32.(1)[3] Because of this, NSRP has requested that the Navy amend 009-32 to allow tank painting at manufacturers recommended conditions (commonly 85% relative humidity). The Navy has determined that the lower relative humidity reduces the risk of pre-mature coating failure and is warranted given the military-unique risk tolerance. Specifically, the Navy believes that achieving and maintaining 50%RH during coating application and curing will reduce performance, cost and schedule risks at a negligible cost.(2) This project explored both sides of the argument and developed proposals for intermediate solutions which address the Navy concern regarding risk reduction while reducing the cost impact of the 50% RH requirement.

The specific project goals and objectives were:

(1) Identify the possible benefits and rationale behind requiring 50% RH
(2) Identify Shipyard capabilities regarding environmental controls
(3) Establish the costs associated with maintaining 50% RH viz less stringent requirements
(4) Establish more cost-effective alternative environmental requirements

Our approach to the project included four interrelated tasks:

<u>Task 1 – Review technical literature and reports</u>. We reviewed technical literature regarding the effects of relative humidity on the corrosion of steel and cure of coatings commonly used in tanks. This included a review of the technical materials used by the Navy when developing the current requirement.

<u>Task 2 – Interview NSRP member shipyards</u>. We contacted NSRP SP-3 panel representatives and others in the shipbuilding industry to identify common capabilities and constraints with respect to meeting environmental control requirements.

<u>Task 3 – Roundtable discussion of alternative requirement concepts</u>. We conducted a half-day roundtable discussing alternative requirements at the March, 2009 NSRP meeting. Participants included over 40 members from various elements of the shipbuilding industry including academics, Navy engineers, coating chemists and shipyard process managers.

<u>Task 4 – Develop SSRAC proposal</u>. Based on the results of the roundtable, a smaller working group was formed. The working group developed seven SSRAC proposals for consideration by the NSRP SP-3 panel. Ultimately 5 were recommended for submittal to SSRAC and 4 were accepted by the Navy.

[3] Numbers in parenthesis refer to the references at the end of this report.

HISTORICAL REVIEW OF THE 50% RELATIVE HUMIDITY REQUIREMENT

Engineering for Reduced Maintenance Tank Protocol

One of the most comprehensive procedural modifications as it relates to corrosion control in the inner structure of US Navy ships and submarines was undertaken by NAVSEA 05M1 beginning in 1995. The effort was precipitated by Engineering for Reduced Maintenance (ERM) programs geared at designing a surface preparation and coating protocol, using existing technology. This would enable coating systems to last 15-20 years in critical coated areas with minimal maintenance prior to complete replacement. A culmination of such a protocol was summarized by Kuljian, Kaznoff, and Parks (3), which included the following key process steps:

- High pressure fresh-water wash down
- Activation of dehumidification equipment to maintain max 50% RH
- Edge Radiusing, Grind rough welds
- Near White metal blast to achieve SSPC-SP-10 profiled finish
- Soluble Chloride checks to achieve levels at or below 3 $\mu g/cm^2$.
- Application of a high solids modified epoxy coating system
- Manually stripe coat all edges, welds, holes
- 100% Holiday checks of the final system
- Enforcement of strict QA requirements from start to finish

After a series of shipboard trials, the above key points were further modified to decrease the shipyard burden, without sacrificing quality. Such modifications included:

- Elimination of edge radiusing in lieu of using a near 100% solids coating with edge retentive properties
- Allowing for spray striping edges due to short pot life epoxy coatings
- Elimination of 100% holiday checks using a holiday detection device

Other research documents have gone into detail describing the above protocol. We will examine the technical justifications used in mandating the requirement to install, activate and maintain dehumidification equipment from the start of blasting to the final cure of the coating system.

Based on NAVSEA shipyard experience, as well as best available industry practices, maintaining a maximum of 50% relative humidity would:

1. Inhibit the formation of “rust back,” thereby eliminating the need for costly re-blasting to meet the SP-10 requirement prior to painting
2. Allow the blast to be “held” in a Near White condition “indefinitely.” This allows for continuous (around-the-clock) un-interrupted surface preparation work
3. Provide optimum environmental conditions for epoxy coatings to cure, virtually eliminating the potential for inter-coat delamination due to amine-bloom.

A brief discussion of each of the above NAVSEA main criteria follows.

Dehumidification Inhibits Rust-Back

Environmental conditions such as ambient humidity, air temperature, and substrate temperature have a substantial impact on surface preparation and coating operations. High performance coatings, such as those used by major industries (petrochemical, municipal water, wastewater, shipping, offshore, and the US Navy) require high levels of surface cleanliness in order to perform as designed. A typical concern of a freshly abrasive blasted surface is the natural tendency of the steel to start to corrode over time if the relative humidity inside the tank creates a situation of surface temperature falling below the dew point. Such occurrences are termed “rust back” and “rust bloom.” These are simply where the blasted surface loses its characteristic bright shine and is covered by a fine layer of oxide from atmospheric corrosion. Such an appearance does not meet the Navy specification limits (NSTM 631 and 009-32) of a Near White Metal Blast (SSPC-SP-10). It is commonly believed that coating over visible rust is unacceptable for optimal coating performance. For decades the traditional thought was that coating over apparent rust back is a risky undertaking. More modern research has shown that the risk is associated with coating over invisible contaminants, chiefly chlorides, which lead to accelerated coating degradation, especially in immersion situations. (4, 5, 6).

A well-referenced study by Vernon (7) showed that high atmospheric pollution, in addition to high atmospheric humidity promoted rapid corrosion of bare steel. He measured the corrosion rate of steel over a wide range of ambient humidity and found a rapid increase in corrosion rate above approximately 60% RH. A 2005 NAVSEA white paper,(2) study further interpreted earlier work by Vernon to show an exponential increase in corrosion rate of bare steel above 50%. In fact, for a certain period of testing time, the corrosion rate of bare steel exhibited a 134 fold increase from measured corrosion rates at 43% RH vs. rates at 68% RH.

Figure 1 is a reproduction of the figure in the Vernon report which is discussed above. Three issues are worth noting. First, the exponentially increasing corrosion rate at increased relative humidity is on iron which has already rusted. The corrosion product will tend to adsorb moisture from the air and thus experience an increasing corrosion rate. Second, the effect of higher relative humidity on a freshly exposed coupon over approximately 50 days at the higher humidity level (curve B) was actually lower in slope than the first 50 days at the lower humidity level (curve A). Third and perhaps most importantly is that the corrosion rates exhibited are extremely low – the initial slopes of lines A and B in Figure 1 represents a corrosion rate of approximately 0.001 mils per day. Given that a very short time elapses between blasting and painting (i.e., days if not hours), such low general corrosion rates are insignificant.

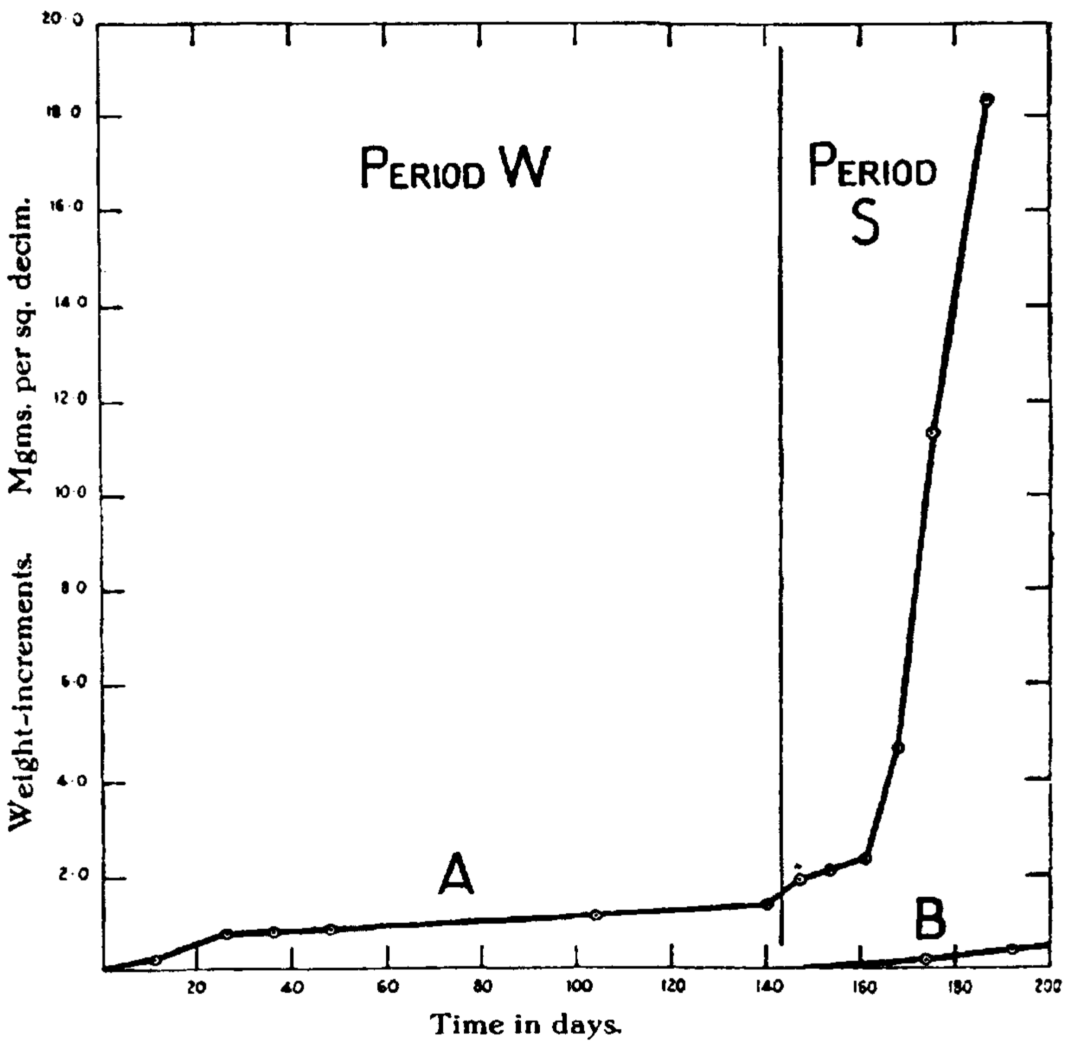

Fig. 25.—A—Effect of increase in atmospheric humidity (Period S) upon iron which has already rusted in a relatively dry atmosphere (Period W).
B—Intrinsic effect of the more humid conditions upon freshly cleaned iron.

Figure 1. Reproduction of figure from Vernon report.

In addition to the data in the Vernon report, there was other support for a low relative humidity during tank painting. Sigma Coatings (now PPG Marine) was intimately involved in the earlier NAVSEA ERM tank and void preservation protocol and recommended relative humidity below 50%.(6) Other referenced recommended relative humidity ranges include, International Paint LLC, which recommends a relative humidity range of 40-60%RH. Danyard Shipyard likewise established a relative humidity range between 25-65% RH, and a French shipyard specifies RH to be less than 30%.(8)

In summary, the notion that corrosion rates increase substantially above 50%, thereby increasing risk of rust-back inside the tank and void, provided technical justification for establishing this range. We will further explore the issues associated with rust back later in this report. Note that regardless of the tendency for rust back to occur, QA inspectors should identify any rust-back which occurs. They would further argue that whether they choose to use humidity control or re-blast steel which rusts is a business decision which they can make if the requirement is 85%, but 50% virtually requires humidity control. The occurrence of rust-back depends on a variety of factors such as the tank geometry, local environmental conditions, work practices employed, etc.

Dehumidification "Holds the Blast"

Prior to specifying dehumidification, a typical scenario for tank blasting may depict an entire blast crew blasting for one, two, or multiple shifts to prepare and entire tank surface area. Routinely, negative air (suction) pressure is employed to remove airborne dust and fractured paint/blast media, reduce explosion hazard, and to provide a visible work environment for the blaster(s). If atmospheric air is then used as the source of ventilation, it would not be uncommon for the entire surface to require re-blasting, due to rust-bloom formation overnight. Simply put, as the air temperature decreases during the hours of darkness, so does the steel temperature. Rising evening air relative humidity results in extremely high relative humidity at the cold steel surface, often rising to 100% and causing condensation. This is the reason that extra shifts of manpower are often required to restore the SP-10 Near White Metal blast prior to painting.

This extra re-blasting is almost always seen on large athwart-ships tanks, such as those found on the larger amphibious warfare, amphibious assault, amphibious transport, and dock landing ships equipped with large well decks, like LHD, LHA, LPD, LPH, and LSD. The shear amount of area to blast requires multiple shifts to accomplish. The painters are faced with the dilemma: Either blast-then-paint what can be accomplished in one day, or be faced with costly re-blasting of surfaces which rust-back. Either way, costly re-work will likely be required. If the blast-then-paint scenario is chosen, subsequent blasting would cover the primer with dust from adjacent blasting, which would have to be cleaned prior to applying subsequent coats of paint. This blast-then-paint scenario can take weeks on a large tank, risking some recoat windows on certain types of primers.

Instead of blast-then-paint, or blasting multiple times to remove rust-back, constant dehumidification displaces all the moisture-laden air in the tank. This allows the contractor to blast the entire surface of the tank, regardless of size, and "hold" the blast with dry air without the worry of rust bloom (3, 9). After dust is removed, painting can begin immediately, regardless of outside ambient conditions. Obvious production advantages of maintaining dehumidification equipment in the tank during the blasting process are:

- Crews may begin early in the morning, without waiting for outside ambient conditions of relative humidity and dew point to be met. (i.e. it can be raining outside and work can continue inside the tank.)
- Overlaps, or "cold-joints", in the coating system are eliminated from the blast-then-paint routine, thereby allowing smooth, uninterrupted painting of the entire tank
- Repeated dust cleaning from multiple blast-then-paint scenarios are eliminated
- Recoat windows are easily achieved
- Production supervisors can more easily predict when a tank will be completed, without being at the mercy of outside ambient conditions

- Multiple man-hour saving switching over from blasting to painting are realized
- Production remains in control of the paint shop

While the benefits of dehumidification to control rust-back are applicable in many cases, mandating such control without consideration of all work options can force the shipyard to perform work in a non-optimal fashion. From the shipyard perspective, many of the above issues are simply business decisions which they must make. When the jobsite conditions warrant, it may be possible to eliminate the cost of dehumidification equipment with little or no risk of losing a white metal blasted condition if the requirement is 85% relative humidity. The requirement to maintain 50% relative humidity eliminates a series of options which the coating applicator would otherwise have available for completing the tank. Depending on the tank size, location within the ship, other work requirements, environmental conditions, etc. it may be more effective for the contractor to blast and paint a large tank in small sections or accept the risk of rework. However, if there is a requirement to maintain 50% relative humidity, the painting contractor will almost certainly be required to utilize dehumidification equipment.

Dehumidification Provides Optimum Curing Conditions

<u>Solvent Evaporation</u>

To achieve the desired 15-20 year coating service life, the coating system needs to be applied and cured umber optimal conditions. Most coatings applied by the US Navy in the mid-1990's contained 55-65% solids by weight, i.e. 35-45% volatiles by weight. These volatiles, mostly solvent, must entirely leave the paint film prior to curing, or else premature failure due to solvent entrapment would most likely occur. Relative humidity has little effect on the evaporation rate of most solvents other than water.(10) The rate of evaporation of a single solvent is affected by four variables: temperature, vapor pressure of the solvent, surface/volume ratio and the rate of airflow over the surface.

It is obvious that at a bare minimum, air movement is needed to evacuate the space of solvents. Conceptually, one could maintain large volumes of air flow during cure of the coating, and ignore dehumidification. However, this may be cost prohibitive due to the size and cost of the equipment, and power requirements. Maintaining airflow would be an ineffective alternative if the supply air (ambient) was saturated with moisture or too cold. If the contractor has both options available, they can choose the most cost-effective given the conditions prevalent during the work.

Solvent evaporation is also a cooling process, whereby when the solvent leaves the wet film, the coating surface cools and can become less than that of the air in the space (tank) or less than that of the substrate. This can lead to moisture condensation at the surface if the surface is now cooled to the dew point. If for example the coating is applied right at the 5 deg F above the dew point criterion, the evaporative cooling effect may lower the temperature at the surface, causing moisture condensation on the evaporating coating system, which has a detrimental effect upon curing. Dehumidification acts to reduce the dew point in the air to well below that experienced by any evaporative cooling.

Amine Bloom

An additional rationale to require lower humidity inside critical tank coating operations relates to the phenomenon of "amine bloom" or "amine blush". Amine bloom is a substance that can form on the surface of an epoxy coating while it nears the end of its tack-free state that can cause intercoat coating delamination. It is a formulation-related phemomenon which can occur when amine based curing agents in the epoxy coating react with carbon dioxide (CO_2) and water vapor from the air. The result is a thin waxy film left on the coating surface. Unless removed, the potential for failure remains. The reaction is more readily prevalent with colder moist conditions, just the opposite as those observed with dehumidification. The US Navy is very familiar with amine bloom, and how to test for it in certain submarine applications (11, 12). Amine Bloom and associated intercoat failures has been discussed in recent technical journal articles.(13, 14, 15, 16, 17)

In general, "epoxy" refers to a family of anti-corrosive coatings that ships built for the US Navy use. Within this generic realm of coatings, a wide variety of epoxy resins can be selected as well as a wide range of amine and amide curing agents. Epoxy coatings which incorporate amine-based curing agents, under certain conditions, can react with moisture in the air and carbon dioxide to form an ammonium—carbamate and hydrates of amine carbonate on the exterior of the coating film. Unreacted amines in the coating can migrate to the surface of the coating film and form this substance we call "amine blush" or "amine bloom". It forms a cloudy-waxy reaction product that can affect intercoat adhesion if not removed. Conditions which exacerbate the formation of bloom include cooler temperatures, high humidity, and poor air circulation.

Detection of amine-bloom is rather easy, however not quantitative. US Navy submarine outer hull coating system procedures call for the use of an indicator agent, B-naphthoquinone-4-sulfonate, which gives a deep red (purple-ish) coloration upon contact with excess amine (hardener). Bloom exudates are typically water-soluble. Upon detection of the compound, a simple wash with a low concentration water/ethanol mixture is used, followed by a re-test.

The greasy layer that forms on epoxy coatings which exhibit bloom are the salts of ammonium bi-carbonate, such as ammonium carbamate. As mentioned, amine compounds on the surface can also combine with atmospheric carbon dioxide and water in humid air to form hydrates of amine carbonate. The reason amine-bloom is considered a coating defect is that it can lead to discoloration over time, poor overcoatability and intercoat adhesion issues. Overcoatability obviously is of utmost concern in tank painting operations involving multi-coat systems (usually two). However, a portion of low molecular weight amines that would normally be reacting with epoxy to make a hard and durable coating are now involved with competing reactions with carbon dioxide and atmospheric moisture (water) to form a waxy substance with no contribution to anti-corrosive properties whatsoever. The result is a coating with weaker properties due to incomplete cure.

The single coat systems presently used by the Navy only have trace amounts of amine, making amine-bloom less of a concern; however it should not be completely discounted.[4]

[4] This was the consensus of coating manufacturer representatives in the SP-3 relative humidity workshop.

DEW POINT AND RELATIVE HUMIDITY

The general target of dehumidification is to provide air dew points well below the existing surface temperature and to reduce the relative humidity at the surface. By reducing the relative humidity at the surface, the likelihood of condensation is reduced.

Air is a mixture of Nitrogen (78%), Oxygen (21%) and the remaining 1% being a mix of primarily Argon and other impurities. Water is soluble in air at all temperatures. The total amount of water which can be absorbed by air at any given time is directly a function of temperature.[5] The actual amount of water in air depends on other factors such as the sources of available water and airflow around those sources. Dew point, by definition is the temperature at which the air becomes saturated. At the dew point, moisture will condense out of the air and deposit on any surface. Condensation is one of the key factors we try to eliminate by lowering the relative humidity with dehumidification equipment.

Inspection of the various parameters that make up "environmental conditions" can be quite arduous. Various conditions must be determined, such as ambient temperature, wet and dry bulb temperatures, surface temperature, relative humidity, and dew point (calculated). Inspectors are most concerned with the conditions at the surface, since that is where moisture can condense, corrosion can occur, and that is where coatings are applied.

A wet and dry bulb thermometer is one way to achieve rapid-evaporation of water from a wetted surface. Manual, fan powered, and electronic versions are available. Essentially the evaporative cooling caused by evaporation of pure water from the wick of a wetted thermometer ("wet bulb" temperature), compared to the ambient temperature of a dry thermometer ("dry bulb" temperature) gives us a means to calculate relative humidity. The difference of these two temperatures provides the basis for RH determination, and can be determined from a psychometric chart or determined electronically. A simplified version of a psychometric chart is depicted in Figure 2.

In a similar fashion, the difference in the wet and dry bulb temperatures and the associated ambient temperature is used to determine the dew point, the temperature at which water will condense at the surface (at a given relative humidity). Though not typically used in the coating industry, the psychometric chart can also be used to determine the absolute humidity in grains of moisture per pound of dry air.

Surface temperature readings are made a number of ways, such as using bi-metallic magnetic contact thermometers, electronic thermo-couple type devices, or hand held, non-contact infrared devices. Surface temperature should never be confused with dry bulb temperature. For example, on a sunny deck, the surface temperature outside of a dark metallic substrate may measure 125^{o}F, whereas the ambient temperature of the air a few feet from the deck may only measure 75^{o}F.

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[5] Technically, the amount of water which can be absorbed by air also depends on pressure. For simplicity, we will assume atmospheric pressure is equal throughout our enclosed space.

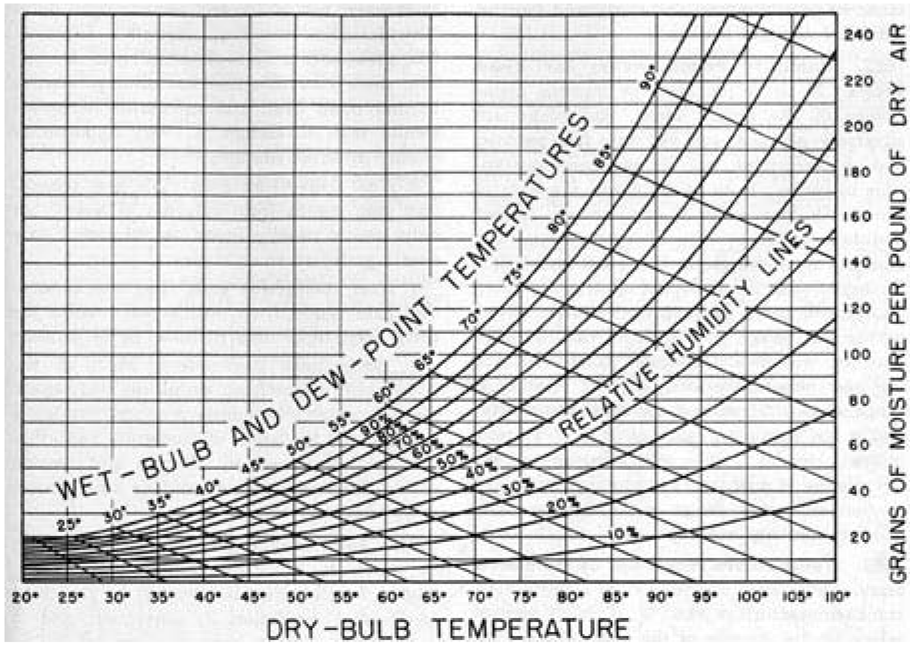

Figure 2. Simplified Psychometric Chart, courtesy of www.maritime.org.

Relative humidity is the amount of water in the air at any given moment in relation (or "relative") to the amount of moisture that the air can hold at saturation (dew point). Dehumidification removes water from the air and treats (drys) it prior to introducing it back into the space or enclosure. Dehumidification not only lowers relative humidity but it also lowers the absolute humidity or amount of moisture in the air. Simply heating the air in a tank will only reduce the relative humidity, ***it will not remove moisture from the air***.[6]

As an example, consider a tank with ambient air and surface temperatures of 57°F and 90% relative humidity in the air. We can see from Figure 2 that this air contains 60 grains of moisture per pound of dry air and has a dew point of 55°F. If we heat the air in the tank to 73°F, we lower the relative humidity to 50%. However, since the air still contains 60 grains of moisture per pound of dry air, the dew point only increases to 61°F. If a sufficient heat sink exists (such as a ship docked in a cold climate), heating the inside air might not increase the temperature of the steel. Conceivably, the steel could stay below 61°F and experience condensation. On the other hand, in situations where the structure to be painted is heated along with the ambient air (such as steel components in a heated blast booth) the dewpoint spread will be increased even though the air has not technically been dehumidified. By increasing the dewpoint spread and lowering the relative humidity we improve painting conditions even though the air has not technically been dehumidified.

[6] Note that dehumidification may employ heat, but is not the same as simply heating the air.

RISK ASSESSMENT

As discussed earlier in this report, specifying a 50% maximum limit on atmospheric relative humidity was an integral step in achieving a 15-20 year coating service life inside ship's internal tanks. Approximately 13 years later, the Navy maintenance philosophy has switched from one of accepting the lowest possible technical risk to one of risk/reward analysis. In other words, what is the tradeoff between added risk and lower cost if the requirement for tank painting is changed from 50% relative humidity to 85% relative humidity?

In this section we will discuss both the technical risks and the potential cost impact of changing the relative humidity requirement from 50% to 85%. The section will address four issues: the conditions which are favorable to rustback, conditions which may impact curing, the cost of dehumidification, and the risk associated with not controlling humidity. In this discussion the notion of "risk" includes the technical risk of the unfavorable event occurring, the process risk of the unfavorable event not being detected and remedied, the schedule risk associated with rework as a result of the unfavorable event, and performance risk associated with coatings applied under the unfavorable conditions.

Risk of Rustback

Atmospheric corrosion of steel is a complex phenomena involving myriad mechanisms. It has been discussed in great detail by a number of authors.(s) Most people involved with corrosion are taught that at "normal" temperatures, corrosion of steel requires the presence of moisture. It has been empirically observed that even in high humidity, contamination is required to form rustback. (5, 18) Figures 3 and 4 are from unpublished work by the authors. In the study, new steel and heavily corroded steel was abrasive blast cleaned to a near white metal condition using aluminum oxide grit. After cleaning the test panels were stored in a humidity chamber controlled to either 42% or 94% relative humidity for one month. The photographs clearly show the effects of surface contaminants are impacted by the relative humidity while not corrosion of contamination-free coupons is noted in either situation.

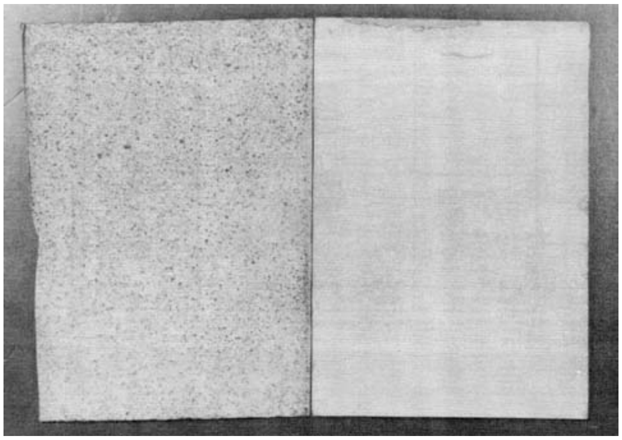

Figure 3. Rust-back of white metal surfaces after 1 month at 42% relative humidity. Right surface was mill scale before blast cleaning. Left surface was heavily rusted before blast cleaning.

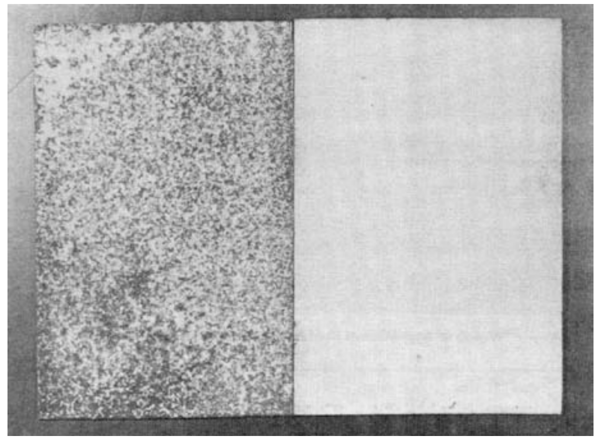

Figure 4. Rust-back of white metal surfaces after 1 month at 94% relative humidity. Right surface was mill scale before blast cleaning. Left surface was heavily rusted before blast cleaning.

While coatings engineers tend to think of salts when discussing surface contamination, there are actually a wide variety of contaminants which can pull moisture from the air and initiate the corrosion process. The amount of water sorbed on iron and steel varies markedly with the composition and morphological properties of the surface.(19) For example, α-Fe_20_3 powder will sorb the equivalent of about two mono-layers of water at room temperature and approximately 60% RH. A detailed review of the wide variety of corrosion products, salts and other materials which may be on a steel surface is beyond the scope of this report, suffice it to say that a cleaner surface can tolerate higher levels of relative humidity while lower relative humidity will reduce the chances of a contaminated surface from exhibiting rustback.

At a practical level, some data was presented earlier in this report on the corrosion rates of steel when held at varying humidity levels. Recall the relatively low corrosion rates exhibited during the initial days of exposure in that work – the data suggested corrosion rates of approximately 0.001 mils per day (0.37 mils per year). More recent work has been sponsored by Naval Surface Warfare Center – Carderock Division on corrosion resulting from protected storage methods at various US Marine Corps facilities. In this study, warehousing or garaging showed a reduction in corrosion by a factor of 65X over uncovered storage for corrosion test coupons. Corrosion rates were:[7]

Open lot = 1.31 mils per year
Under cover = 0.55 mils per year
Warehouse = 0.02 mils per year
Dehumidified = 0.01 mils per year

A few key points are worth observing. First, note that the corrosion rates observed under cover, in the warehouse and in dehumidified storage were considerably lower than those observed in an open lot. This data quantifies the notion that rustback will be less likely in spaces which are enclosed (i.e., shipboard tank or enclosed blast room) versus open to the environment. Second, note that the corrosion rate in the warehouse is lower than that reported in the Vernon study.

[7] http://www.marcorsyscom.usmc.mil/cpac/chp.asp; accessed September 1, 2009

Data from a briefing that has not been made public shoes that while the humidity in the outdoor environment varied throughout the day, humidity in the warehouse remained relatively constant.

In the event that rustback does occur, the QA inspection prior to painting should detect any significant (i.e., visually observable) rustback. Rustback which is detected would be removed using abrasive blasting or local surface preparation technique prior to painting. Such "touch-up" surface preparation is fairly common in industrial coatings processes and does not pose substantial cost or schedule risk. In the event that rustback is not detected and painted over, the subsequent coating performance risk would depend on the extent and chemical makeup of rustback, coating material, and service environment. One would hope that rustback which goes undetected would be insignificant enough to have minimal performance impact.

Risk of Inadequate Cure

In a previous section the benefits of lower relative humidity to coating cure were discussed. Specifically, the lower relative humidity helps ensure against amine bloom. Detection of an uncured coating or amine bloom is straightforward in extreme cases, however more subtle situations may occur which go undetected. Once detected, amine bloom is fairly easy to remedy, while a coating with retained solvent may need to be replaced in the worst cases.

It was the opinion of coating manufacturers at the NSRP relative humidity workshop that the adoption by the Navy of single coat coating materials significantly reduces these risks. Single coat materials are near solventless and have negligible risk of amine bloom.

Cost Factors

The cost associated with meeting the relative humidity requirement depends on a wide variety of variables. Obviously, a large portion of the cost is for dehumidification equipment. The lowest cost scenario is when the requirements and local environment are such that the surface preparation and painting can be accomplished without dehumidification equipment. Assuming dehumidification equipment is required, there are a number of factors which drive the cost:

- Equipment cost – includes the costs associated with renting or purchasing dehumidification equipment. For purchased equipment, the manner in which costs are allocated to a job can impact the cost analysis.
- Mobilization cost – includes the costs associated with moving the equipment to the work area and installing necessary duct work and power. For maintenance work, this can involve long lengths of ducting through various manned and unmanned spaces aboard the ship. This also includes demobilization of the equipment.
- Operation and maintenance costs – includes the costs associated with operating the equipment. This may include operator training, having operating engineer on-site, routine equipment maintenance, and fuel or electricity costs.

From either a shipbuilding standpoint or ship repair standpoint cost of operating and maintaining added equipment, such as dehumidification, is a concern to all since it is an added expense to the overall job. To some contractors, the added benefits of humidity control (e.g., placing control of the job in the hands of those doing the work, not the environment) are worth the extra expense. From the round-table discussions at NSRP meetings, and general investigator interviews, it seems that the opinions of new-building yards, repair yards, and coating contractors all differ based on their personal experience. For example, one argument against using dehumidification may be that it simply is "just another expense" to an already complicated process. An equally salient argument may be "Dehumidification actually saves me money in the long run, since I do not have to worry about re-blasting (and then cleaning up) areas that have rusted overnight, prior to painting."

The cost of dehumidification as a percentage of the overall cost to blast and paint a tank varies depending on factors such as the size of the job. Investigators have attempted to quantify the cost on a percentage basis. One analysis suggests that the cost differential between requiring 50% and 85% relative humidity is approximately 0.03%.(2) However, this analysis assumed that dehumidification would be required in either scenario so the cost difference was only for the power consumed. In the instance where the production risks were deemed acceptable, a considerably larger savings could be realized by not bringing in any dehumidification equipment. Another reference provides cost data for a hypothetical small tank showing that the cost of dehumidification equipment (mobilization, rental and operation) was 25% of the overall tank coating cost.(20) Obviously the significant cost driver is not the specified relative humidity level per se, but rather whether dehumidification equipment is required to achieve that level.

Risk of not Controlling Humidity

The most significant cost savings are associated not with the level of humidity required but with the decision of whether or not to install humidity control equipment. Thus it is important to consider the risk of not having any controls in place. Each ship repair and shipbuilding location in the United States, has its own unique humidity concerns depending on the geography, time of day and the time of year. Those involved with coating operations have to manage the humidity in their own way to meet current or proposed specification requirements. Figure 5 shows data for eight US shipbuilding regions. The graph shows the percentage of days when the average reported relative humidity did not exceed either 50% or 85%.[8] Clearly, requiring 50% relative humidity versus 85% has a significant impact on the number of days one could conceivably operate without dehumidification equipment in any of the major US shipbuilding regions.

The data in Figure 5 present an average ambient relative humidity at an official monitoring station remote from the shipyards of interest. The data does not have the resolution to capture individual excursions beyond the requirement (i.e., the average could be less than 50% but sometime in the day an individual observation probably exceeded that value). To explore the relationship between local weather data and worksite measurements, we evaluated data from shops in two different shipyards and compared it to the local weather station. Figure 6 shows the data. The data suggests that locally reported daily low relative humidity more consistently predicts the relative humidity in a shop environment. The data also suggests that a shop in these environments will meet an 85% relative humidity requirement more than 99% of the time without dehumidification yet will only meet a 50% requirement 75% of the time. One percent

[8] Data obtained for calendar year 2008 from an official NOAA weather station within 5 miles of the shipbuilding industrial complex in the geographic region noted.

downtime might be an acceptable production risk for a shipyard, but 25% would most likely be an unacceptable risk. Thus, a 50% relative humidity requirement requires a capital investment to dehumidify the facility while 85% relative humidity requirement does not require the capital investment.

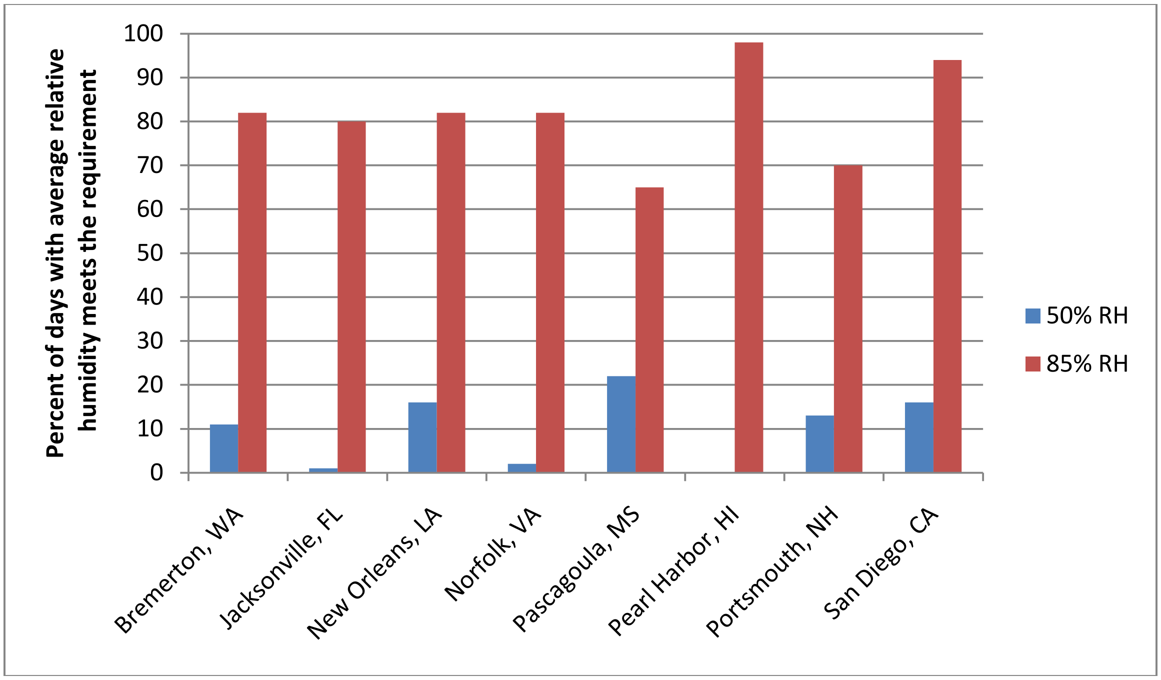

Figure 5. Ambient humidity measured at eight major shipbuilding locations.

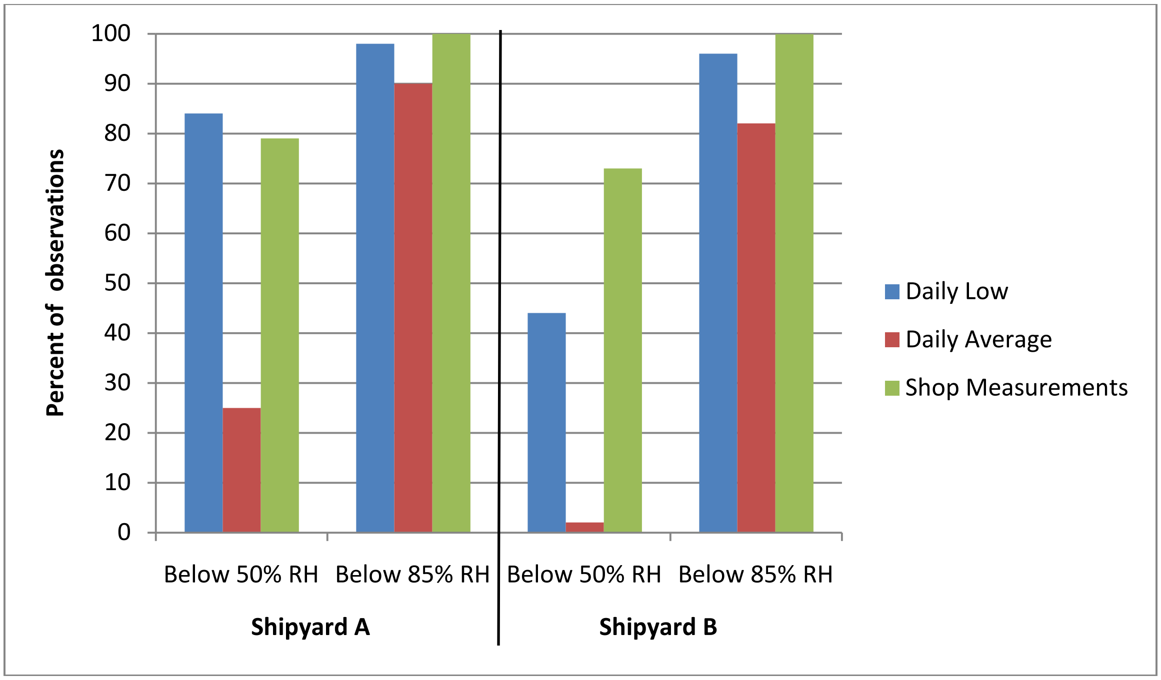

Figure 6. Relationship between ambient humidity and humidity in a paint shop.

Assessing the Risks

The decision to specify maximum limits to dehumidification for tank painting on US Navy vessels boils down to a tolerance of risk. We have already discussed the benefits of a lower relative humidity requirement pertaining to rust-back of a blasted surface. Additionally, the joint report published by the Society of Protective Coatings (SSPC) and the National Association of Corrosion Engineers (NACE International) on industrial dehumidification recommends coating operations to take place when the substrate temperature is 17 to 25 ^{o}F above the dew point, with a relative humidity not to exceed 40 to 55%. (21)

What is gained and what is lost if dehumidification requirement is relaxed? If the requirement is relaxed such that it could be met without dehumidification equipment, there is potentially an upfront cost savings from not having to acquire and operate equipment. However, there is risk involved. A week of rainy weather could basically shut down a tank painting job if the conditions are not adequate and dehumidification equipment is not available. Furthermore, it would result in re-blasting prior to painting. Fundamentally, an owner (in this case the Navy) must consider whether to pay to eliminate the risk or let shipyards determine the “market value” of taking the risk versus eliminating the risk. Note that any assessment of risk must not only include direct costs (equipment, labor, etc) but also the opportunity cost (such as not having a ship available for a few additional days). Assumptions about opportunity costs can easily dominate any analysis.

As noted earlier, a formalized laboratory test has not been conducted to quantify the impact of relative humidity on coating performance. The above discussion of risk might leave the reader to conclude that such a test program would not provide useful data. However, a properly designed test program would generate data that would be useful in the evaluation of risk. Appendix B presents considerations which would be important for such a test program. A key consideration of such a test program would be to determine how much rust back can be tolerated without impacting coating performance.

PROPOSED CHANGES TO NAVY STANDARD ITEM 009-32

A previous NSRP panel project has identified the requirement to maintain the relative humidity in a tank or void space at a maximum of 50 percent from the start of surface preparation to cure of the topcoat as one of the most expensive requirements in Navy Standard Item 009-32.(1) Currently, the Navy is willing to accept greater performance risk in return for cost savings in many areas, including acquisition (new construction) and maintenance. As part of this project we conducted a brainstorming session on the issue of maintaining relative humidity during an NSRP SP-3 panel meeting. The results of this session are presented in Appendix C. Follow-up interviews with several participating shipyards, coating suppliers and other interested parties helped to fully understand the issues which were raised. In general, the investigators found that there were several different opinions about the requirement, and how they pertained to individual situations. In order to address the shipyard concerns, the investigators developed a listing of what they thought were most applicable to the ship repair/shipbuilding environment today. The change proposal ideas needed to meet three basic criteria:

- Have some scientific or logical basis which could be readily accepted without extensive testing
- Have the potential to reduce the tank preservation cost to the Navy
- Not introduce significant risk to the preservation process or coating performance

The ideas generated were disseminated to all NSRP SP-3 interested parties, and discussed during a conference call. Seven proposals resulted from the working group. The proposals were discussed at an NSRP SP-3 panel meeting with members of the Navy and shipbuilding community. Following are the seven proposals which resulted from the process:

Proposal 1 – Allow excursions from 50% relative humidity

Append Note (26) to state "Limited excursions of up to 8 hours at 85% relative humidity shall be allowed provided that there is data to show that the 5 degree dewpoint spread has been maintained and other requirements of 009-32 are met."

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." The primary reason for this requirement is to ensure a robust process where all surfaces of a complex tank remain within acceptable limits. The requirement by its very nature is intended to more restrictive than the condition which is absolutely necessary. Explicitly allowing reasonable excursions from the stated conditions would reduce costly re-work associated with dehumidification equipment interruptions. Time consuming rework will not be required for upset conditions which are within commercially acceptable practices.

Ultimately the working group recommended against submitting this proposal because they felt it had a low chance of being approved. The group felt it would be in conflict with the NAVSEA adjudication decision matrix and difficult to enforce. Perhaps a modification of the NAVSEA adjudication decision matrix would be a better alternative.

Proposal 2 – Replace 50% relative humidity requirement with larger dew point spread

Append Note (26) to state "As an alternative to 50% relative humidity, the contractor may show that the surfaces maintain a dew point spread of greater than 17 degrees F."

Note 26 requires that 50% relative humidity be maintained. Joint Technical Committee Report SSPC-TR 3/NACE 6A192, "Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces" states that surface relative humidity is more critical than ambient relative humidity. Because it is impractical to measure relative humidity at a surface, it is more convenient to measure dew point differential. The standard suggests that a dew point differential of 17 to 20 degrees F likely corresponds to 50% relative humidity at the surface.

The working group felt this proposal was worthwhile and has good technical merit, though they were concerned because there was no specific field experience working to such a requirement. Upon further review at the NSRP SP-3 panel meeting, it was decided to eliminate this proposal because it is not practical to continuously monitor dew point spread and the potential cost impact was uncertain.

Proposal 3 – Do not require 50% relative humidity when time from blast to prime is short

Append Note (26) to state "tanks and tank components which have the initial coating applied to all surfaces within 8 hours from start of surface preparation to completion of primer coat shall be allowed to reach 85% relative humidity provided the 5 degree dew point spread is maintained."

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." The primary reason for this requirement is to ensure a robust process where all surfaces of a complex tank remain within acceptable limits. For small tanks or portions of tanks blasted and painted in a shop this requirement can be an unnecessary burden. If we assume simple tank geometries and shop steel is coated within a few hours of blasting, the robustness provided by the 50% RH requirement may not be required. If this modification is adopted, smaller tanks will not require the added expense of dehumidification equipment and shipyards will not have to incur the cost of controlling relative humidity in controlled shop painting environments.

The working group recommended that this proposal be edited to specifically not require 50% for blasting and painting performed in the shop. Since proposal 4 addresses small tanks, this would be a more direct statement of the remaining intent of the proposal.

Proposal 4 – Do not require 50% relative humidity for small tanks

Append Note (26) to state "For tanks under 2,000 square feet which are blasted and coated in one evolution, 85% relative humidity shall be considered adequate if ventilation is maintained from the start of surface preparation through cure of topcoat."

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." The primary reason for this requirement is to ensure a robust process where all surfaces of a complex tank remain within acceptable limits. Smaller, less complex tanks are easier to coat, require only one blast/paint iteration, and should not be susceptible to problems when preserved under the less restrictive commercial standard of 85% relative humidity. Smaller tanks may not require the added expense of dehumidification equipment.

There was much discussion by the working group on the rationale for and wording of this proposal. In essence, it assumes that the 50% requirement is primarily to eliminate the blast-paint-blast cycle associated with larger tanks. Concerns were expressed regarding the large population of small tanks on ships and the definition of "one blast/paint iteration." Specifically, the group felt that by virtue of impacting such a large tank population the proposal would not be well received. The group also felt that "one blast/paint iteration" could conceivably allow a blasted surface with problems to sit for days before priming which is not the intent of the proposal. The final workgroup consensus was to submit this proposal.

During the discussion of this proposal at the NSRP SP-3 meeting, the group decided to reduce the risk of the proposal by limiting the tanks where 85% humidity would be allowed to CHT tanks and chain lockers. The rationale was that the lifetime of coating materials in these spaces is relatively short and limited by chemical and abrasion resistance; performance parameters which are unlikely to be influenced by the relative humidity. Furthermore, it was believed that most of these spaces would be small enough to have the work completed in one evolution.

Proposal 5 – Modify the service life associated with 85% relative humidity

Revise note (38) to read "Maintain the relative humidity in the tank at a maximum of 85 percent from the start of abrasive blasting to final cure of the topcoat. By allowing 85 percent vice 50 percent relative humidity, this will reduce the service life of the tank from 15-20 years to 12-15 years."

Note 38 and Table 4, Line 7 incorporate the notion that by allowing 85 percent vice 50 percent relative humidity, this will reduce the service life of the tank from 15-20 years to 10-12 years. Commercially, similar tank coatings are applied with the 85% relative humidity requirement and a 15-year warranty is provided. Based on this experience, we proposed adjusting the referenced shortened life to "12 to 15 years." If adjusted, it is likely that more RMC's will specify the less restrictive relative humidity requirement which should reduce the cost of tank painting.

Most participants felt the change from 10-12 year service life to 12-15 year service life was "splitting hairs". The cost impact of this proposal is hard to quantify. It may have significant impact on systems designed with a 12-15 year maintenance cycle, however it is not known is such tanks exist. It was decided not to submit this proposal.

Proposal 6 – Clarify the extent of cure which must be carried out at 50% relative humidity

Revise Note (26) to read "Maintain the relative humidity in the tank or void space at a maximum of 50 percent from the start of surface preparation until topcoat "Cure to Recoat" time. 85% RH shall be considered adequate for final coat touch-up iterations."

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." It is unclear what degree of cure is required. For some products, the commercial equivalent product data sheet does not place the 50% relative humidity restriction on the cure time. If the humidity requirement could be relaxed after "Cure to Recoat," as much as 6 days of humidity control could be eliminated from the process. Furthermore, the requirement to maintain 50% RH during final touch-up may also add days to the requirement.
If adjusted, as much as 6 days of humidity control may be eliminated, allowing equipment to be used for other tank work. For projects where space or equipment limitation drive project schedule, more tanks will be able to be completed within the same timeframe.

The working group felt that this proposal was viable and would provide minimal risk while offering cost savings.

Proposal 7 – Allow 85% relative humidity during touch-up

Append Note (26) to state "For new and disturbed areas which are individually 2 sq ft or less and cumulatively are less than 0.03 percent of the total tank surface area (as defined in ASTM D-610/SSPC VIS-2), 85% relative humidity shall be considered adequate."

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." The primary reason for this requirement is to ensure a robust process where all surfaces of a complex tank remain within acceptable limits. This requirement can be unnecessarily costly for small areas of preservation work. The present proposal relaxes the requirement for small areas defined in a manner similar to paragraph 3.6.2.4. The incremental cost to control humidity is proportionally greater for small repair and touch-up work. As a result, it drives the cost per square foot up considerably. Furthermore, these small areas could probably be planned such that no equipment would be required to maintain 85% relative humidity. In addition to cost, staging of equipment and waiting for the humidity to be lowered in a space extends schedule for what should be a small, quick touch-up.

The group felt that this was a good proposal which would provide minimal risk while offering cost savings. However there was much debate about how much surface area compromised reasonable "touch-up." Some representatives believed as much as 10% touch-up should not be subject to the lower relative humidity requirement. In the end the proposal was submitted using the definition of touch-up area which is currently in SI 009-32.

Appendix D presents the five actual change proposals which were submitted to NAVSEA Standard Specification for Ship Repair and Alteration Committee (SSRAC) for consideration. Four of the five proposals submitted to SSRAC as a result of this project to target the 50%

relative humidity cost driver were reviewed and accepted by the SSRAC Hull and Preservation Committee for the FY 2011, 009-32 SI. Appendix E is an easy, one-page reference which can be provided to deckplate personnel on the changes.

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APPENDIX A – INDUSTRIAL DEHUMIDIFICATION BASICS

Dehumidification Uses

The use of dehumidification equipment is a common way to control a work environment to achieve working conditions that promote a more desirable end result. Dehumidification is very common to many industries.

In the petroleum and petrochemical industries dehumidification is used as a means to control the environment inside large tanks during abrasive blasting and coating operations. Dehumidification enables large storage tanks to be coated regardless of ambient conditions, eliminating one risk to scheduled downtime.

In the marine and ship repair industry, dehumidification can reduce the amount of time required for degassing tanks for personnel entry. It also significantly reduces the time required for drying a tank after steam cleaning, wash-downs via low pressure hydro blasting, or even after complete or spot-repair of tank coatings in a water-jetting operation. For tank washing of cargo ships, for example, dehumidification allows for quicker drying of the tank, enabling the ship to receive cargo sooner. During blasting and coating, dehumidification is employed for elimination of rust-bloom during blasting, as well as evacuating solvents during paint cure, and acceleration of the curing process, thereby returning tanks back to service in a quicker amount of time.

In aviation, dehumidification is used for the protection of highly sophisticated equipment during extend ground time periods, or for long-term storage.

In building restoration, dehumidification can be employed to quickly dry out buildings and their contents after catastrophes such as floods, hurricanes, and water damage from fires. Additionally, in restoration drying times of poured concrete, joint compounds, and general painting can be expedited with dehumidification.

Dehumidification can be used to minimize the formation of algae, mold, fungi that are found in flour and other similar product storage facilities. It can be used to facilitate the drying of grain products such as wheat, barley, and corn, as well as being used to control the environment during perishable food shipping. For example, candy and pharmaceuticals become sticky and hard to package without dehumidification.

In order to maintain perfect skating conditions, large dehumidification units are specified for all National Hockey League venues and International Olympic figure skating competition venues. Optimum specifications for NHL hockey venues are 60^{o}F and 40% RH.

Types of Dehumidification Equipment

The two most practical types of dehumidification technologies employed in industrial blasting and coating operations involve either refrigeration-based equipment, or desiccant-solid sorption based equipment.

Desiccant based DH systems pass the moisture-laden air over a desiccant, typically lithium chloride or silica gel. When the moist air is blown over the desiccant wheel, the desiccant absorbs the moisture from the air stream. The desiccant is then heated which forces the moisture to "evaporate out", thereby regenerating the desiccant for continuous use. This moisture is exhausted into a different air stream, typically the local environment outside the containment, or tank. The heat of regeneration often caused the temperature of the air ducted into the enclosed space to be substantially higher than the ambient air, typically by as much as 10 to 15^{o}F. Due to the heat-of-regeneration requirement, there is a power requirement to operate the equipment, which can be substantial. In very hot climates, process coolers are combined to cool the air entering the space to make it more habitable for workers. Desiccant type units are used at a wide variety of climactic conditions of ambient temperatures and relative humidity.

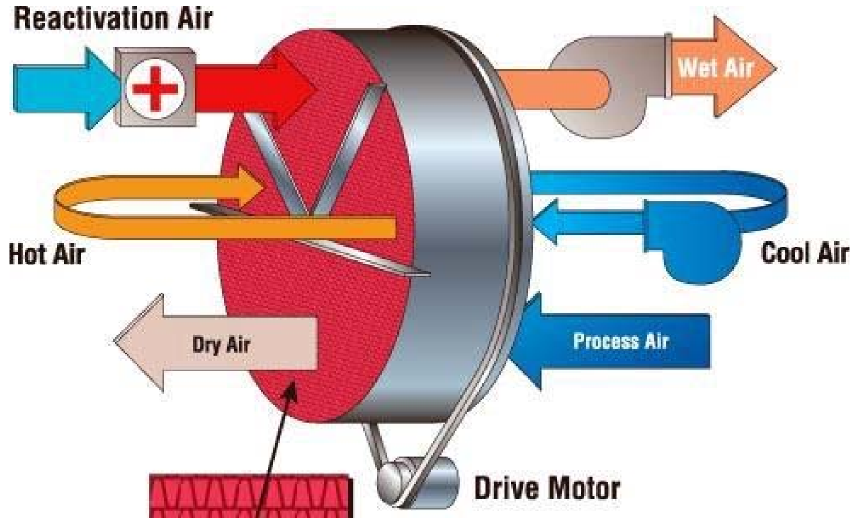

FIGURE 2 – Typical Desiccant DH process diagram

Refrigeration-based units operate by cooling the air below its dew point. These work by crossing incoming moisture laden air over evaporator coils to reduce the amount of moisture in the air by condensation. This condensation is collected and removed. The air exits the cooling coil section at a lower temperature, dew point and absolute humidity. It can be reheated even further to reduce the relative humidity. Such units are commonly used in environments of high heat and high humidity, such as a tropical location of 85% RH and 85^{o}F. These units have relatively low power consumption requirements – approximately one-half the power consumption of a desiccant unit with similar air flow ratings.

Dehumidification Control

Recent advancements in climate control technology have created very useful and beneficial tools which can save money. Specifically, one available system monitors the dehumidification, heating, and cooling equipment on a jobsite. Such units consist of a wall mounted control panel on the dehumidification unit itself, with a wall mounted sensor inside the tank, mounted on a bulkhead.

The amount of fuel savings associated with a controlled and monitored system can be significant. For example, once a 40% relative humidity is achieved the machine can save electricity by stopping dehumidification and only operating in air movement mode. The machine would then cycle on at 50% relative humidity to maintain the conditions well within the specified range. Units without such devices would run all night long, reaching relative humidity values sometimes as low as 5% (depending on air-tightness and size of the tank) – an unnecessary waste of energy for a specification requirement of below 50%. For a 24 hour shift, once the 50% relative humidity value is reached, the unit may only have to be running one hour out of an 8 hour shift to maintain acceptable conditions.

Other benefits of an automatically controlled and monitored system to those in shipbuilding and ship repair are:

- The system can alert the operator (via email, fax, or mobile phone) if the DH unit has gone down of ceases to function properly.

- The system can provide around-the-clock data capture of all necessary checks (e.g., inside dry bulb, RH and dew point) reducing or eliminating the need for onsite QC.

- The system can alert the operator if the unit is not holding the appropriate temperatures or pre-set relative humidity points. This could allow for repair to be dispatched to the site before the blast turns to rust bloom.

- For tanks, the system can send out an alert message when a tank surface temperature is approaching the dew point, of the tank is out of the humidity range specified.

APPENDIX B – TEST PROTOCOL CONSIDERATIONS

As discussed in the body of the report, formal testing has not been performed to determine the impact of relative humidity on tank coating performance. While the development of such a test sounds straightforward, there are a number of process variables which must be considered. This appendix presents some of the key issues which must either be controlled or identified as test variables in a test program.

Test Panel Preparation

At a minimum, the following should be controlled during the test panel preparation. Any of the items would be valid test variables. The scope of the test program would limit the number of variables considered.

Dew point spread – The surface temperature of the test panels should be controlled relative to the dew point. A 5°F dew point spread would be the worst case condition allowed.

Non-visible contaminants – These contaminants are normally controlled such that the conductivity of a water extraction test is below a certain value. It is convenient to select the worst case allowed for tanks (30 µS/cm). However, the non-visible contaminants which contribute to conductivity may not be the contaminants of importance. Contaminants which will draw moisture out of the air might be more important. These have not been identified.

Temperature – Blasting and application temperature should be controlled. Consideration should be given to three temperature levels – the lowest allowable, highest allowable and 77°F. It is difficult to pick one “worst case” temperature. For example, a lower temperature will be the worst case for coating cure but a higher temperature will be the worst case for rustback.

Relative Humidity – Obviously this is the test variable of interest. At a minimum testing needs to be performed at 50% and 85% relative humidity. An intermediate condition would also be appropriate.

Coating types – The testing should consider a range of Navy tank coatings such as the single coat systems, 2 coat high solids edge retentive coatings and legacy MIL-PRF-24441 used in feedwater tanks. Coatings from more than one manufacturer should be selected.

Dry film thickness – The applied thickness of the coatings should be near the lowest allowed as this is the worst case condition.

Surface preparation – Obviously abrasive blasting surface preparation will be performed to a near-white metal condition. However, the specific procedures and materials used for blasting should be identified. Solvent cleaning per SSPC SP-1 solvent cleaning should not be allowed after blasting is completed.

Initial surface condition – Because of the impact of residual contaminants on rustback, it is recommended that pre-weathered (i.e., rusted) test panels be used.

Time between surface preparation and coating application – The potential for rustback is impacted by the environmental conditions as well as the time exposed. It is important to control the time between surface preparation and coating application. It is recommended that this time be the longest time which could be reasonably expected on a tank painting project (i.e., days not hours).

Extent and composition of rustback – Many of the above conditions are designed to create various quantities and chemistries of rustback. Determining how much rust back can be tolerated without impacting coating performance is a key component of the test program. Understanding the extent and composition of rustback which is present is a pre-requisite to understanding its impact on coating performance.

Evaluation Criteria

The prepared test panels should be evaluated to see if the humidity level impacted the degree of coating cure or subsequent performance of the coating. The degree of coating cure can be evaluated using simple tests such as MEK double rubs or chemical spot tests. More sophisticated testing for cure such as electrochemical impedance spectroscopy or a chemical analysis of paint chips might also be considered. The performance of the coated test panels could be evaluated using any of the test procedures described in MIL-PRF-23236. Recommended procedures include cathodic protection compatibility (paragraph 3.5) and immersion resistance (paragraph 3.9). The potable water tests described in paragraph 3.4 should be considered for potable water coating systems.

APPENDIX C – NSRP SP-3 RELATIVE HUMIDITY WORKSHOP NOTES

Assessing the Need for 50% Relative Humidity During Tank Painting

Pete Ault & Gordon Kuljian
March 24, 2009

Shipyard Sponsor – Judie Blakey

Agenda

- Project Overview
- RH Workshop
- Historical Review

Project Overview

- Previous NSRP panel project has identified the requirement to maintain the relative humidity in a tank or void space at a maximum of 50 percent from the start of surface preparation to cure of the topcoat as one of the most expensive requirements in Navy Standard Item 009-32
- This project is intended to establish more cost-effective alternative environmental control requirements and propose them as an alternative to be included in Navy Standard Item 009-32.
- Task 1 – Review technical literature and reports
- Task 2 – Interview NSRP member shipyards
- Task 3 – Roundtable discussion of alternative requirement concepts
- Task 4 – Develop SSRAC proposal

Relevant NSI 009-32 Text

- SI 009-32, Note (26)
  - Maintain the relative humidity in the tank or void space at a maximum of 50 percent from the start of surface preparation to cure of the topcoat.
- SI 009-32, Note (38)
  - Maintain the relative humidity in the tank at a maximum of 85 percent from the start of abrasive blasting to cure of the topcoat. By allowing 85 percent vice 50 percent relative humidity, this will reduce the service life of the tank from 15-20 years to 10-12 years.
- Paragraph 3.1.4
  - Abrasive blast….and coat, prior to shipboard installations…. *Except for potable water tanks, feedwater tanks, and freshwater drain collecting tanks, the requirements of Notes (26) and (29A) do not apply to these materials.*
    - Notes (26) and (29A) require 50% relative humidity

Relative Humidity Control Workshop

Objectives

- Brainstorm to collect a range of perspectives on the issue of environmental controls during tank painting
- These will be explored in greater detail as part of the project

Ground Rules

- Express Ideas
- Ask for Clarification
- Avoid Judgment
- Avoid Debate
- Don’t be Afraid to Share Crazy Ideas
- Think Outside the Tank

Why do we care about relative humidity?

- Hold the blast/rusting of surface
- Avoid condensate
  - Robust process avoiding excursions
  - Does dew point compliance accomplish this?
- Paint cure more of an issue with standard paint than high solids
  - 2 coat high solids didn’t cure at 90%+ RH
  - Formula dependant
  - Water miscibility of components

What impact can relative humidity have on a project?

- Waterborne painting
- Footprint of equipment
- Restrict access into tank (i.e., ducting)
- Utility access (electrical/fuel)
- Personnel to monitor equipment
- Schedule (confidence that there won’t be weather delays)/ Risk Management
- Time of year/location of shipyard

What affects relative humidity in a tank?

- Power interruptions
- Weather
- Number of workers
- Pierside vs drydock
- Ship air conditioning (condensation)
- Ventilation/airflow
- Time of year
- Location of plate within ship (shell/interior/etc)
- Adjacent space
- Spills (transfer of fluids into tank)
- Cement based materials (e.g., CHT fairing cmpd)

How can we control relative humidity?

- Dessicant (disks, wheel,
- Heater
- Refrigerant
- Ventilation (Clean Dry Air – ambient or “manufactured”)
- Recirculate air
  - Probably want fresh air
- Small DH in tank
- Air Exchange Rate
- Lower temp gradient across boundaries (manage dew point)

What cost impacts are associated with RH control?

- DH Unit/equipment
- Electricity/Fuel
- Maintenance of equip
- Continuous monitoring
- More and/or larger access cuts
- Setup/disassembly
  - Crane service
- “Toxic” coating requires more exchanges increasing RH cost
- Ducting (doesn’t last long)
  - Maintaining air tightness
  - Not always easy (need to go through ship)
- Containment (scaffolding/plastic wraps) e.g., flight deck tenting
- Worker training/awareness (why are we doing this?)
- Cost more significant during touch-up

What do we do when the required RH is exceeded?

- Adjudication allowing process to continue
  - Monitor performance
  - Extend warranty period
- Re-establish conditions & re-work
  - Extend cure time
  - Re-blast as necessary (i.e, what doesn't meet SP-10)
  - Assess if there is a problem
    - How big is the excursion
  - Possibly remove and replace coating (rare)
    - Uncured material
    - 08 tank
- Delay project completion
- What happens depends on decision making process and technical ability of people involved

What would happen if we stopped monitoring and controlling relative humidity?

- Potential failures
  - Paint over rustback
  - Coating delamination
  - Osmotic blistering
  - Improper cure – lack of chemical resistance, etc.
  - Paint company wouldn't stand behind paint
  - Probably do something for worker comfort & safety (i.e., ventilation)
  - Could cause project extension/rework (uncured coating)
  - Amine blush (have to remove, may need to add amine blush test)
  - Greater risk for NAVSEA, customer, paint company & maybe contractor

If you were unable to measure RH, what would you do instead?

- Dew point spread
- Internal temperatures (substrate, ambient)
  - If substrate temperature is high enough (i.e., flight deck) RH may not matter
- Number of air exchanges
  - Driven by OSHA (<10% LEL)
  - Increase ventilation
- Don't paint in rain
  - Check weather
- Absolute humidity (grains of available moisture)

Will Test Panel Data Help Resolve the Issue?

- For 08 Issues, probably required
- Yes?
- Data does not need to "prove beyond a shadow of a doubt"
  - Need to quantify risk
- Should develop a test looking at the issue of a robust process
  - Let all other parameters (salts, DFT, welds, etc) be "worst" and vary RH from 85% to 50%

Other Comments?

- How far through the cure process do we need to maintain RH conditions?
- Excursions should be allowed for some time at some elevated RH
  - 55% for < 2 hrs can be locally adjudicated per DFS decision tree
  - Perhaps 85% for < 24 hrs is acceptable?
    - Ties in with ingles notion of time-humidity
  - Perhaps excursions are OK if dewpoint spread condition is met (or exceeded [e.g., 10 degrees])
- In a situation where the paint is applied immediately after blasting (e.g., shop or small tank) higher humidity is probably fine
- One attendee indicated that he believed "non-visible oxides" of steel would form regardless of RH
- Notion of acceptance criteria for blast being more important of "how we got there"
- With legacy systems RH control after primer was important to eliminate pinpoint rusting

APPENDIX D – SSRAC PROPOSALS SUBMITTED BY NSRP

SSRAC # 157
H

NAVSEA Standard Specification for
Ship Repair and Alteration Committee
(SSRAC)

2009 SSRAC MEETING

NSRP SP-3 Panel
(ACTIVITY)

Submitted by: Steve Cogswell (NAME/CODE)   Date: 20MAY2009

Item No: 009-32   Title: Cleaning and Painting Requirements

1. Paragraph No: Note (26)   Page No: 28

2. Problem and Rationale:

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." It is unclear what degree of cure is required. For some products, the commercial equivalent product data sheet does not place the 50% relative humidity restriction on the cure time. If the humidity requirement could be relaxed after "Cure to Recoat," as much as 6 days of humidity control could be eliminated from the process. Furthermore, the requirement to maintain 50% RH during final touch-up may also add days to the requirement. This has obvious cost and schedule impacts.

3. Proposed Change:

Note (26) Maintain the relative humidity in the tank or void space at a maximum of 50 percent from the start of surface preparation until topcoat "Cure to Recoat" time. 85% maximum RH shall be considered adequate for final coat touch-up iterations.

Gk Comment- backing from coating manufacturers will give this proposal more strength - perhaps a letter from SW or IP.

MAJOR ☒ MINOR ☐

COST IMPACT? YES ☒ NO ☐

If Yes, describe cost impact
If adjusted, as much as 6 days of humidity control may be eliminated, allowing equipment to be used for other tank work.

SCHEDULE IMPACT? YES ☒ NO ☐
If Yes, describe schedule impact
For projects where space or equipment limitation drive project schedule, more tanks will be able to be completed within the same timeframe.

SUBCOMMITTEE ACTION TAKEN:

STEERING COMMITTEE ACTION/INITIAL:

SSRAC # 158
H

NAVSEA Standard Specification for
Ship Repair and Alteration Committee
(SSRAC)

2009 SSRAC MEETING

NSRP SP-3 Panel
(ACTIVITY)

Submitted by: Steve Cogswell (NAME/CODE) Date: 20MAY2009

Item No: 009-32 Title: Cleaning and Painting Requirements

1. Paragraph No: Note (26) Page No: 28

2. Problem and Rationale:

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." The primary reason for this requirement is to ensure a robust process where all surfaces of a complex tank remain within acceptable limits. This requirement can be unnecessarily costly for small areas of preservation work (touch up and rework). The present proposal relaxes the requirement for small areas defined in a manner similar to paragraph 3.6.2.4.

3. Proposed Change:

Append Note (26) to state "For new and disturbed areas which are individually 2 sq ft or less and cumulatively are less than 0.03 percent of the total tank surface area, (as defined in ASTM D-610/SSPC-VIS-2), 85% maximum relative humidity shall be considered adequate."

MAJOR ☒ MINOR ☐

COST IMPACT? YES ☒ NO ☐

If Yes, describe cost impact
The incremental cost to control humidity is proportionally greater for small repair and touch-up work. As a result, it drives the cost per square foot up considerably. Furthermore, these small areas could probably be planned such that no equipment would be required to maintain 85% relative humidity.

SCHEDULE IMPACT? YES ☒ NO ☐
If Yes, describe schedule impact
In addition to cost, staging of equipment and waiting for the humidity to be lowered in a space extends schedule for what should be a small, quick touch-up.

SUBCOMMITTEE ACTION TAKEN:

STEERING COMMITTEE ACTION/INITIAL:

SSRAC # 159
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NAVSEA Standard Specification for
Ship Repair and Alteration Committee
(SSRAC)

2009 SSRAC MEETING

NSRP SP-3 Panel
(ACTIVITY)

Submitted by: Steve Cogswell (NAME/CODE) Date: 20MAY2009

Item No: 009-32 Title: Cleaning and Painting Requirements

1. Paragraph No: Note (26) Page No: 28

2. Problem and Rationale:

Note 26 requires that 50% relative humidity be maintained. Joint Technical Committee Report SSPC-TR 3/NACE 6A192, "Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces" states that surface relative humidity is more critical than ambient relative humidity. because it is impractical to measure relative humidity at a surface, it is more convenient to measure dew point differential. The standard suggests that a dew point differential of 17 to 20 degrees F likely corresponds to 50% relative humidity at the surface.

3. Proposed Change:

Append Note (26) to state "As an alternative to 50% relative humidity, the contractor may show that the surfaces maintain a dew point spread of greater than 17 degrees F."

MAJOR ☐ MINOR ☒

COST IMPACT? YES ☐ NO ☒

If Yes, describe cost impact

SCHEDULE IMPACT? YES ☐ NO ☒
If Yes, describe schedule impact

SUBCOMMITTEE ACTION TAKEN:

STEERING COMMITTEE ACTION/INITIAL:

SSRAC # 160
H

NAVSEA Standard Specification for
Ship Repair and Alteration Committee
(SSRAC)

2009 SSRAC MEETING

NSRP SP-3 Panel
(ACTIVITY)

Submitted by: Steve Cogswell (NAME/CODE) Date: 20MAY2009

Item No: 009-32 Title: cleaning and Painting Requirements

1. Paragraph No: Note (26) Page No: 28

2. Problem and Rationale:

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." The primary reason for this requirement is to ensure a robust process where all surfaces of a complex tank remain within acceptable limits. Smaller, less complex tanks are easier to coat, require only one blast/paint iteration, and should not be susceptible to problems when preserved under the less restrictive commercial standard of 85% relative humidity.

3. Proposed Change:

Append Note (26) to state "For tanks and voids under 2,000 square feet which are blasted and coated in one evolution, 85% relative humidity shall be considered adequate if ventilation is maintained from the start of surface preparation through cure of topcoat."

MAJOR ☒ MINOR ☐

COST IMPACT? YES ☒ NO ☐

If Yes, describe cost impact
Smaller tanks may not require the added expense of dehumidification equipment.

SCHEDULE IMPACT? YES ☒ NO ☐
If Yes, describe schedule impact
Smaller tanks will not require the added time associated with lowering the relative humidity.

SUBCOMMITTEE ACTION TAKEN:

STEERING COMMITTEE ACTION/INITIAL:

SSRAC # 161
H

NAVSEA Standard Specification for
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(SSRAC)

2009 SSRAC MEETING

NSRP SP-3 Panel
(ACTIVITY)

Submitted by: Steve Cogswell (NAME/CODE) Date: 20MAY2009

Item No: 009-32 Title: Cleaning and Painting Requirements

1. Paragraph No: Note (26) Page No: 28

2. Problem and Rationale:

Note 26 requires that 50% relative humidity be maintained "…from the start of surface preparation to cure of the topcoat." The primary reason for this requirement is to ensure a robust process where all surfaces of a complex tank remain within acceptable limits. For tanks or portions of tanks blasted and painted in a shop this requirement can be an unnecessary burden. If we assume simple tank geometries and shop steel is coated within a few hours of blasting, the robustness provided by the 50% RH requirement may not be required.

3. Proposed Change:

Append Note (26) to state "tanks and tank components which are blasted and primed in a shop shall be allowed to reach 85% relative humidity provided the other requirements of the specification are maintained."

MAJOR ☒ MINOR ☐

COST IMPACT? YES ☒ NO ☐

If Yes, describe cost impact
Shipyards will not have to incur the cost of controlling relative humidity in controlled shop painting environments.

SCHEDULE IMPACT? YES ☐ NO ☒
If Yes, describe schedule impact

SUBCOMMITTEE ACTION TAKEN:

STEERING COMMITTEE ACTION/INITIAL:

SSRAC # 163
H

NAVSEA Standard Specification for
Ship Repair and Alteration Committee
(SSRAC)

2009 SSRAC MEETING

NSRP SP-3 Panel
(ACTIVITY)

Submitted by: Steve Cogswell (NAME/CODE) Date: 20MAY2009

Item No: 009-32 Title: Cleaning and Painting Requirements

1. Paragraph No: Note (38) Page No: 28 and Table 4, Line 7

2. Problem and Rationale:

Note 38 and Table 4, Line 7 incorporate the notion that by allowing 85 percent vice 50 percent relative humidity, this will reduce the service life of the tank from 15-20 years to 10-12 years. Commercially, similar tank coatings are applied with the 85% relative humidity requirement and a 15-year warranty is provided. Based on this experience, we propose adjusting the referenced shortened life to "12 to 15 years."

3. Proposed Change:

Note (38) Maintain the relative humidity in the tank at a maximum of 85 percent from the start of abrasive blasting to final cure of the topcoat. By allowing 85 percent vice 50 percent relative humidity, this will reduce the service life of the tank from 15-20 years to 12-15 years.

MAJOR ☒ MINOR ☐

COST IMPACT? YES ☒ NO ☐

If Yes, describe cost impact
If adjusted, it is likely that more RMC's will specify the less restriuctive relative humidity requirement which should reduce the cost of tank painting.
SCHEDULE IMPACT? YES ☐ NO ☒
If Yes, describe schedule impact

SUBCOMMITTEE ACTION TAKEN:

STEERING COMMITTEE ACTION/INITIAL:

APPENDIX E – INTERPRETING RELATIVE HUMIDITY REQUIREMENTS IN NAVY STANDARD ITEM 009-32

Notes (26) and (29A) of Navy Standard Item 009-32 FY10 require the contractor to "Maintain the relative humidity in the tank or void space at a maximum of 50 percent from the start of surface preparation to cure of the topcoat." Maintaining a lower relative humidity may help prevent rustback of a blasted surface, prevent amine bloom on the coating and increase the factor of safety associated with condensing humidity on the surface. This stricter relative humidity requirement provides a greater margin of safety when coating tanks and voids. In some cases the cost to achieve and maintain 50% relative humidity are not warranted given the relative risk of rustback, amine bloom or condensation. In those cases, the standard item either has existing language to relax the requirement or will be incorporating such language.

In the current version of Standard Item 009-32, the following exceptions to Notes 26 (surface ships) and 29A (submarines) exist:

1. Paragraph 3.1.4 specifically states that Notes (26) and (29A) do not apply to material blasted and painted prior to shipboard installation. This would include components such as pipe hangars, access cuts, and hatches which are painted in the shop.
2. Paragraph 3.6.2.4 is not intended to require 50% relative humidity be maintained for new and disturbed areas of individual areas 2 sq ft or less totaling less than 0.03 percent of the total surface area. Paragraph 3.6.2.4 states that the requirements of 3.10.1.1 shall be maintained but not documented. 3.10.1.1 only requires 85% relative humidity. To clarify this requirement, the FY11 version of 009-32 will specifically state in paragraph 3.6.2.4 that the requirements of Notes (26) and (29A) do not apply.

Based on the results of this project, the requirement for maintaining 50% relative humidity will be further relaxed in the FY11 version of 009-32 by making the following changes:

1. Note (26) and (29A) will be modified to clarify that the 50% relative humidity condition only needs to be maintained from surface preparation g-point acceptance until the "cure to recoat" time for the final touch-up has been reached. During the remaining cure to immersion, 85% relative humidity shall be adequate.
2. Table 4, line 11 (CHT/MSD tanks) under surface preparation references note (38) instead of note (26). Table 4 Line 17 (Chain Lockers) already does not require 50% relative humidity.