Setting New Standards: Icing and Freezing Rain Testing Automation

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Abstract

The purpose of a MIL-STD Icing and Freezing Rain Test is to evaluate the effect of icing against the operational capability of material. Likewise, these tests evaluate the effectiveness of de-icing equipment and/or the de-icing techniques available to the user in the field. Some of the biggest challenges in this testing arena are a lack of automated process controls, operator safety, consistent and reliable ice formation, tight temperature control, and excessively long test times to reach the desired ice accumulation.

The fully automated Icing and Freezing Rain (IFR) Test Chamber developed by System of Systems, Inc. addresses all these challenges. It can simulate, on a reliable and repeatable basis, the conditions of icing and freezing rain on a given test item while satisfying all requirements in the MIL-STD 810H Method 521.4 for Icing/Freezing Rain Testing. The IFR will institute new standards in this field of testing.

Background

Prior to 1980 there was little extensive freezing and icing rain testing research. One of the pioneers in ice testing was the Tennessee Valley Authority (TVA). The TVA had high voltage switches that were more than 60 feet tall located on mountaintops and installed using helicopters. Failure to the switches caused by freezing rain and ice was both expensive and inconvenient as it caused power outages for TVA electric consumers.

The testing methods used by the TVA included spraying water from fire hoses onto high voltage switches outdoors when the ambient temperature was below freezing. This method proved ineffective as they were unable to replicate ice that was formed under naturally occurring weather conditions. The results from the TVA testing research, in collaboration with the Climatic Laboratory at the Eglin Airforce Base, were the basis for the freezing rain and ice procedures introduced in the MIL-STD-810D in 1983. However, the initial test procedure only addressed Glaze Ice conditions. It was not until 1989 that Rime Ice was introduced in the MIL-STD-810E.

Icing and Freezing Rain testing has continued to be one of the more difficult tests to simulate. In the 30 plus years since being introduced to the MIL-STD there has been little advancement in this field of testing. Subsequently, much of the research for the IFR was conducted by speaking with various members of the environmental testing community. In doing so it was apparent that there was a need for more convenient and repeatable means for performing icing and freezing rain tests.

This test has typically been performed in a manual setting where a standard low temperature test chamber is used. An operator physically enters the chamber to spray the test item using a hand pump sprayer to form ice, resembling the methods used by the TVA decades ago. Other methods include a chilled water storage tank used to pump cold water to a stationary nozzle that sprays the test item. The operator would move the nozzle to different positions to try to get even ice distribution. With the information available it is assumed that no repeatable automation process has ever been used. The main challenges with the existing test methods, as well as the solutions provided with the IFR test chamber, are as follows:

1. *Accelerated Ice Formation Using Continuous Spray*

   The ability to continuously spray a test item during the ice accretion process has proved to be difficult with previous designs. The IFR system incorporates several unique processes that promote accelerated ice accretion. Our diagram (Figure 1) shows an overhead view of a horizontal air flow technique, a horizontal water spray arrangement, and a rotating test item. The soak zone of the test item is coated with a liquid droplet and freezes when the leading-edge position reaches the freeze zone. The item is continuously rotating at a slow speed providing accelerated ice formation.

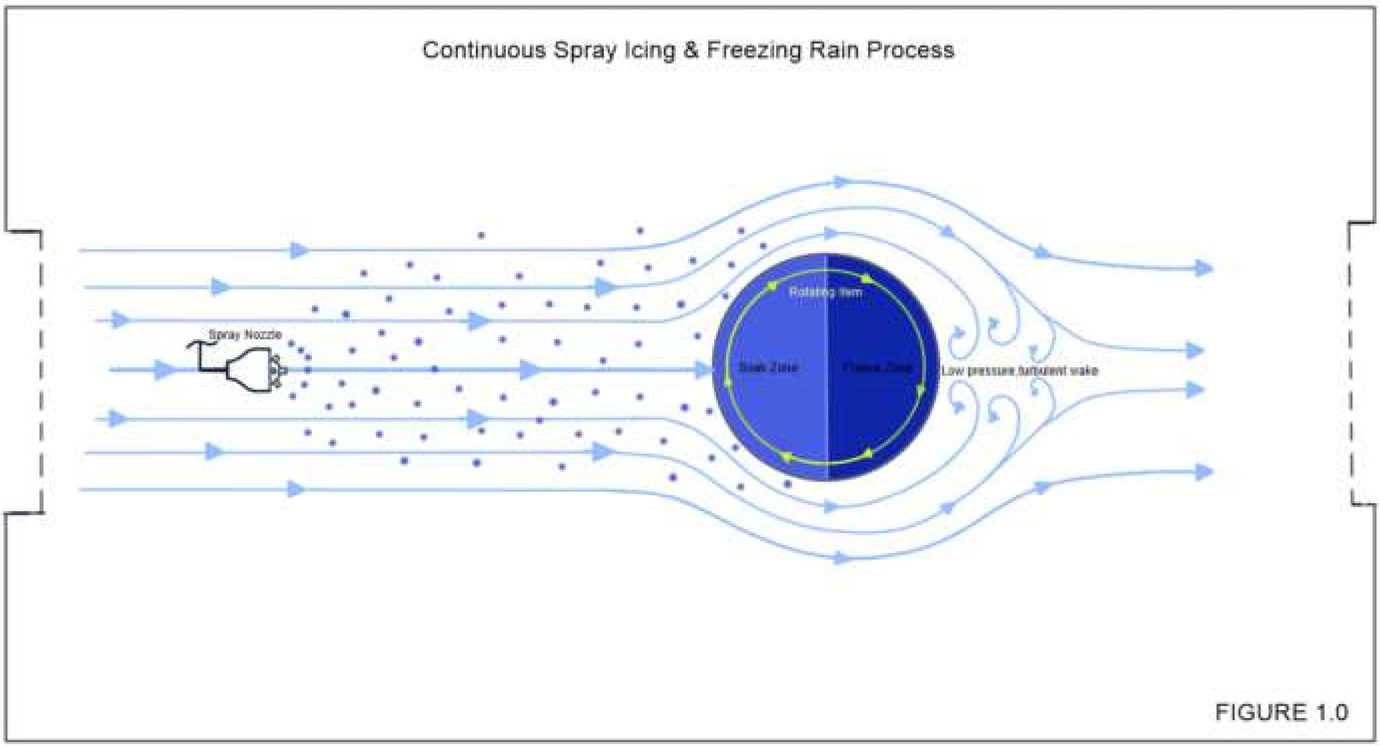

FIGURE 1.0

2. *The ability to keep the Evaporator coils from freezing during the testing.*

   This is a typical problem seen with all refrigeration evaporator coils when humid air passes over the coils. The humid air condenses, freezes, and the system stops operating properly. To keep coils from freezing in a high humidity system, first capture water droplets from the air stream and remove them. Second, use built in defrost coils on the evaporator to defrost the coil during operation. This can be accomplished while maintaining chamber temperature.

3. *The ability to keep nozzles and piping inside the chamber from freezing without the use of heating systems.*

   Since heating systems raise the water temperature of the spray water and decrease the ability to build ice at controlled temperatures a Reverse-Flow Nozzle Drain Pump may be used to evacuate water from the water lines and nozzles. This ensures that there is no freezing of the nozzle piping or nozzle outlets if the operator chooses to pause the spray nozzles.

4. *The ability to build a specific amount of ice over a pre-determined time. Existing methods can take days if not weeks to accumulate 3 inches of ice.*

   By eliminating manual operator applications of water to the test item the fully automated process continuously operates the test without interruptions while maintaining the set test requirements. This allows for ice accumulation rates that vary from 10mm to 12mm (.39 - .47 in) per hour. Horizontal spray and rotation of the test item greatly improves ice accumulation rates. Below are the MIL-STD ice thickness recommendations. The estimated IFR time intervals to achieve each accumulation is in parenthesis.

   a. 6 mm (0.24 in) - represents general conditions, light loading. **(< 1 hour)**

   b. 13 mm (0.5 in) - represents general conditions, medium loading. **(1-2 hours)**

   c. 37 mm (1.5 in) - represents heavy ground loading and marine mast loading. **(3-4 hours)**

   d. 75 mm (3 in) - represents extremely heavy ground loading and marine deck loading. **(6-7 hours)**

5. *The ability to evenly coat a test item with ice.*

   Placing the test item in the center of a rotating table while spraying horizontally provides even ice distribution on the sides and top surfaces of the test item. The underside of a test item will build ice sickles or ice bridges to the surface below the test item. It is recommended that you elevate the test item to maintain an even accretion on all surfaces. If you are performing a 3-inch ice test, allow for a 3-inch air gap between the test item and support surface before starting a test.

6. *The ability to safely enter a test chamber with ice build-up on the floor.*

   The flooring in the test chamber is both heated and coated with an Anti-Slip epoxy coating. The heated floor is operational during a test to capture and recirculate chilled water to save energy and maintain chilled water temperature. At no time during or after a test is there any ice buildup in the immediate area of the test item, which allows an operator to safely enter the chamber if required.

7. *The ability to make Glaze (Clear) Ice.*

   Glaze Ice poses the most serious threat due to its high density (as high as 0.92 g cm^3) and weight. Glaze ice is formed by a combination of large drop sizes, rapid accretion, slight supercooling, and slow dissipation of heat (Toliver, 1988). Using this theory, the IFR implements the following techniques to create glaze ice. The nozzle that is specifically used for the IFR disperses a larger droplet size of 1.6mm and is pushed out at a rate of 2.5in/h. The laminar air flow that is forced across the test item both supercools the water droplet as well as drops the temperature of the test item within the test parameters.

8. *The ability to automate the test process.*
   Because the system is automated it can be tailored to meet different Systems Requirement Documents (SRD). The SRD defines system level functionality and performance requirements.

9. *The ability to automatically drain the water after a test.*
   The system's discharge pump will remove excess water from the test chamber during the test. The chilled wastewater is filtered and recycled back into the test. At the end of the test the discharge pump will automatically drain and dispose of all water from the system as the test item is melting.

Water Delivery Rate

Water Delivery rate is suggested to be 25 mm/h (1 in/h) in the MIL-STD for Glaze Ice. We have found that rates up to 2.5 in/h are reasonable and capable of building ice at an increased rate. The IFR delivers 2.5 in/h during the Glaze Ice Test. The different nozzles distribute droplet sizes accordingly and water delivery rates are determined by the spray pattern cross section area.

Glaze Ice Nozzle has a 1.6 mm Droplet size

Hard Rime Nozzle has a .79 mm Droplet size

Soft Rime Nozzle has a .41 mm Droplet size

Water Delivery Method

The water delivery method in the IFR has nozzles that spray horizontally in conjunction with a horizontal laminar airflow ranging from 1-3 m/s. The dwell time of the droplet in a -10°C horizontal air stream provides supercooling, allowing the droplet to freeze on contact with the test item. While the test item is rotating it is impacted with a uniform spray.

Test instrumentation

Sensors and instrumentation in the IFR are suitable for the intended environments. The IFR system incorporates resistance temperature detector (RTD) sensors to accurately depict process temperatures with an excellent degree of repeatability and interchangeability in harsh environmental elements. All sensors (including test item temperature transmitters, air temperature transmitters, air velocity transmitter, water level switches, and ice measurement sensors) are automated and work simultaneously with the system processes to provide repeatable test results.

Tolerances, interruptions

The full automation allows for the test to be conducted without interruption. This upholds the standardization and validity of the testing. Interruptions in Ice and Freezing rain tests affect the chamber test condition tolerances.

However, the IFR does allow for in-tolerance interruptions. The test chamber can hold test conditions in tolerance with the chamber door open and an operator inspecting or operating the test item (with the option to “pause” the spray process). Since it is an in-tolerance interruption it does not constitute as a test interruption. This means that the test duration does not need to be modified as proper test levels are maintained during the interruption. This also allows for scheduled interruptions to the test without deviating from the test tolerances, thus saving time as prescribed conditions do not have to be reestablished. Undertest conditions (tolerances fall below the minimum tolerance value) are eliminated.

Combined Tests

The system has the option to combine tests. Combinations of tests allow the user to obtain a more realistic simulation of environmental effects than can be collected from a single test. Combination testing should be encouraged as they can be expected in an operational environment. Combined environments include MIL-STD Rain, Blowing Rain, Drip, Blowing Sand & Salt Fog.

Different Ice Formations

Table 1: Glaze and Rime Ice Characteristics

Characteristic	Type of Ice	
	Glaze	**Rime**
Droplet Size	1.6mm	.41 - .79mm
Accretion Temp	0 to -10	0 to -10
Opacity	Clear	Opaque
Hardness	Brittle	Compressible
Wind Velocity During Accretion	2 m/s	2 m/s

Table 2: Different Types of Ice (Toliver, 1988)

GLAZE	RIME
Clear Ice – no air	*Opaque Rime* – Dull and White
Transparent Ice – moderate air trapped	*Kernel Rime* – Similar to kernels of corn on a cob. Crumbles as opposed to cracks
Milky Ice – Substantial air trapped	*Feathery Rime* – More open and fragile than Kernel Rime

Measuring Ice Density

Density is defined as the ratio of an object's mass to its volume. In other words, density is the ratio between mass and volume, or mass per unit volume (Density = Mass/Volume).

A slightly deviated version of the Archimedes Principle was developed (Figure 2) to measure the density of ice layers in seasonal snowpacks (Watts, 2015). Place a centrifuge tube with mineral spirits in the chamber. The mineral spirits prevent the ice sample from melting and giving skewed results while taking a volume measurement. Mineral Spirts freeze around -70°C.

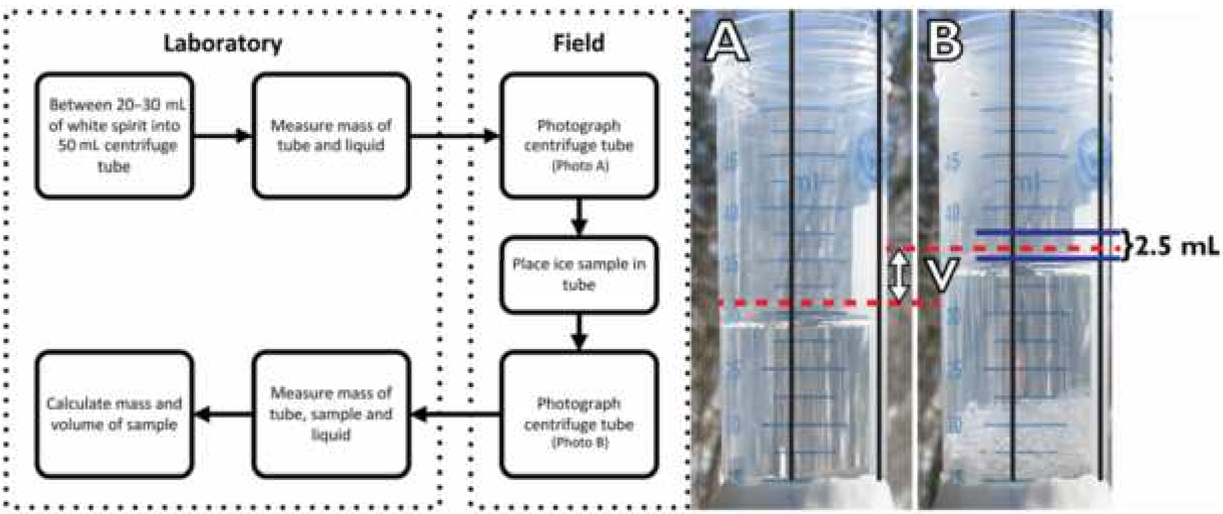

FIGURE 2

Conclusion

The MIL-STD-810H for Ice and Freezing Rain Testing is meant to evaluate how ice and freezing rain can compromise the functionality of a test item. Our Ice and Freezing Rain test process will provide consistent and optimal results. The IFR's automation solves existing problems with the previous testing methods and sets new standards in the industry for icing and freezing rain testing.

References

Toliver, R. (1988) *Ice is Ice?* [White Paper] Retrieved January 30, 2020 from Journal of the IEST: https://iestjournal.org/doi/pdf/10.17764/jiet.1.31.3.y1421304rgg67121

Watts, T., Rutter, N., Toose, P., Derksen, C., Sandells, M., Woodward, J. (2015) *Brief Communication: Improved Measurement of Ice Layer Density in Seasonal Snowpacks* [White Paper] Retrieved February 13, 2020 from ResearchGate: https://www.researchgate.net/publication/308081646_Brief_communication_Improved_measurement_of_ice_layer_density_in_seasonal_snowpacks