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Fiberboard Humidity Data for 9975 Shipping Packages

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Summary

The 9975 surveillance program is identifying a technical basis to support extending the storage period of 9975 packages in KAC beyond the currently approved 15 years. A key element of this effort is developing a better understanding of degradation of the fiberboard assembly under storage conditions. This degradation is influenced greatly by the moisture content of the fiberboard, which is not well characterized on an individual package basis.

Two efforts have been undertaken to better understand the levels and behavior of moisture within the fiberboard assemblies of the 9975 shipping package. In the first effort, an initial survey of humidity and temperature in the upper air space of 26 packages stored in KAC was made. The data collected within this first effort help to illustrate how the upper air space humidity varies with the local ambient temperature and package heat load.

In the second effort, direct measurements of two test packages are providing a correlation between humidity and fiberboard moisture levels within the package, and variations in moisture throughout the fiberboard assembly. This effort has examined packages with cane fiberboard and internal heat levels of 5 and 10W to date. Additional testing is expected to include 15 and 19W heat levels, and then repeat the same four heat levels with softwood fiberboard assemblies.

This report documents the data collected to date within these two efforts.

Background

The 9975 surveillance program [1] includes elements to predict the service life of 9975 shipping packages used to store special nuclear materials in the K-Area Complex (KAC). One key area of inquiry is the potential degradation of the fiberboard overpack in these packages. The fiberboard contains moisture which can migrate within the package during storage under the influence of internal temperature gradients [2-4]. The moisture content of as-manufactured fiberboard is less than 10 wt% [5]. However, the moisture content can change during storage and handling as the fiberboard approaches equilibrium with the humidity of the surrounding environment. This process can continue after the overpack assembly is loaded into the 9975 package, although the 9975 drum provides a significant degree of isolation from the environment such that the rate of moisture exchange is greatly reduced [6].

The thermal gradient that develops within the fiberboard overpack will lead to internal moisture redistribution, with the moisture preferentially concentrating in the cooler areas. This behavior can lead to sufficient concentration of moisture as to support the growth of mold. In addition, some constituents present in the fiberboard (such as chlorides) can leach out and concentrate with the moisture at levels that could lead to degradation of the stainless steel drum. Such behaviors have been observed in test packages with a nominal initial moisture level that contained a 19 watt internal heat load [3, 4], the maximum heat load for which the 9975 is approved. In order to better understand the degree to which packages in storage are susceptible to this behavior, several efforts have been undertaken as part of the surveillance program. These include the following:

- The relative humidity in the air space above the fiberboard overpack was measured in a number of packages stored in KAC. This was accomplished by removing a caplug from the side of the drum and inserting a humidity probe through the caplug hole. The external drum temperature was also recorded.
- Two fiberboard assemblies are being tested to measure moisture and humidity profiles for several internal heat loads ranging from 5 to 19 watts. These assemblies started with different initial moisture content, one with a "typical" moisture level, and one with an elevated moisture level. These two assemblies are fabricated from cane fiberboard. After completion, two additional softwood fiberboard assemblies will be tested in the same manner.

This report summarizes the humidity and temperature data collected in KAC, and includes some preliminary humidity data from the second effort. It is hoped that data from the second effort will provide understanding to relate humidity in the upper air space with moisture conditions in the fiberboard.

Temperature / Humidity Data in Storage

Humidity and temperature data were collected in KAC on February 9, 2015. Two separate entries were made, one in the morning, and the second in the afternoon. Personnel present and involved in the measurements include W. Daugherty (SRNL). E. Hackney and B. Eberhard (NMM Engineering), C. Butler (K Facility Operations) and several facility Operators and RadCon personnel. Data were collected in two ways:

- A humidity probe was inserted through a caplug hole into the upper air space of the 9975 package to record the temperature and relative humidity at that location (see Figure 1). A rubber stopper on the probe cable ensured a consistent insertion distance (6 inches) and sealed the caplug hole to minimize influence from the room air.
- An infrared pyrometer was used to measure the drum surface temperature. This non-contact measurement was typically taken at mid-height on the label.

A list of packages of interest had been prepared which would provide data on packages with a range of heat loads and at differing elevations in several areas of the storage facility. Typically, moving one stack of pallets (with four packages per pallet, stacked 3 high) would provide access to the 12 packages in that stack and 24 of the 36 packages in adjacent stacks. For packages of interest, one caplug was pushed into the package, the probe was inserted through the caplug hole, and a replacement caplug was installed from the package exterior.

The fiberboard assembly height within a package can vary, with the result that the upper air space varies accordingly. In some of the packages, the fiberboard assembly was high enough that it blocked access through the caplug hole, and no humidity data was collected from those packages. Preliminary tests performed on an empty package showed that the humidity meter would take a little time to reach a steady reading. Typically, the meter would be within ~1 percentage point of equilibrium within 3 minutes. Therefore, a wait time of 3 minutes was used between probe insertion and recording the data. Drum surface temperatures were measured on the packages for which humidity data were collected, as well as a number of additional packages that were convenient to access.

Three humidity probes were used for measurement. All were compared against each other and agreed to within ~1 percentage point. One or more of the probes were placed in packages at one time, depending on the targeted packages in each stack. The general room environment was ~64 %RH at 64 °F during the morning session, and ~65 %RH at 65 °F in the afternoon.

Humidity and temperature data are summarized in Table 1 for packages that included upper air space measurements. Packages for which only drum surface data are available are summarized in Table 2. The drum surface measurements were taken at mid-height on the drum label. In one case (package 9975-01979) the drum surface temperature was also measured on the adjacent bare metal. The temperature was 1.8 degrees F cooler on the bare metal.

The external drum temperature data and upper air space relative humidity data are plotted in Figure 2 as a function of package internal heat load. In addition, the upper air space absolute humidity is plotted in Figure 2c. For each of these parameters, there is a general trend of increasing value with increasing heat load, as shown by the trend lines. However, there is also significant scatter around the trend lines.

Temperature / Humidity Profile Data in Test Packages

Two 9975 test packages had been previously modified to allow placement of an internal heater (in a dummy 3013 container), several thermocouples throughout the package and several additional features for monitoring package component performance [2, 3]. The fiberboard in these packages was replaced, and the packages were further modified to provide channels for a humidity probe along the fiberboard ID and OD surfaces. These channels extend through the drum lid and can be closed off between measurements, to maintain normal patterns of air circulation within the package.

The fiberboard assemblies used for this effort were removed from packages that had been removed from service due to NCR conditions not relating to the fiberboard (9975-03892 and 9975-03449) and are fabricated from cane fiberboard. Both had a typical initial moisture content of ~8 – 9 % wood moisture equivalent (WME), or ~8 – 8.6 wt% moisture. One assembly was placed into test with this moisture condition, while the other was conditioned in a high humidity environment (enclosed in a plastic bag with a water source) until a moisture content of ~13 – 15 %WME (~11.3 – 12.6 wt%) was reached. This moisture level was targeted to provide an example of elevated moisture similar to that which might be expected in service. It is expected that moisture segregation during testing will produce regions of both higher and lower moisture content.

Once testing of each package begins, the package remains closed with periodic monitoring of internal temperature and humidity until an equilibrium condition is reached. The initial test condition includes a 5 watt internal heat load. A significant degree of fluctuation in internal temperatures was observed due to varying room ambient temperature. However, temperature and humidity gradients developed and stabilized within a few weeks. An insulating blanket was subsequently placed on the side and top of the drum to provide a slightly elevated temperature environment, thus extending the temperature range over which data could be collected. Fiberboard temperatures at two locations (at the bottom of the ID surface, and on the upper assembly OD surface) are shown for each package in Figures 3 and 4.

Once equilibrium data were collected with the 5W heat load (both with and without the insulating blanket) the package was opened to make limited direct measurements of the fiberboard moisture content, and then the heat load was increased to 10W and the process repeated. Data has been collected to date for the 5 and 10 watt conditions. Both temperature and relative humidity values can vary within the package, especially with an internal heat load (Figure 5). However, it is observed that the absolute humidity (a function of temperature and relative humidity) tends to be much more uniform throughout the package. Accordingly, typical absolute humidity data are used to illustrate the fiberboard behavior for the different environments tested to date in the two test packages (Figures 6 and 7).

Discussion

For packages in storage, the heat load is known, and the ambient temperature can be estimated. However, the moisture content of the fiberboard is not known for most packages. When manufactured, ASTM C208-95 specifies a maximum fiberboard moisture content of 10 wt% (~11 %WME). However, there are no requirements to control the moisture content subsequently, and the fiberboard moisture content will tend to approach equilibrium with the surrounding environment.

After manufacture, the fiberboard layers are laminated with a water-based glue, which provides a modest increase in the moisture content of the assembly. Since most of the 9975 packages in storage were manufactured, loaded and placed in storage within a relatively short time, it is likely that the majority have remained close to their initial fiberboard moisture value, although a range of moisture levels will exist. This is supported by destructive examination data from the surveillance program for which typical fiberboard moisture content ranges from about 9 to 16 %WME (~9 to 13 wt%). Similar values are also seen in field surveillance of 9975 packages in KAC, but since these measurements do not include much of the lower fiberboard assembly, they are less conclusive as to the overall moisture content.

Published data for wood in an outdoor atmosphere show the equilibrium moisture content will vary seasonally between 12 and 14 wt% in this area (taken as an average of reported behavior for Columbia SC and Augusta, Ga) [7]. Since cellulose is the primary constituent of wood and fiberboard (both cane and softwood based) products, it is expected that fiberboard will behave similarly. However, with indoor storage and at least modest climate control (heating and cooling), the higher humidity levels will be reduced somewhat. Therefore, it is expected that conforming packages will not experience significant moisture gain from the environment while in approved storage conditions.

Variation in fabrication, storage and handling conditions will lead to changes in the fiberboard moisture content, although such changes will occur very slowly once the fiberboard assembly is enclosed in the 9975 drum.

The degree of scatter in Figure 2 indicates relatively little correlation between a package heat load and the internal humidity level. This reduces the likelihood of characterizing the fiberboard condition just through correlation with the internal heat load. In an attempt to improve this likelihood, temperature and humidity data have been sorted by the following parameters, looking for trends with less scatter:

- Fiberboard type, cane vs softwood (Figure 8)
- Package elevation, bottom, middle or top position in a 3-pallet stack (Figure 9)
- Location within the storage facility, characterized by its row designation (Figure 10)

Of these parameters, there is significant improvement in the correlation between heat load and internal humidity for specific storage rows. For packages within a specific row, the drum surface temperature, upper air space relative humidity and upper air space absolute humidity all show a consistent increasing trend with increasing internal heat load. This rate of increase is similar for the different rows. This suggests the overall variations may be driven in part by the ambient temperature in the immediate vicinity of a stack of pallets.

These results were provided to a statistician (E. Kelly, Los Alamos National Laboratory) for review in combination with ongoing efforts to identify candidate packages for future surveillance activities. These humidity data did not alter the statistical attractiveness of the packages already selected for examination. However, one package with a higher humidity level was selected to replace another package recommended for surveillance but unavailable for other reasons.

Segregation of moisture within the fiberboard has been observed with 12 and 19 watts internal heat that increased local moisture concentration to the point that mold growth occurred [2, 4]. In the presence of a thermal gradient, the moisture develops a gradient with higher concentrations in the cooler areas. This would be expected to some degree at any internal heat level. Moisture measurements on packages removed from KAC for destructive examination have shown that this moisture gradient can persist for an extended period (several months or more) after the heat load is removed. On occasions where elevated moisture and/or mold has been observed in KAC, these occurred on the outer and bottom surfaces, which would be the cooler fiberboard regions. Some examples of packages with elevated moisture content observed in K Area (excluding those of obvious moisture intrusion) include:

- 9975-01903, ~12 – 17 %WME, a few small patches of mold which appeared dormant [8]
- 9975-02287, ~13 – 18 %WME, no mold observed [8]
- 9975-01968, ~10 – 14 %WME, no mold observed [9]
- 9975-02130, ~14 – 24 %WME, patches of mold on lower assembly [10]
- 9975-02274, ~13 – 19 %WME, some mold on lower assembly which appeared dormant [11]

Conclusions

Two efforts have been undertaken within the 9975 surveillance program to better understand the levels and behavior of moisture within the fiberboard assemblies of the 9975 shipping package. In the first effort, an initial survey of humidity and temperature in the upper air space of several packages stored in KAC was made. Significant scatter can occur in the total moisture content of a fiberboard assembly, and the humidity in the surrounding air will tend to come to equilibrium with that moisture level. Variation is also seen in the measured humidity within the upper air space. The data collected within this first effort help to illustrate how the upper air space humidity varies with the local ambient temperature and package heat load.

In the second effort, direct measurements of two test packages are providing a correlation between humidity and fiberboard moisture levels within the package, and moisture gradients throughout the fiberboard assembly for different internal heat levels. This effort has examined packages with cane fiberboard and internal heat levels of 5 and 10W to date. Additional testing will continue and will include 15 and 19W heat levels. The test sequence will then be repeated with softwood fiberboard assemblies.

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Table 1. Humidity and temperature data from 9975 packages in storage.

Position	9975	Heat Load (watts)	Air Space Relative Humdity (%)	Air Space Temperature (deg F)	Drum Surface Temperature (deg F)	Air Space Absolute Humidity (g/m^3)
Packages measured in the morning						
K31B	3985	3.2	59.3	64.4	66.4	9.11
K31M	4252	15.0	84.2	67.0	67.2	14.08
K32B	2438	10.2	94.7	65.3	66.2	14.98
K32M	4344	8.0	72.1	64.9	67.0	11.26
M64B	4993	16.4	78.0	65.5	64.8	12.41
T56B	1485	0.8	62.7	64.6	65.2	9.69
T56T	547	9.9	76.0	67.1	69.0	12.75
O30B	2062	7.8	74.6	67.1	66.2	12.52
O31B	4285	12.3	65.7	68.1	68.4	11.39
O31M	3060	11.9	72.0	66.0	68.4	11.66
Packages measured in the afternoon						
J31B	3984	6.2	75.9	66.2	67.2	12.37
J31M	4440	9.3	67.3	67.5	68.0	11.43
K31T	3962	3.6	65.5	65.5	66.8	10.42
K31T	4397	16.1	95.9	67.0	69.8	16.04
K32M	3826	15.3	89.9	67.6	69.4	15.33
K32T	4164	15.9	95.9	66.7	69.2	15.91
O26M	3342	15.7	86.9	67.3	68.4	14.68
O26M	3232	16.3	83.0	67.8	69.2	14.26
O26T	6386	1.4	66.7	64.0	65.0	10.12
J08B	6259	16.5	94.7	66.5	68.4	15.58
J09M	1889	10.0	92.5	66.6	68.4	15.25
S19M	6419	8.8	61.4	64.3	65.0	9.40
S19B	6437	17.0	70.3	64.8	65.8	10.93
J09M	1987	9.0	77.9	65.5	67.2	12.40
J09M	1979	3.0	66.2	63.9	63.6	10.00
X54B	5146	14.6	74.2	69.3	71.2	13.36

Table 2. Additional drum surface temperature data from 9975 packages in storage

Position	9975	Heat Load (watts)	Drum Surface Temperature (deg F)	Position	9975	Heat Load (watts)	Drum Surface Temperature (deg F)
Packages measured in the morning							
J31B	4041	8.8	67	K32T	4398	8.4	66.6
J31M	4466	9.0	68	K32T	4464	10.1	66.8
J31T	4408	10.6	68	M64B	4762	10.6	63.4
J31T	4475	10.7	68.8	O30B	4666	12.3	66.6
K31B	4467	10.6	66.4	O30M	3865	10.6	66.8
K31M	4547	11.9	66.4	O30M	3929	12.1	66.8
K31T	3546	12.3	67.2	O30T	3536	8.0	66
K31T	3732	11.7	66.4	O30T	3943	10.8	67.2
K32B	2407	10.9	66	O31B	3774	11.8	67.4
K32M	4411	8.9	67.2	O31M	3316	12.2	67.4
Packages measured in the afternoon							
S19M	489	6.1	64.8	X54T	4948	1.5	68.6

Figure 1. Humidity meter inserted through caplug hole into upper air space of 9975 package

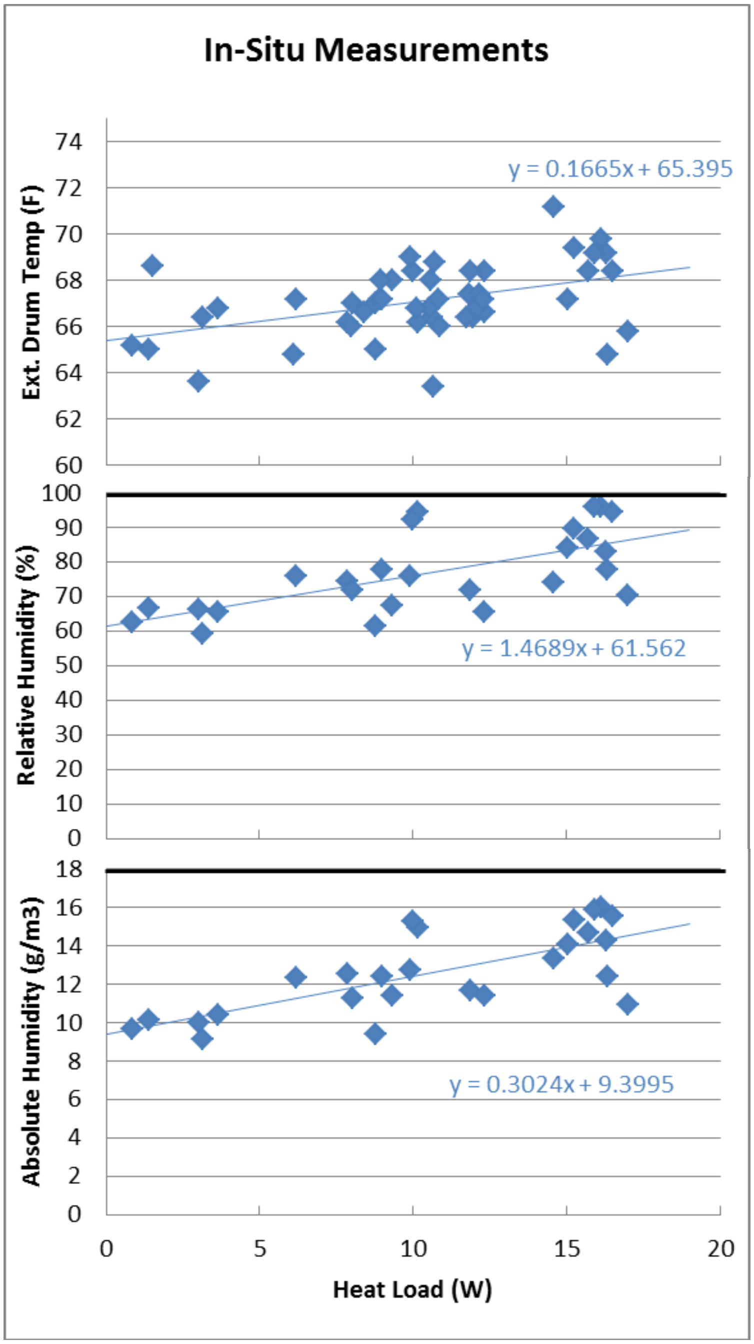

Figure 2. Temperature and humidity data taken on packages in storage, plotted as a function of internal heat load.

(a) External drum temperature

(b) Upper air space relative humidity

(c) Upper air space absolute humidity

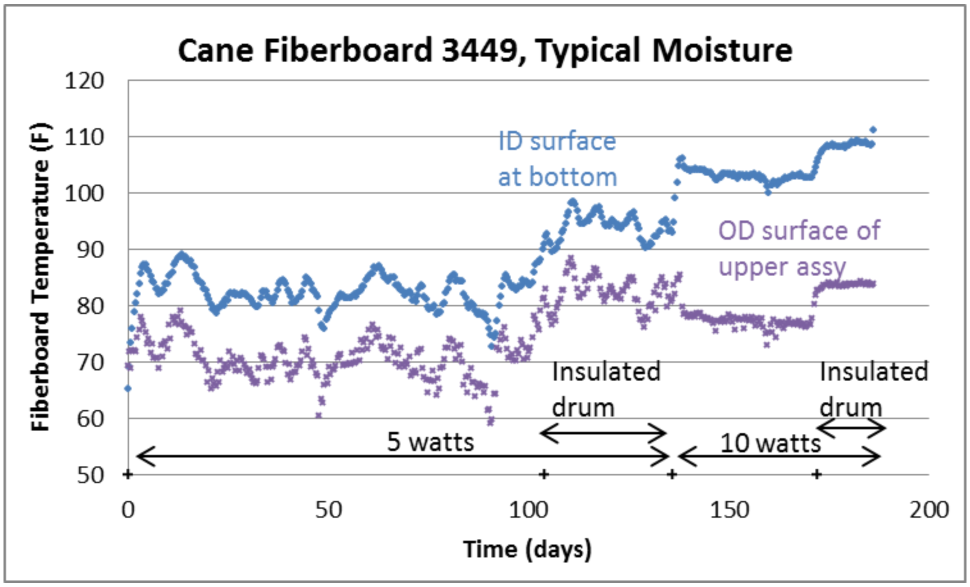

Figure 3. Temperature history for two locations within fiberboard assembly 9975-03449

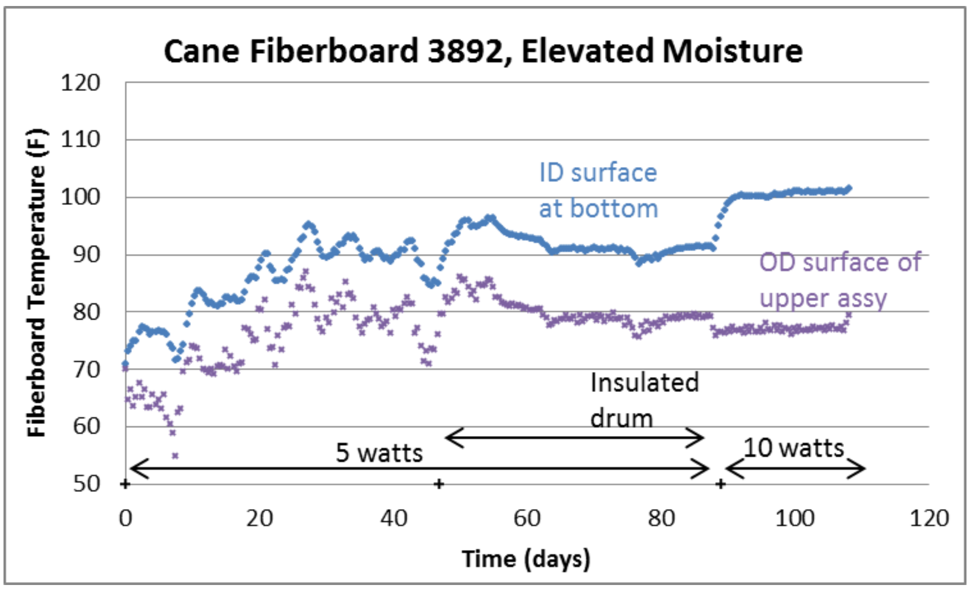

Figure 4. Temperature history for two locations within fiberboard assembly 9975-03892

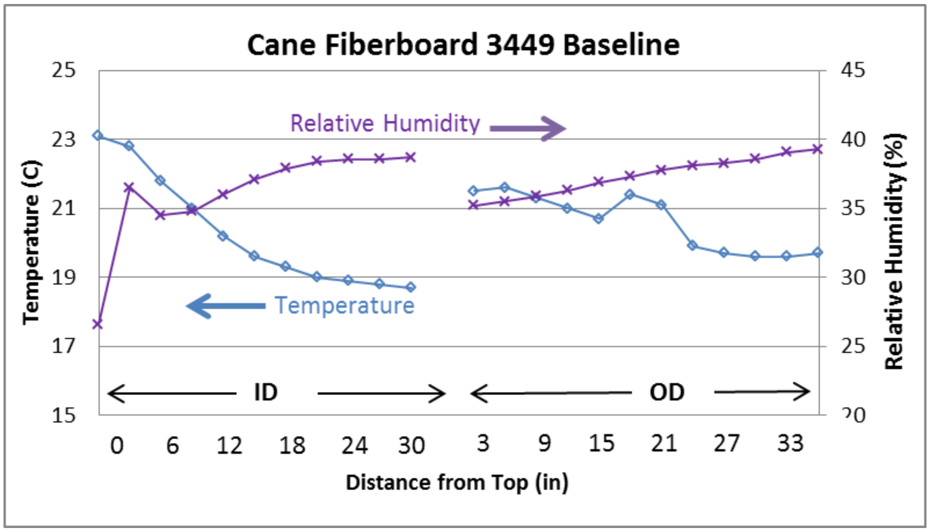

Figure 5. Typical baseline temperature and relative humidity data within 9975 package, taken adjacent to the fiberboard ID and OD surfaces.

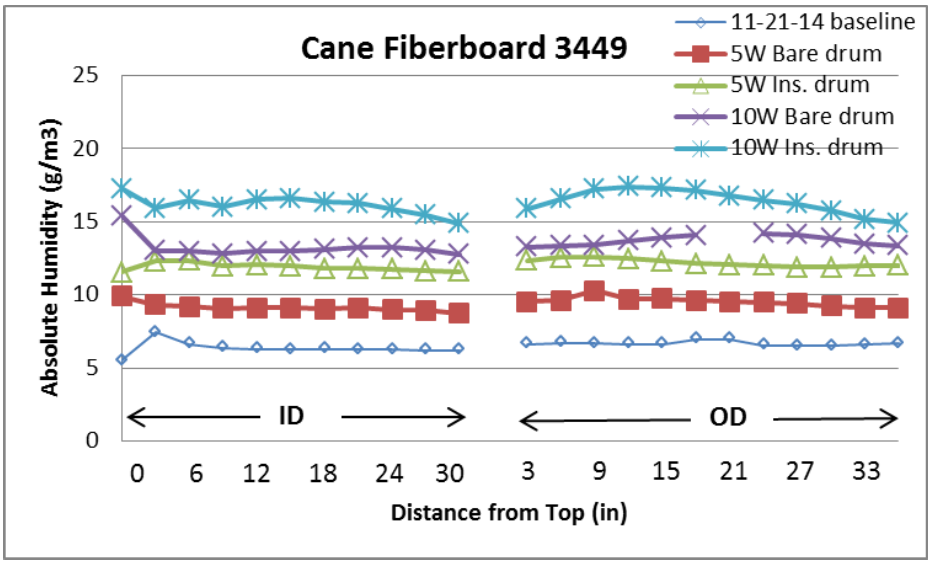

Figure 6. Typical absolute humidity data for the various test environments for package 9975-03449.

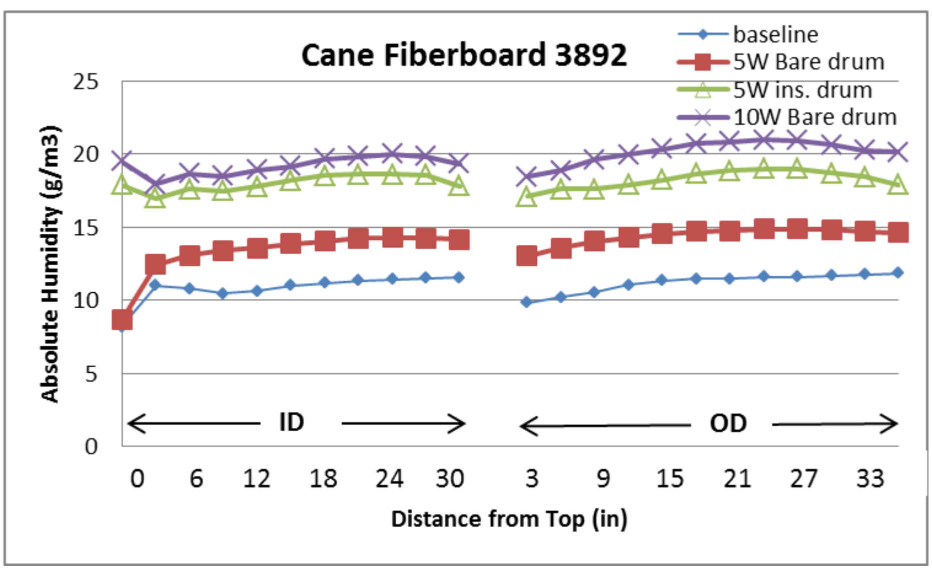

Figure7. Typical absolute humidity data for the various test environments for package 9975-03892.

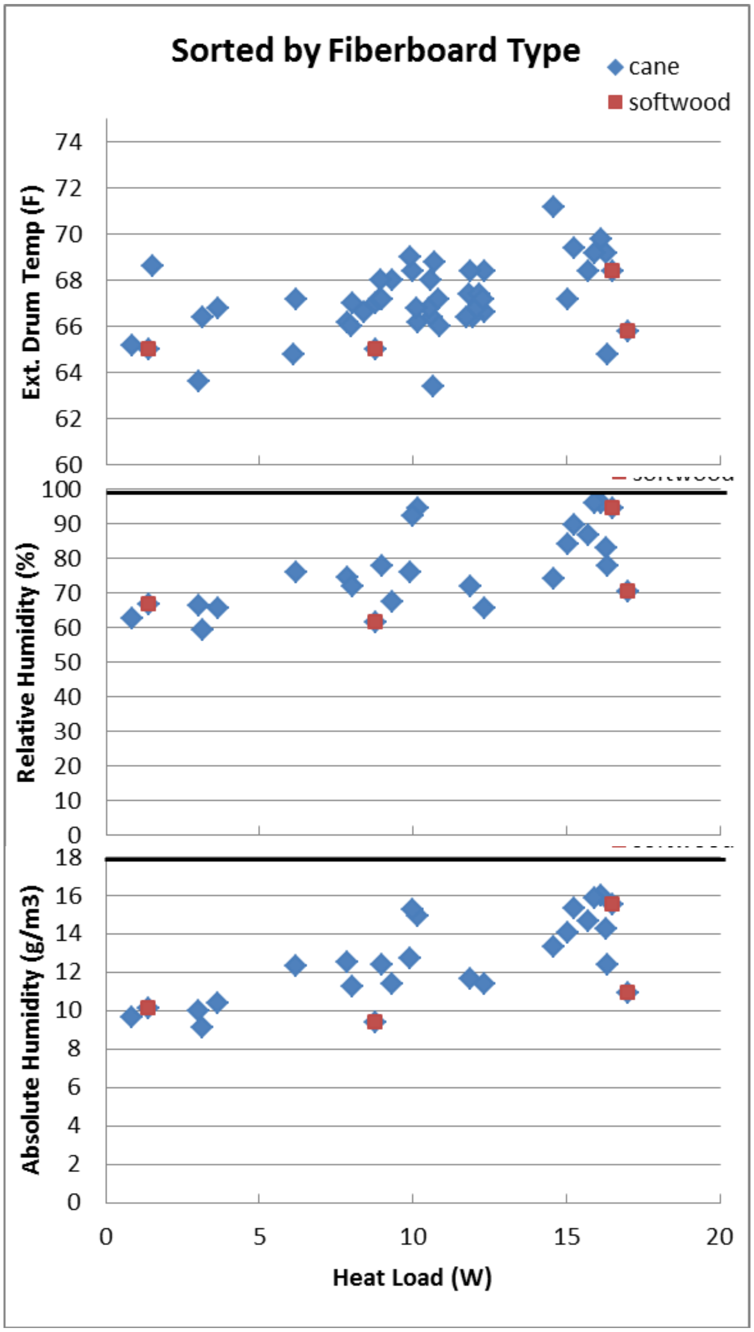

Figure 8. Temperature and humidity data taken on packages in storage, plotted as a function of internal heat load and sorted by fiberboard type.

(a) External drum temperature

(b) Upper air space relative humidity

(c) Upper air space absolute humidity

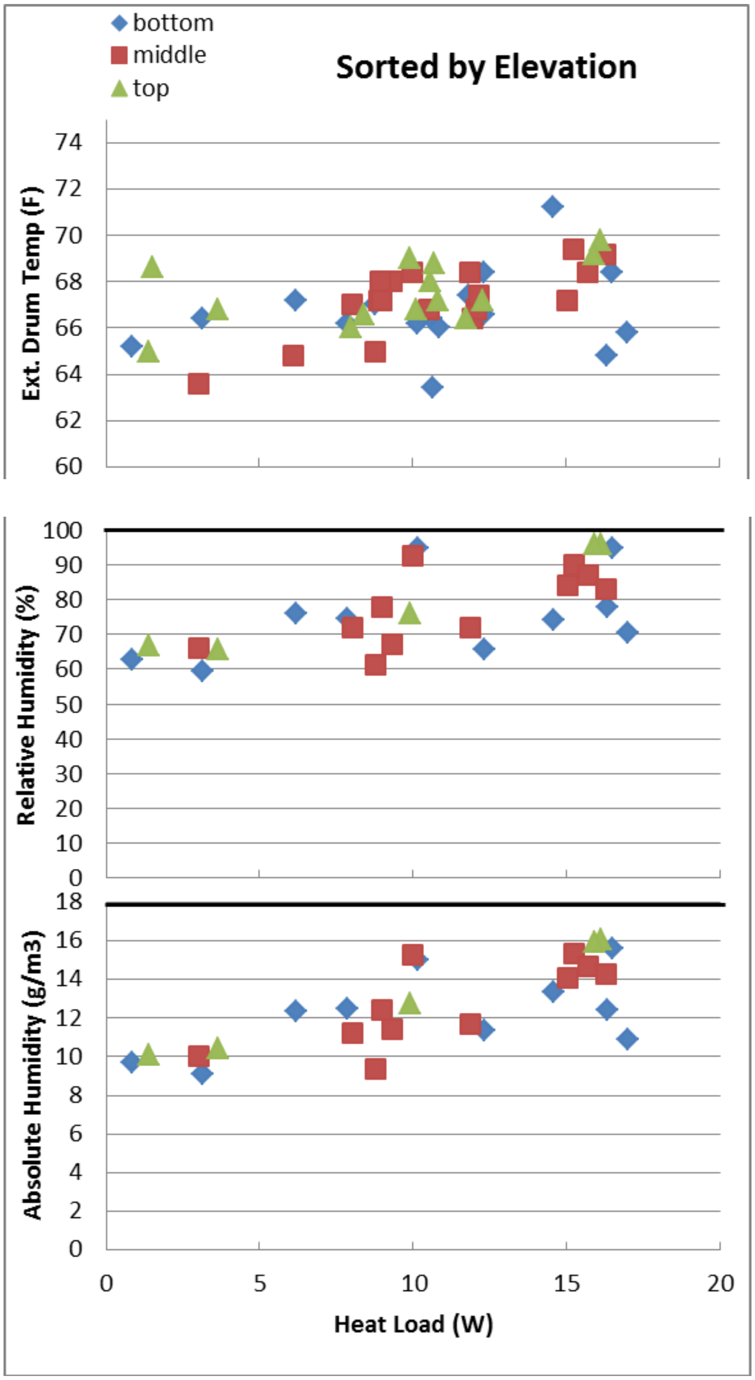

Figure 9. Temperature and humidity data taken on packages in storage, plotted as a function of internal heat load and sorted by storage elevation.

(a) External drum temperature

(b) Upper air space relative humidity

(c) Upper air space absolute humidity

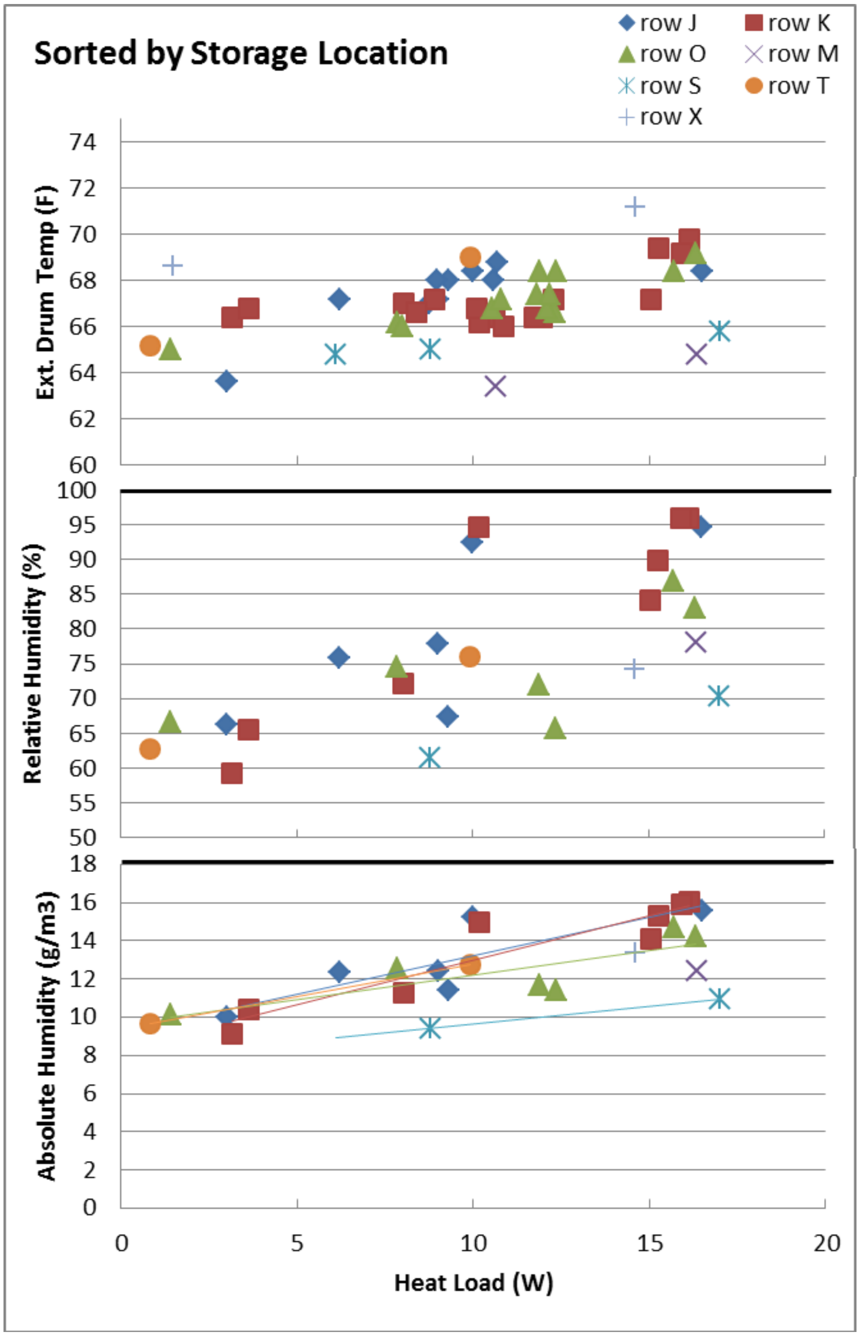

Figure 10. Temperature and humidity data taken on packages in storage, plotted as a function of internal heat load and sorted by storage location.

(a) External drum temperature

(b) Upper air space relative humidity

(c) Upper air space absolute humidity. Trend lines are given for storage location rows with 2 or more points to highlight the similarity in slope.

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