An Investigation into Alternative Methods of Drying Moisture Sensitive Devices in Storage and in Re-Work Applications

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ABSTRACT

Desiccants are materials used to keep a given environment (or product) stable and dry through a prolonged duration. They absorb moisture from the air through chemical reactions or by physical adsorption (dependent on the material base itself). In the case of ceramic-based desiccants, the capillaries or pores of the desiccant aid in the physical adsorption of moisture. Polymeric desiccants, on the other hand, absorb moisture by chemical reactions. This causes these water-absorbing polymers to be hydrogels when they are fully saturated. Depending on the makeup of the polymer, it can hold its weight 300 times over.

The current desiccant market is primarily based on ceramic desiccants. Those desiccants being silica gel, montmorillonite clay, and bentonite clay desiccants. Polymeric desiccants and other super absorbent polymers are not widely used for the purposes of electronic packaging. However super absorbent polymers have been studied for both academia purposes and for the purposes of commercializing this commodity. Moreover, its success can be seen with products like in diapers, napkins, and other hygiene products. However, in particular, sodium polyacrylate-based absorbent bags have entered the food and packaging industry with FDA approval allowing for meats and seafood to be packaged along absorbent cellulose-based pads. Allowing the product to look more attractive and stay relatively fresher as the water and other liquids are absorbed through these absorbing bags.

Key words: Desiccant, silica gel, clay,

INTRODUCTION

Desiccants have played a pivotal role in reducing moisture-related damage during the transportation and packaging of products like printed circuit boards. Moisture propagated in PCBs can accelerate the ionic corrosion of the pins, sockets, conductors causing electrical shortages [1]. Moreover, moisture can also lead to the oxidation of the copper surfaces on PCBs causing poor wettability and solderability [2]. Moisture can also reside in the resins and the defects of the board thereby also accelerating various failure mechanisms [3]. Therefore, moisture removal products like desiccants are needed to increase the reliability of printed circuit boards.

Some of the most commonly used desiccants for PCB packaging and transportation involve silica gel, bentonite clay, montmorillonite clay, and other ceramics like molecular sieves. Silica gel in particular are essentially a network of microscopic pores allowing for a large surface area capable of adsorbing moisture through capillary condensation [4]. This as well as their relative low cost in mass manufacturing is a popular product in packaging. Though they can be reused, buying virgin silica gel is more of an attractive option not only as a time saving measure but as a faster streamlined packaging procedure as well. However, silica gel is not advised to be used in high humidity and high temperature environment as the efficacy in its adsorption rate of water decreases considerably in those environments.

Both bentonite clay and montmorillonite clay are composed of various elemental compounds including but not limited to silica, aluminum oxide, ferric oxide, calcium oxides, aluminum oxides, and other oxides in lower compositional amounts [5]. Like silica gel, the low cost in manufacturing these desiccants is attractive and although not efficient in, high humidity and high-temperature environments, they are effective enough in general packaging and transportation. Furthermore, it is more efficient in ambient environment then they are in high humidity and high temperature ones

Other non-ceramic desiccants like polymeric desiccants have not been as widely adopted but have been theorized and researched upon by academia and governmental institutions [6]. Notably the biggest difference between polymeric and ceramic desiccants is the ability to absorb water molecules rather than adsorb them. Due to this, they are often an attractive way to have a product last longer in a high moisture environment without the need of more maintenance in compared to ceramic desiccants. Furthermore, modern developments of polymeric desiccants show extremely large absorption capacities in comparison to their ceramic counterparts [7]. Even showing better effectiveness in higher temperature and higher humidity situations as well [8].

Established standards for PCBs exist primarily through the Institute of Printed Circuits (IPC) and JEDEC (Joint Electron Device Engineering Council). Before the establishment of these standards, military specifications were used with PCBs. Though with the transition to lead-free standards and newer materials, new standards were adopted. Moreover, this meant new storage and handling of PCBs as well. IPC-1601A and IPC-1602 outline these new practices as necessary precautions alongside needed moisture barrier bags and humidity indicator cards for better protection against humidity and moisture [9] [10]. Specifically, IPC-1602 has become a modern standard for moisture handling in PCBs. Additionally, the joint industry standard of J-STD-033B further outlines what are acceptable moisture bags, desiccant standards, and drying/baking temperatures amongst other practices [11]. Other standards like J-STD-020E also provide guidelines in moisture uptake for both absorption and desorption [12].

Furthermore, IPC also has test methods in determining the moisture content for PCBs as well can be seen in IPC – TM-650 2.6.28 [13]. Certain test methods like HAST, though similar, look for a different situation. Where IPC-TM-650-2.2.28 looks for the ambient moisture that the board will or has absorbed, HAST asks what happens to it in a moist environment. Both important tests to be had but not necessarily the same scenarios. Nevertheless, dependent on the industry sector who are using the PCB, sometimes the results of other test methods like IPC-TM-2.6.2.1A are satisfactory enough as concerns of moisture absorption are typically given by the material manufacturers [14].

EXPERIEMNTAL SETUP

In order to achieve both objectives of; providing results of a polymeric desiccant in comparison to other commercial grade ceramic desiccants and efficacy data of a polymeric desiccant in absorbing moisture from a saturated circuit board. The experimental setup is split into two parts, one to primarily focus on the guidelines listed in MIL-D-3464 and the other to focus on the guidelines provided by IPC-TM-2.6.28.

Initial tests were the basic water retention of each desiccant; the weights of each sample were weighed out to just 1 gram. This is due to the nature of super absorbent polymers and their ability to hold considerable amounts of water. Larger amounts of ceramic desiccants would be needed in order to reach the water retention levels of the polymeric desiccant this amount could not be found experientially due to limitations on the resources at hand.

Furthermore, in order to provide comparison results to other desiccants, a chamber was needed to be built in the same manner how thick acrylic vacuum chambers are made. As seen in figure 1, the first iteration of this chamber was constructed with dimensions of 9.44” x 9.44” x 9.44”. Inside the chamber would be mason jars holding the various desiccant as well as a temperature and humidity probe. The temperature and the humidity was measured every hour. A small humidifier unit was placed inside the chamber as well that would intermittently disperse vapor into the chamber.

Figure 1. An acrylic box with dimensions of 9.44” x 9.44” x 9.44” housed as the first iteration of the chamber.

Because the chamber is not one fixed sheet but multiple sheets fixed together, the concerns of vapor, leaking into the greater atmosphere was a concern. The chamber was first glued to one another with acrylic cement, this would allow a strong but optically clear walls. In order to further mitigate any potential vapor loss and or potential humidity fluctuations, electrical tape secured alongside duct tape was used to further seal the side panels as seen in figure 2.

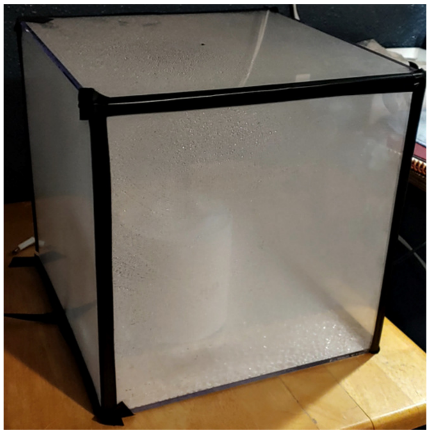

Figure 2. The acrylic chamber in use during the efficacy tests of the various desiccants

This was used initially until the second iteration and replication of tests was needed to further verify and make a reasonable conclusion about the polymeric desiccant. An 8” x 8” x 8” polycarbonate chamber was constructed with a thickness of .5 inches as seen in figure 3. Again, the chamber was constructed by gluing the individual sheets with acrylic cement taped again with electrical tape and duct tape for even more sealing of the chamber.

Figure 3. Polycarbonate sheets made up the second iteration of the chamber. With dimensions of 8” x 8” x 8”

Efficacy tests produced in both boxes were meant to find the long-term effectiveness of various desiccants over a prolonged period of time (24 hours) in an enclosed environment.

In order to further examine if there were significant mass changes and to adhere to the alternative procedure in Mil-D-3464E, subsection 4.6.1.3 and 4.6.1.4 (in relation to the alternate apparatus and procedure outlined in the standard). A commercial humidity chamber was needed capable to achieve humidity percent ranges from 20-80 at 25ºC.

This experimental setup was to show whether a polymeric desiccant is able to absorb moisture from a saturated circuit board. A tote box was constructed in a manner to mimic a dry cabinet / desiccator cabinet that the saturated circuit board could be placed in alongside the polymeric desiccant as seen in figure 4.

Figure 4. The constructed tote box with a Vivosun 4” inline tube fan attached alongside ducts.

The ducts and the inline fan were attached and placed on top of the desiccant in order to create an enclosed environment where air would constantly be circulating. The point of the cabinet is not to bring fresh air or exhaust air, but to circulate the air already inside with some sort of desiccator inside. This can be better visualized in figure 5 where two desiccant bags are placed inside the tote bag and ran over a period of 24 hours. Concurrently, a standard toaster oven was used to bake the test coupons for 24 hours at 105 ºC per the IPC specification.

Figure 5. The tote box with the polymeric desiccant bags inside

However, before this was done the boards were first weighed on a Mettler AT261 analytical balance scale to the nearest .0001 g. Three weighing occurred, before saturation, after saturation, and then after drying/baking. In theory, the initial weight and post bake weight would reveal the moisture content left inside the boards as mentioned in the standard TM-650. Ideally, the weight of the circuit boards would share similar weights to one another and would indicate that the polymeric desiccant did absorb moisture retained on the board.

RESULTS

As seen in figure 6, a basic water retention test was conducted for each of the desiccant. Silica gel had the lowest water retention levels only being able to hold .50 ml of water per 1 gram. With both montmorillonite clay and bentonite clay able to hold around 1.38 and 1.59 ml of water per 1 gram respectively. The polymeric desiccant was able to hold 141.67 ml of water in relation to 1 gram.

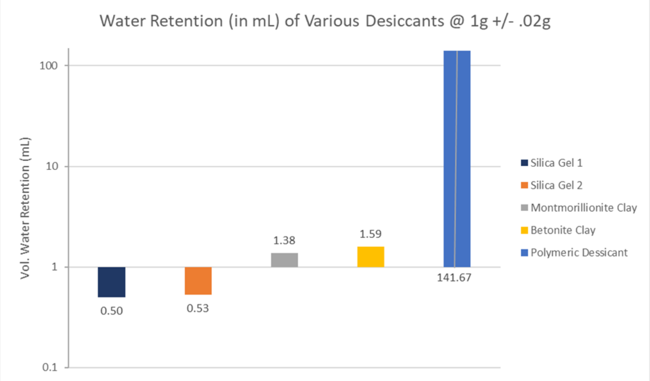

Figure 6. Water retention of each desiccant per 1 gram of each

Next was the finding the long-term effectiveness of the desiccants seen in figure 7. The goal is to maintain the lowest humidity at an extended period as PCB boards are often in warehouses, storage containers, and the like for extremely long period. In earlier periods, some of the ceramic desiccants beat out the polymeric desiccant. However, at longer times the polymeric desiccant is able to maintain the lowest humidity lending credence to its effectiveness in long-term storage.

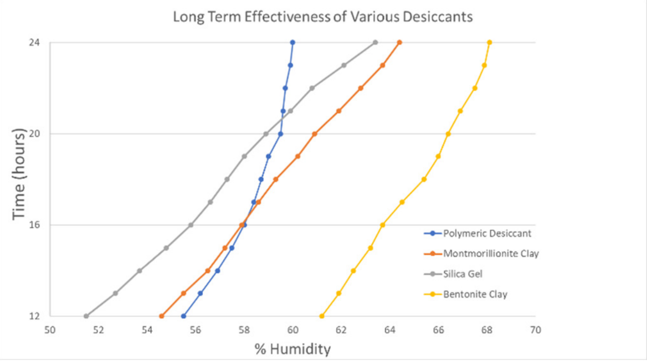

Figure 7. Long-term effectiveness of the various desiccants

As outlined in MIL-D-3464E, tests will be stopped and signaled as a success when the desiccant does not exceed a 5 mg weight in successive weighing's. Generally, the weight will rise to a maximum weight value and then decrease slightly before approaching a constant value. Which is expected and foretold by the MIL-D-3464E standard itself. After the first hour of exposure at 25ºC, 20% RH, none of the samples shows 5% or greater mass increase as seen in Table 1. Continued testing shows that the polymeric desiccant was able to achieve this within the last hour of testing. Testing was unable to continue any longer due to unavailability of the machine. Further data shows the efficacy with respect to each desiccant and the polymeric desiccant shows relatively less variance in comparison to others with significantly less mass change as well. Lending support in displaying its effectiveness especially in longer-term packaging.

Table 1. The mass change of each desiccant in the Welltrix Humidity Chamber

Steel Camel		Montmorillonite Clay	
5.9318	% change	5.6213	% change
5.9493	0.30%	5.8277	3.67%
5.9498	0.01%	5.8228	-0.08%
5.9516	0.03%	5.8002	-0.39%
5.9439	-0.13%	5.8071	0.12%
5.9361	-0.13%	5.8060	-0.02%
5.9321	-0.07%	5.7977	-0.14%
Silica Gel		Bentonite Clay	
6.0142	% change	5.9336	% change
6.2737	4.31%	6.0404	1.80%
6.2619	-0.19%	6.0430	0.04%
6.2010	-0.97%	6.0399	-0.05%
6.2160	0.24%	6.0412	0.02%
6.2290	0.21%	6.0424	0.02%
6.2140	-0.24%	5.9980	-0.73%

Next is the efficacy results of the dry box vs oven seen in table 2. Weighing of circuit boards reveal a decrease in weight in both methods of baking; with an oven and enclosed drying with a polymeric desiccant. A decrease in weight can be seen across all the circuit boards, supporting the assumption that the desiccant does absorb the moisture retained from the circuit board. However, the baking of the coupon boards with an oven still show a considerable amount more of moisture removal than any result of the drying with the polymeric desiccant. This can especially be seen in coupon board #2.

Table 2. The desiccant mass change of the coupon boards with relation to baking and "drying"

Circuit Board Mass (g)		
Baking of Coupon Board #1		
Initial Weighings	Saturated Weights	Drying Weight
36.6881	36.7395	36.6735
36.6878	36.7382	36.6737
36.6877	36.7384	36.6736
Baking of Coupon Board #2		
Initial Weighings	Saturated Weights	Drying Weight
31.2226	31.2352	31.1228
31.2225	31.2345	31.1296
31.2223	31.2336	31.1296
Polymeric Desiccant Drying of Coupon Board # 4		
Initial Weighings	Saturated Weights	Drying Weight
31.3850	31.3913	31.3736
31.3833	31.3906	31.3738
31.3819	31.3902	31.3740

	Moisture Content %
Baking of Coupon Board #1	0.04
Baking of Coupon Board #2	0.31
Polymeric Drying of Coupon Board # 4	0.03

CONCLUSION

The polymeric desiccants was able to successfully absorb moisture from a circuit board and its efficacy in relation to other commercial desiccants have shown certain advantages as well. Experimental setups were built in relation to both MIL-D-3464E and IPC-TM-650 method 2.6.28 to provide comparable data results. In all tests, the polymeric desiccant has met or exceeded the commercial desiccants and or standards.

Further experimentation is needed to determine if the moisture absorption rate has changed in a significant manner between the measurement of ambient temperature and humidity during weighing's. Specifically in IPC-TM-650, the measurement and recording of ambient temperatures and relative humidity of the analytical balance measurement station is required. However, simply cannot be abided by in this testing due to logistical reasons in both equipment and needing a "clean room" like environment.

Whether the boards do not see some level of delamination should be looked at as well, though that testing does not pertain to the standards above but pertains to the standard of IPC-TM-650 method 2.4.24.1. Future works with polymeric desiccants should also be expanded into other products that heavily rely on a dry and stable environment i.e. 3D filament. This can be more easily seen in physical and tangible results with printed objects.

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