The Effectiveness of Water Vapor Sealing Agents When Used in Application with Thermoelectric Cooling Modules

Michael J. Nagy
TE Technology, Inc., 1590 Keane Drive, Traverse City, MI 49686
Tel: (231) 929-3966, Fax: (231) 929-4163, e-mail: cool@tetech.com

Abstract
The inherent reliability of thermoelectric modules (TEMs) can be destroyed when water vapor is allowed to condense within the device. This causes corrosion in the TEM and eventually leads to catastrophic failure. TEM manufacturers and users combat this problem by applying sealing agents to the perimeter of the devices. However, not all sealing agents are equally effective or even beneficial to long-term, reliable operation of the TEM.

This paper presents an analysis on the various sealing agents used throughout the industry. Sealed TEMs were cooled in a high humidity environment and monitored for the visual evidence of water and it's associated weight gain.

A marked difference in the effectiveness of the various sealing agents was noted. Some sealing agents, such as the ubiquitous silicone rubber, yielded unacceptable sealing capability. That is, water vapor was shown to easily penetrate the silicone based "sealant" leaving trapped liquid water inside. In sharp contrast, the epoxy sealant was found to be essentially impervious to vapor penetration.

Introduction
Thermoelectric modules (TEMs) are used in medical, military and aerospace applications where reliability is of utmost importance. They can be made to operate for hundreds of thousands of hours when utilized properly. However, their inherent reliability can be destroyed when water vapor is allowed to condense within the device.

Condensation leads to corrosion within the TEM. Water mixes with residual acidic solder flux (used during the module's assembly) and creates an active electrolyte which can be highly corrosive. Solder junctions eventually degrade until the TEM is rendered useless and the cooling system has undergone catastrophic failure. These failures occur most rapidly when TEMs are operated continuously in a high humidity environment.

Engineers have combated this problem by applying sealing agents to the outer perimeter of the TEM between the substrates. Several classes of sealing agents are used throughout the industry. These include acrylics, epoxies, urethanes, and silicone rubbers.

Each sealant has different water vapor permeability characteristics. Consequently, their effectiveness also varies. Some sealing agents are permeable to water vapor, allowing moisture to enter a sealed TEM, yet they prohibit the condensed water from escaping. The use of such a sealing agent can actually be more detrimental than not sealing the device because the water can neither dry or drain out of the module. Conversely, other sealing agents are practically impervious to water vapor and can make otherwise unreliable products highly reliable.

This paper rates the effectiveness of four sealing agents by employing two different test methods. The visual test used specially made TEMs with transparent substrates (see Figure 1). The TEMs were sealed with the various sealing agents and cooled below dew point in a high humidity environment. Visual inspection and comparison of moisture within the TEMs was facilitated through the transparent substrates. The crux of this method was that it allowed periodic inspection for internal condensation without physically destroying the TEM (separating one substrate from another).

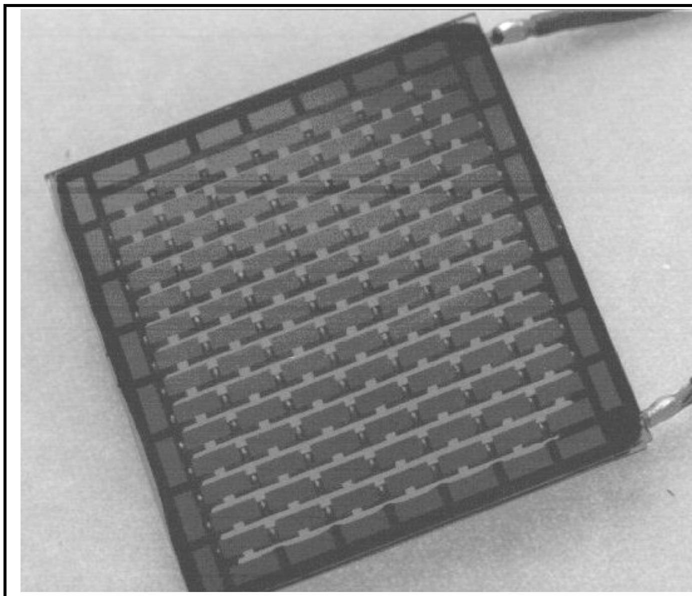

Figure 1 Transparent TEM After Sealing

The second test monitored moisture penetration by tracking the weight gain of a TEM. Standard TEMs were sealed with the various sealing agents. Next, they were cooled below dew point in a high humidity environment. The TEMs were then periodically removed and weighed on a high resolution laboratory scale. The effectiveness of each sealing agent was determined by measuring the weight gained by each of the TEMs. This weight gain is directly correlated to the amount of water condensed within each TEM.

Selection of Sealants
The four classes of sealants chosen for this study were acrylics, epoxies, polyurethanes, and silicone rubbers. All classes are currently being used in the thermoelectric industry. One specific sealant was chosen to represent each class. The Dow

Corning 738 silicone rubber and TE Technology 1034-01 epoxy were chosen because they are known to be used on existing products. 3M 606NF acrylic and Sikaflex 221 were recommended by a sealant distributor because they offered good adhesion characteristics, were relatively common, and were easy to work with. No vapor permeability data was available for any specific sealant in any of the classes.

Experimental Apparatus

The experimental apparatus consisted of a thermoelectrically cooled cold plate contained within a high humidity environment. The cold plate was a 19 mm thick aluminum base plate, approximately 150 x 200 mm in length and width, which provided an isothermal platform to cool the TEMs. Aluminum pedestals (40 mm square, 14 mm thick) were evenly spaced and bonded to the cold plate. All areas of the cold plate not covered by the pedestals were covered with insulation. Band clamps were then placed on the cold plate, strapping the TEMs against the pedestals. Figure 2 details this apparatus. The thermoelectric cold plate was driven by a power supply/temperature controller which maintained the temperature of the pedestals at 4 ± 1°C.

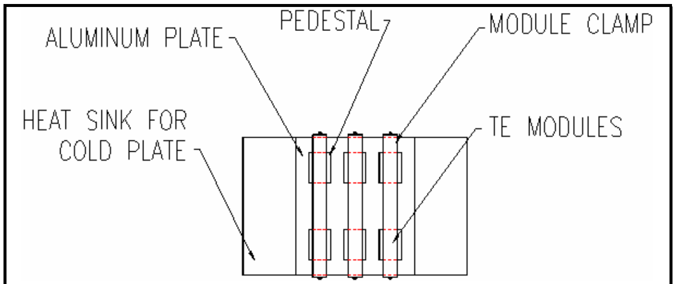

Figure 2 Thermoelectrically Cooled Cold Plate

The environmental chamber consisted of an enclosure with dimensions of 0.75 x 0.75 x 1.25 m. A small humidifier was placed inside the chamber to elevate the relative humidity above 90%. The temperature within the chamber was 28 ± 2°C throughout the experiment. The entire experimental apparatus is depicted in Figure 3.

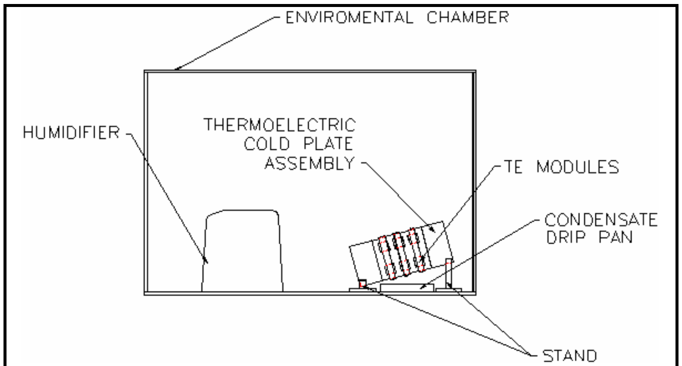

Figure 3 Complete Experimental Apparatus

Visual Test Method

The visual test for moisture penetration utilized four specially fabricated TEMs with transparent substrates. These substrates, made from highly polished, single-crystal aluminum oxide, allowed visual means for inspection of condensation within the TEM. An industry standard 40 x 40 mm, 127 couple device was chosen for these tests. Pellet geometry was 1.4 x 1.4 mm square by 1.6 mm tall. Separation between the substrates was 2.2 mm (the thickness of two conducting tabs plus the pellet height).

Each of the four TEMs were sealed with one of the commonly used sealing compounds (acrylic, epoxy, polyurethane, or silicone rubber). The sealant extended into the TEM approximately 3.0 mm between the pellets. The TEMs were clamped onto the cold plate and placed in the environmental chamber. Moisture within the TEMs condensed and dried the air trapped within the TEM. Thus, an absolute humidity differential was established across the potting compound which pumped" water into the module via osmosis. The TEMs were then removed and inspected on a daily basis.

Weight Gain Test Method

The weight gain test method monitored the weight of a TEM as it was exposed to a humid environment.

This test for moisture penetration utilized four TEMs with standard pressed and sintered ceramic substrates. A 40 x 40 mm, 127 couple TEM was chosen for this test as in the previous test. Pellet geometry of the TEMs was 1.4 x 1.4 mm square by 1.5 mm tall. Separation between the substrates was 2.3 mm. Lead wires were not attached to the TEM.

Each of the four TEMs were sealed and subjected to the same high humidity environment as in the visual test. The TEMs were periodically removed, dried, and weighed on a laboratory scale with a resolution of 0.0001 grams. Weight gain was directly attributed to the penetration and collection of moisture within the TEM.

Results and Discussion

The results of the visual test method are compiled in Table 1. The TEMs sealed silicone rubber and acrylic sealants both showed condensation within 24 hours of exposure to the test environment. The TEM sealed with the polyurethane sealant underwent 72 hours of exposure before showing condensation within the TEM.

Table 1

Sealant Type	Exposure Time Before Condensation Detected
3M 606NF Acrylic	24 Hours
TET 1034-01 Epoxy	Data Not Meaningful
SIKAFLEX 221 Polyurethane	72 Hours
DOW 738 Silicone Rubber	24 Hours

Condensation also appeared inside the epoxy sealed TEM within 24 hours of exposure. This TEM, in fact, absorbed more water than any other in the initial 24 hours of testing. The data was judged not meaningful, however. Inspection of the TEMs before testing revealed that the epoxy would not properly bond to the highly polished substrates. Slight shrinkage of the epoxy upon curing, combined with this insufficient bond, yielded an air gap between the substrate and the sealing agent. Thus, the TEM was not adequately sealed and condensation fully expected.

The results of the weight gain test method are shown in Figure 4. Clearly, the epoxy sealant had the lowest weight gain (zero, within the error of measurement). TEMs used in this test were made with pressed and sintered ceramic substrates. These substrates had a rougher surface texture and facilitated a proper bond with the epoxy sealant. Therefore, the epoxy was capable of sealing the TEM (unlike the visual test). The remainder of the weight gain results seemed to correlate with the visual test results. Silicone rubber and acrylic sealants gained the most weight; and the polyurethane sealant was considerably better but far from perfect.

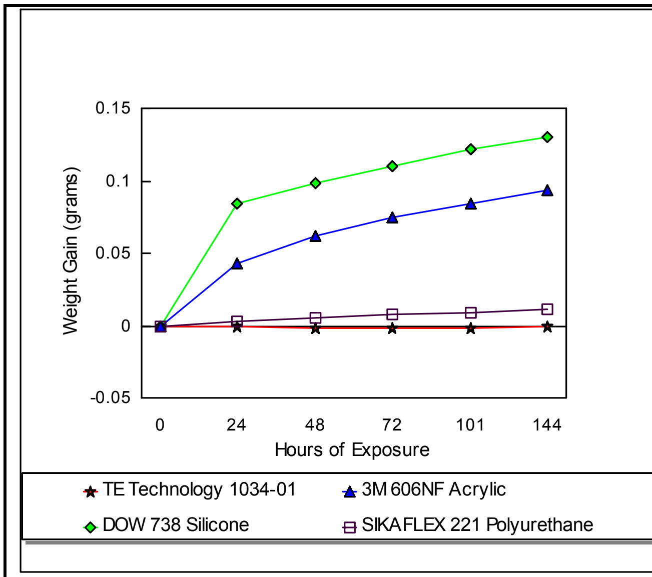

Figure 4 Weight Gain of Thermoelectric Modules

The results obtained in these tests are relative in nature. They do not yield TEM failure rates relative to the amount of internal condensation. One can only make the inference that failure rates will increase with increasing condensation levels.

Published data[1] regarding the vapor transmission rates of the sealant classes is shown in Table 2 (data was unavailable for the specific sealants). This data supports the effectiveness as ranked by the testing. The published data also indicates that, while polyurethanes can have lower transmission rates than silicones, they can also have higher transmission rates. Epoxies, as a rule, have lower transmission rates than polyurethanes and silicones.

Table 2

PUBLISHED PERMEABILITY DATA	
Type	Vapor Transmission Rate g•mm/m^2•day
Acrylic	Not Listed
Epoxy	0.7 - 0.94
Polyurethane	0.94 - 3.43
Silicone Rubber	1.73 - 3.11

Conclusion

Epoxy based materials should be used when sealing TEMs against water vapor. Acrylic, silicone rubber, and polyurethane based sealants proved inferior to epoxy in direct comparison testing. Published vapor transmission data for the various classes of sealants also indicates that epoxies are the most effective choice for TEM sealing.

Silicone rubber, the most commonly used sealant proved to be the least effective of all the types tested. This sealant was very permeable to water vapor yet blocked condensed water from leaving the TEM. Using such a sealant would actually be detrimental and not beneficial for many applications.

References

[1] Permeability And Other Film Properties Of Plastics And Elastomers, Plastics Design Library, 1996