Fundamental Concepts of Environmental Testing Techniques in Electricity and Electronics

Part 2: Fundamental concepts of the standard condition and movement of water or moisture for performing temperature and humidity tests

Toshio Yamamoto*

Part 2 in this issue discusses standard environmental values for environmental testing, and also analyzes the thermal stress and humidity stress related to humidity testing. Finally, the article explains the physical mechanism by which the moisture content in the test environment penetrates the specimen.

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*Environmental Test Technology Center

1. Introduction

Aims and methods of environmental testing differ depending on the functions of products, their purposes, and the usage environments of the targeted markets. For example, when heaters are not properly maintained for the worst-case rainy season environment (e.g., removing accumulated dust from the internal equipment), the equipment will suffer from defective insulation and fail when the heater is brought out and turned on in the winter. Because of this, the home appliance manufacturer's group sets the worst-case conditions for absorbing moisture as the model test conditions for simulation. The communications equipment group as well, realizing the importance of the conditions and functions fulfilled by the communications equipment in the market, checks the failure mode from humidity absorption in the initial period. Therefore, these conditions use test methods presupposing acceleration.

As this illustrates, the differences in test purposes and test methods dictate completely different details in such areas as test sequence, test items, collecting and handling data, and evaluation methods and results.

Therefore, I would like to discuss a variety of topics such as on what sort of standards environmental conditions should be based when planning individual environmental tests, as well as what sort of effects temperature and humidity stress will have on products, and how to understand the mechanisms by which moisture penetrates the internal parts.

When performing environmental testing, the testers must first be aware of the standards for environmental conditions and base the tests on those conditions, and then they must determine the aims of tests and develop the proper test methods. Test planning, preparation and execution must be in accordance with those aims, and recovery procedures must be set in advance. The test must not be started before all these preparations have been completed, as this is a scientific test.

2. Standard environmental values

2-1 Standard environments determined by standards

In all standards, the standard conditions are established for the specific environments that serve as a common base in a particular series. Therefore, all individual standards are constructed on the premise that these standard values exist, but in most cases these are not individually noted. At this point, I would like to discuss these standard values based on the IEC standards.

(1) Standard reference atmosphere (standard conditions)
...(IEC 60068-1/JIS C0010)
—Temperature: 20°C
—Air pressure: 101.3 kPa (1013 mbr)

Note: The relative humidity is not prescribed, because in general calculated correction is not possible.

Parameters that should be measured are influenced by temperature and pressure, and when the correlation between them is known, they should be measured using conditions in part (3) below. If necessary, they should be compensated using the above “Standard reference atmosphere”.

(2) Standard atmosphere for referee measurements and tests (judgment conditions) ... (IEC 60068-1/JIS C0010)

Parameters that should be measured are influenced by temperature, pressure, and humidity, and when the correlation between them is not known, prescribed atmospheric conditions are chosen from the following table.

Table 2-1 Atmospheric conditions for judging

Temperature (°C)		Relative humidity (%)	
Nominal value	Close tolerance / Wide tolerance	Close range	Wide range
20	± 1 / ± 2	63 to 67	60 to 70
23	± 1 / ± 2	48 to 52	45 to 55
25	± 1 / ± 2	48 to 52	45 to 55
27	± 1 / ± 2	63 to 67	60 to 70

Note: Atmospheric pressure (kPa) is 86 to 106.

Notes:
1. The above values include values prescribed in ISO 554 (Standard atmospheres for conditioning and/or testing) and 3205 (Preferred test temperatures).
2. 25°C is required (hence used) for testing ICs and semiconductor devices. (Not included in ISO 554 and 3205.)
3. Close tolerances may be used for referee measurements, while wide tolerances may only be used when allowed by the referee specification.
4. Relative humidity may be ignored when it doesn’t affect test results.

(3) Standard atmosphere conditions for measurement and tests (standard conditions) ... (IEC 60068-1/JIS C0010)

This shows the standard reference ranges for atmospheric conditions for measuring and testing. (In other words, this points to all actions that affect the test, except test conditions inside the test equipment, and can be understood as referring to normal peripheral conditions and room temperature.)

Table 2-2 Atmospheric conditions other than test conditions

Temperature (°C)	Relative Humidity (%)	Atmospheric pressure (kPa)
15 to 35	25 to 75 (Absolute humidity ≦ 22 g/m^3)	86 to 106 (860 to 1,060 mbr)
10 to 40	For large specimens and specimens left inside the chamber the measurements and tests (However, judgment must be made according to the relevant specifications.)	

Notes:

1. Fluctuations in temperature and humidity should be kept to a minimum during serial measurements performed on specimens as one section of the test.
2. In sites where temperature cannot be kept within the limits on the upper level of the table when measuring large specimens or specimens left inside the chamber, it is possible to expand the temperature range to a low of 10°C to a high of 40°C as shown on the lower level of the table when allowed by the relevant specifications. (In JIS C0010, the upper limit for relative humidity is 85%, and is suited to Japanese domestic climate.)

Furthermore, military standards differ from standard reference values set by the IEC. For example, in the MIL-STD-810E (Environmental Test Methods and Engineering Guidelines, 1989) they are as follows.

(a) Standard ambient. Ambient measurements and checks (e.g.,pre-and post-test) are conducted at room ambient conditions as follows:
Temperature : 25°C ± 10°C
Relative humidity : Uncontrolled room ambient
Atmospheric pressure : Site pressure

(b) Controlled ambient. When the ambient conditions must be closely controlled, the following shall be maintained:
Temperature : 23°C ± 2°C
Relative humidity : 50 % ± 5%
Atmospheric pressure : 96.45 + 6.6 / –10.0 kPa

Note: Other allowable values for test conditions are prescribed, but are omitted here.

As you can see from this, it is necessary to be aware that standard reference condition values differ according to test standards.

2-2 Test chamber conditions

In IEC standards, there are currently no performance provisions that must be maintained by the test chamber performing the environmental test. There are also no prescribed methods of confirming that performance. Therefore, at present, standard test equipment is based on the manufacturer’s experience and actual results, while test equipment for special purposes is based on discussions between the user and the manufacturer to work out the performance details. Often, this approach results in test equipment being designed specifically for individual products.

In Japan, the only test equipment manufacturer’s group, the Testing Machinery Association of Japan, has created the following performance standards for environmental testing equipment.

JTM K01 Standards for performance of humidity chambers (1991)
JTM K03 Standards for performance of humidity rooms (1992)
JTM K05 Standards for performance of high temperature chambers (1991)

These standards were created by the manufacturers rather than the users, but they serve to organize the approach to testing equipment, as well serving as reference materials. At the very least, they effectively serve as standards clarifying rated performance for current standard testing equipment. However, in measuring humidity, differences from other public standards arise in some areas, and those areas are currently being revised, along with other areas.

For reference, the standard atmospheric conditions of these standards are as follows.
Temperature: 23 ±5°C
Humidity: 65 ±20%

2-3 Structure of environmental tests

According to IEC/JIS, environmental tests are structured according to the following work sequence to evaluate the influence of tests on specimens or serial tests.

a. Pre-conditioning
Specimens are treated to remove pre-test influences or to neutralize specific parts.
b. Initial examination and measurements
Necessary measurements are made prior to exposure to the test environment.
c. Conditioning
Specimens are placed in the prescribed test environment conditions to investigate the affects of the test conditions on the specimens.
d. Recovery
After exposure to environmental test conditions, specimens are stabilized before measuring characteristics.
e. Final examination and measurements
Necessary measurements are performed after exposure to the test environment.

Notes:

During the test conditions (during exposure) and during recovery, intermediate measurements may be requested, but in this case the IEC standards stipulate that the test environment not be disturbed once the test has begun. Therefore, specimens inside the chamber during the test cannot be removed from the test chamber for intermediate measurements.

Furthermore, in standard categories specimens are prescribed products to be tested according to standard sequences. (“Products” include systems and auxiliary parts that provide essential functions.)

3. Fundamentals of environmental testing

At this time, let's look at the fundamental relationship between the products and the environment, a relationship that forms the background to specific environmental tests. We shall look into how the environment affects the products as stress. For industrial products, at least for electrical and electronic products, fundamental environmental stress means temperature stress and humidity stress. In some cases we must also consider mechanical stress, electrical stress, or gas stress. In reality, the resulting stress is rarely from a single source, but instead is usually from a sequential combination of these stresses, or from a complex stress formed by a simultaneous combination of these stresses.

3-1 Heat stress

Heat stress is one of the most frequently discussed type of stress, the other being humidity stress, which we shall look at later. These types of stress are deeply implicated in a large number of actual failure phenomena. Heat stress is a physical phenomenon that can independently cause failure due to heat introduced from outside sources or due to heat generated by the part itself. In this case, when the product heats up, an internal structural part may be destroyed, or in the opposite instance, when heat is leaked externally, the product may experience a drop in temperature leading to weakened functionality or damage.

3-1-1 High temperature environments (temperature rise due to heat gain)

In general, the following results can be attributed to heat stress when the temperature rises:

1. Heating leads to a drop in viscosity of the substance, promotes softening of materials, generates mechanical and structural degradation such as weakened sealing functions, and also lowers electrical qualities.
2. Heating melts substances. In particular, when resins are heated above the glass transition temperature, resistance to distortion is reduced, and support cannot be maintained. When the temperature of a material nears its melting point, the original form cannot be held.
3. Because heating causes materials to expand, heating generates strain between materials restricted together when there is a difference in the thermal expansion coefficient of those materials, causing distortion.
4. Temperature rise due to heat gain promotes chemical reactions. In addition, heating results in the evaporation of decomposed substances in the materials as well as evaporating unreacted substances in resins through such means as sublimation and evaporation. These phenomena cause hardening and degradation of the product itself, as well as giving rise to corrosion of other materials.
5. Furthermore, repeated raising and lowering of the temperature leads to repeated expanding and contracting of materials, which can lead to stress on the attached parts and on the material itself, thus leading to destruction of the material (thermal fatigue).

By the way, in designing electrical and electronic parts, thermal design is extremely important in regard to the relationship between the part and the product in which it is to be used. The heat emitted by the operation of today's low-voltage-consumption home appliances remains an important topic.

A direct example of extreme environmental stress would be the equipment used aboard aircraft, especially supersonic aircraft and spacecraft such as the space shuttle. Besides being exposed to extremely harsh temperatures, this equipment also sustains an extremely severe temperature fluctuation gradient, obliging the parts to operate in a harsh, high-temperature environment. Aircraft operating environments have the following characteristics:

(1) Acceleration and increases in altitude (with sharp gradients for such increases and decreases),
(2) Electronic equipment concentrated in narrow equipment space,
(3) Increased functions and capacity of equipment, and an increase in the type of equipment,
(4) Miniaturization of equipment and concentration of heat-generating parts, and
(5) Power equipment unavoidably placed near other heat sources.

In such cases, the equipment's internal high-temperature environment softens materials with a low melting point, and in extreme cases causes the material to melt and run. For example, wax, grease, and compounds fall into this category. In aircraft in particular, any of these could cause an extremely dangerous situation. The temperature at which heat distortion begins in most materials known as heat-resistant plastics is not as high as you might think. The temperature at which insulation materials begin to degrade as a result of heat from the surrounding environment is also lower than might be expected. The previously mentioned differences in thermal expansion of different materials can cause installed parts to loosen, or cause overtightening. Heat can also cause problems due to breaking down such materials as seals. These types of aging processes normally occur at high temperatures, thus promoting the dissolving of organic materials as well as increasing the hardness of such materials as rubber and artificial materials, causing solidification.

Incidentally, equipment that normally emits a lot of heat has low electrical efficiency and emits most of its power consumption as heat. When this type of equipment is operated in an atmosphere with high ambient temperature or near other equipment emitting a lot of heat, there is a further influx of heat, causing problems. These phenomena, as has been noted, cause changes in the quality of the materials in the parts, and the molecules that make up the materials strongly affect the electrical characteristics. These types of changes are accelerated by temperature increases, producing early period failure both physically and chemically.

In general, the following can be done to avoid these problems:

(1) Improve the life and reliability of the components.
(2) Improve circuit stability in regard to heat resistance.
(3) Improve the heat resistance of the materials themselves.

These and other methods can be used, but since materials not activated by heat are currently rare, improving parts is easier said than done. In most cases, this will depend on developing newer, more stable materials.

To summarize, problems caused by stress due to rising temperatures are linked to (1) critical failure, (2) reduced operating life, (3) temporary physical changes, and (4) exposure to long-term severe high temperatures leading to permanent physical and chemical changes, and finally to permanent failure.

3-1-2 Low temperature environments (cooling due to heat loss)

Phenomena caused by cooling generally exhibit the opposite aspects as the phenomena caused by heat stress.

1. Cooling promotes solidification of structural materials, restricts the free movement of molecules, causes structural degradation, e.g., by crushing, and degrades electrical functions.
2. At low temperatures, the hardness of many resins drops markedly and the resins become brittle, becoming quite easily damaged by shock. This leads to cracking, compromises the effectiveness of seals, accelerates structural degradation, and lowers electrical quality.
3. Cooling increases the viscosity of materials, resulting in lowering the effectiveness of lubricants, and accelerating mechanical degradation from friction.

However, rather than receiving critical damage in a low temperature environment, products usually experience a loss of quality, such as functional degradation.

3-1-3 Low temperature and low pressure

When considering the earth's environment from a global standpoint, the danger of low temperature environments exists not only in the polar regions, but at high altitudes as well. The relationship between altitude and temperature is shown as representative values in Fig. 3-1.

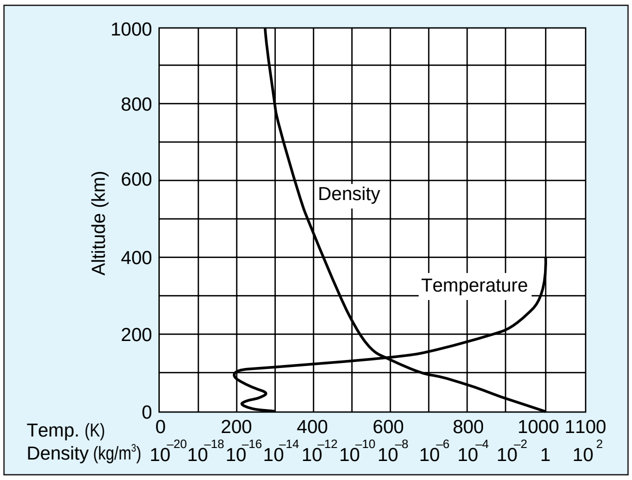

Fig. 3-1 Altitude distribution of atmospheric temperature and air density

At this point, for reference, I would like to briefly touch on the relationship between altitude and standard atmospheric temperature and pressure. Standard atmosphere is one atmospheric model, and in 1964 the "ICAO Standard Atmosphere" was supplied by the International Civil Aviation Organization (ICAO) as a representative international standard atmosphere. This is the same content as the lower strata of the "US Standard Atmosphere 1976" up to 32 km altitude.

This atmosphere is represented with temperature curves for three geopotential altitudes. Namely,

- Pressure/temperature on the earth's surface: 1013.25 hPa/15.0°C
- Temperature change ratio up to 11 gpkm altitude: –6.5°C
- Altitude, pressure, and temperature of boundary: 11 gpkm, 226.32 hPa, –56.5°C
- Temperature change ratio up to 20 gpkm altitude: 0.0°C/gpkm
- Temperature change ratio up to 32 gpkm altitude: +10°C/gpkm

Altitude is determined by the WMO (World Meteorological Organization, under the auspices of the United Nations) so that 1 gpm (geopotential altitude) is equal to 9.80665 m^2/s^2, and in areas of standard gravity (9.80665 m/s^2) 1 m altitude corresponds to 1 gpm. Even in other areas, the geopotential value represented by gpm is roughly equivalent to the altitude in meters. For details, please refer to the US Standard Atmosphere 1976.

3-1-4 Low temperature and electrical and electronic equipment

When temperature is at the level of –40°C, electrical and electronic equipment becomes difficult to operate on semiconductor devices, and human activity also slows. Because of this, most equipment is operated inside a heated building or similar arrangement. However, such equipment as cellular phones, or business communications equipment must be operated in all types of environments. Performance of electrical and electronic equipment operated in low temperature environments must have improved low-temperature characteristics for capacitors, inductors, resistors, and semiconductor parts such as CPUs, and components of parts and circuits are also affected. The simple solution would be to use a heater, but this is often not economically feasible. For example, equipment such as a tracking radar system that is mounted on an aircraft must be viable for operating in low-temperature environments without heating equipment.

Different contraction rates for different metal materials tends to induce mechanical failure at low temperatures as well. In addition, oil and grease harden at low temperatures, so special oil and grease must be used to lubricate moving parts, and daily maintenance is crucial.

Low temperature environments remove heat from products, and so they tend to cause phenomena that are opposite to those brought on by high temperature environments.

3-2 Humidity stress

When analyzing product failure, problems caused by humidity are found to be extremely common. Humidity testing results in characteristics that can be roughly summed up in the following three points.

(1) Extremely large fluctuations in the failure rate for parts and equipment
(2) Difficulty in specifying the causes of failure due to a tendency for variations in test results
(3) Great difficulty in correlating with nature, or with other types of tests or with others doing the same test.

Other characteristics include problems in measuring relative humidity over a long period and difficulties in maintaining measurement accuracy, and the great variety of treatment when testing is required.

Even when the level of humidity stress isn't high enough to cause a problem independently, these humidity characteristics create complex conditions when combined with other external disturbances such as contamination, and can be considered the cause of a very large number of failure modes occurring under complex conditions.

At this point, let's look at the physical characteristics of water, the basis of this type of stress.

3-2-1 Liquid phase

The electrical characteristics of water (liquid phase) includes three extremely interesting physical properties when handling humidity. They are density, viscosity, and surface tension. These properties change as temperature changes.

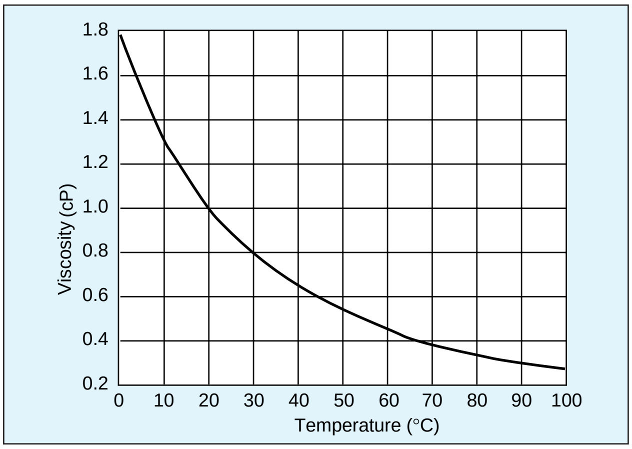

Fig. 3-2 Viscosity of liquid water vs. temperature

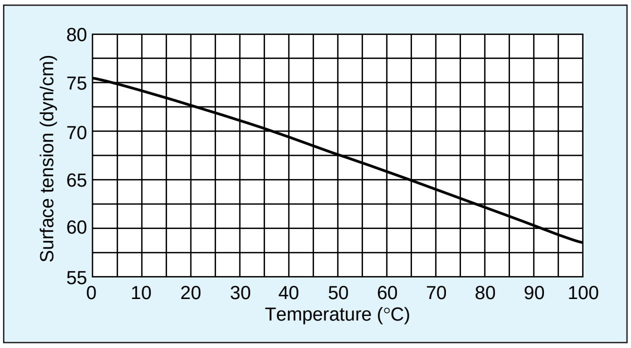

Fig. 3-3 Surface tension of water (against air) vs. temperature

Density changes from 0.998 g/cm^3 at 20°C to 0.958 g/cm^3 at 100°C. Fig. 3-2 shows changes in viscosity, and Fig. 3-3 shows changes in surface tension.

Furthermore, in electrical properties, the volume resistivity of pure water is approximately 20 $M(\Omega)/cm^3$, but water is a solvent that becomes contaminated easily, and the electrical resistivity of the water film on the surface of a body of water shows a high tendency to change.

3-2-2 Gaseous phase

The representative physical constants of water in the gaseous phase are density, viscosity, pressure, and diffusion coefficient.

Viscosity is internal friction within a gas when being pulled by any layer. Fig. 3-4 shows changes in viscosity due to temperature. The diffusion coefficient is the quantity of water vapor that can pass through a layer of air, and at atmospheric pressure in c.g.s units is 1.6×10^{-10} $(g/cm^2/sec)$.

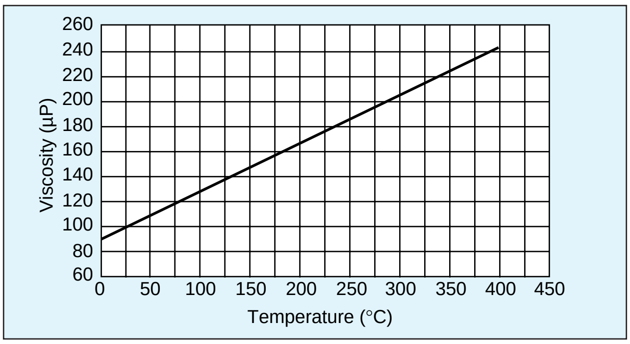

Fig. 3-4 Viscosity of water vapor vs. temperature

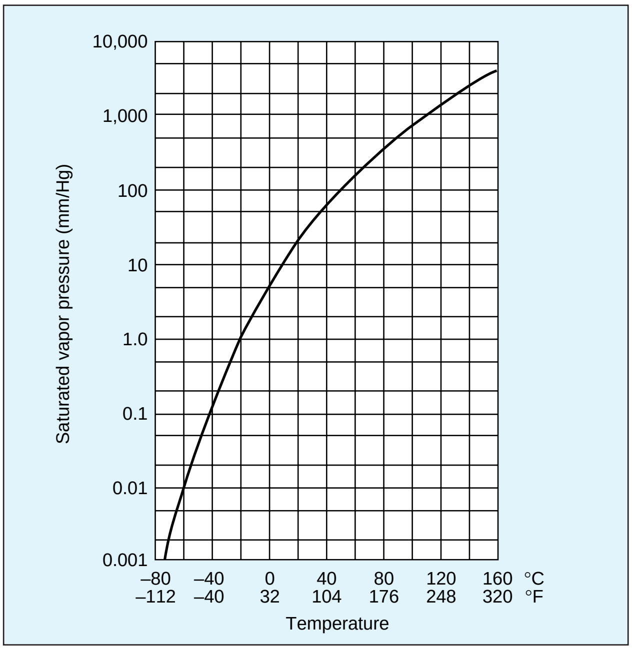

Fig. 3-5 Vapor pressure of saturated water vapor vs. temperature

In Fig. 3-5, the pressure changes of saturated air are shown as a function of temperature. A noteworthy characteristic is that between 40°C and 100°C the vapor pressure gradient increases roughly at a coefficient of 10.

Water vapor is a gas, and its temperature, pressure, and volume behave in accordance with the ideal gas law. Pressure from water vapor is partial pressure in the atmosphere, and in the natural atmosphere, is added to the partial pressure of other gases to form atmospheric pressure.

When the air is saturated with water vapor, the weight of the water present in the air varies according to the temperature, just as water vapor pressure does. Fig. 3-6 shows absolute humidity in the range from –60°C to +160°C in units of g/cm^3. In this type of saturated air, water vapor changes to the liquid phase when the temperature drops or when dirt and other condensation nuclei are present.

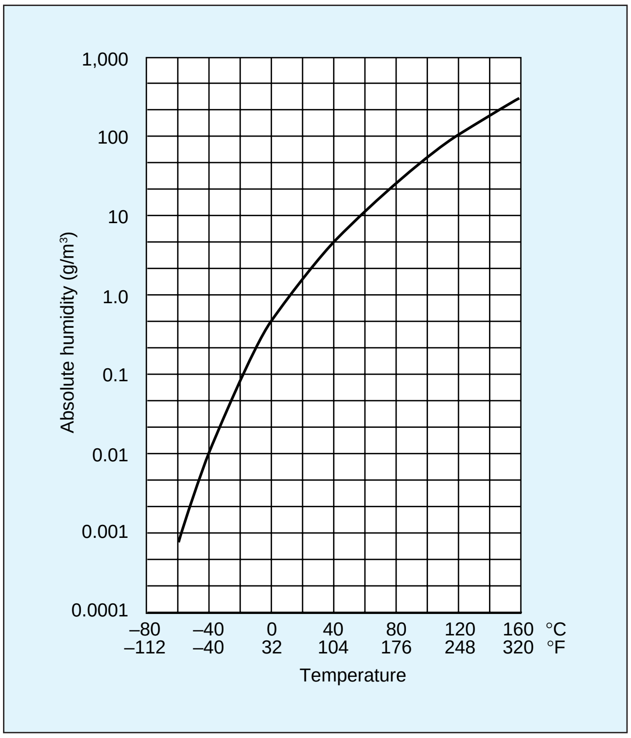

Fig. 3-6 **Absolute humidity of saturated water vapor vs. temperature**

Furthermore, water vapor has two interesting electrical characteristics. An increase in absolute humidity causes a drop in the Frashover voltage between the terminals of a product, and absorbs electromagnetic energy.

Fig. 3-7 shows the energy absorbed by water vapor from electromagnetic fields in a wide range of frequency bands.

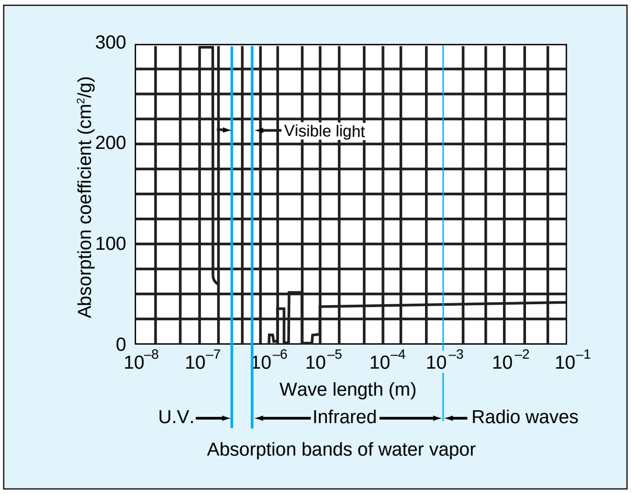

Fig. 3-7 **Electromagnetic wave absorption bands of water vapor**

3-2-3 Humidity environments in nature

Absolute humidity in nature is distributed throughout a wide range of geographical regions, but in general is higher in warm regions and lower in cold areas. In other words, this indicates that the capacity of air to maintain water vapor is higher in warm regions and lower in cold areas. The average value of absolute humidity in the atmosphere over land varies from 0.1 g/m^3 in the polar regions to approximately 27 g/cm^3 in the tropics. Occasionally in the tropics humidity as high as 32 g/cm^3 will be recorded.

While considering the surface conditions, a number of factors affect the absolute humidity in the various regions, and we cannot cover all the environments and classify them here. However, Fig. 3-8 shows the major types of regions in relation to absolute humidity and indicates the changes throughout the year. The types include polar, tropical, desert, and warm. Next, Fig. 3-9 shows the relationship between altitude and absolute humidity.

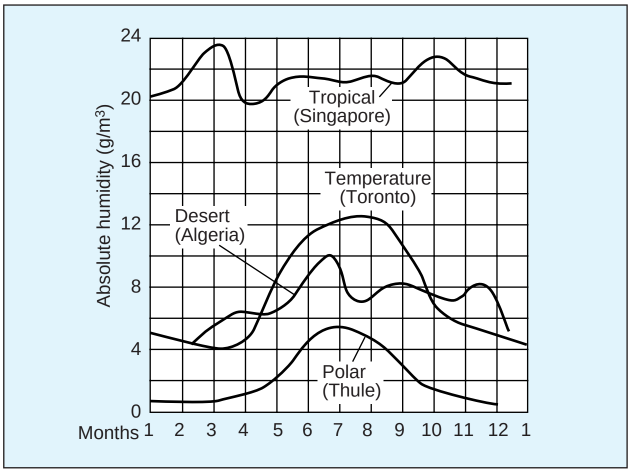

Fig. 3-8 **Monthly changes in absolute humidity in each atmospheric region**

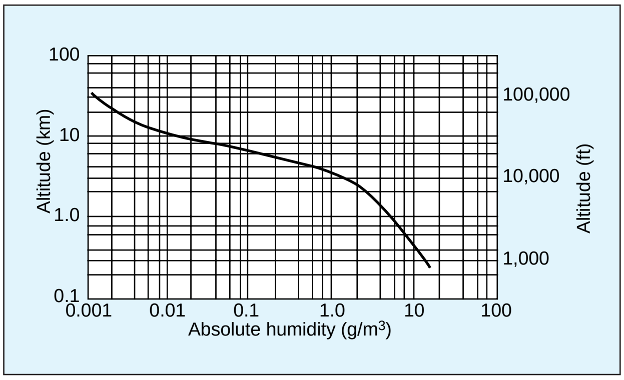

Fig. 3-9 **The relationship between altitude and absolute humidity**

Fig. 3-10 through 3-13 show daily fluctuations in temperature and water vapor. For further meteorological information, please refer to literature on geography.

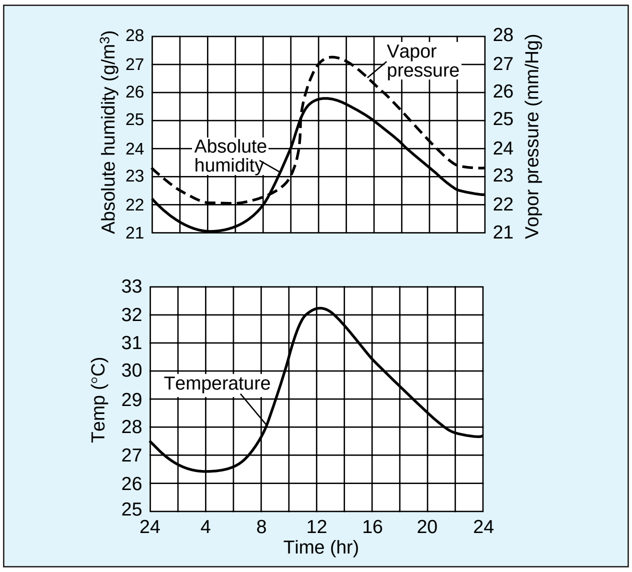

Fig. 3-10 Daily fluctuations (summer) in a tropical region (Singapore)

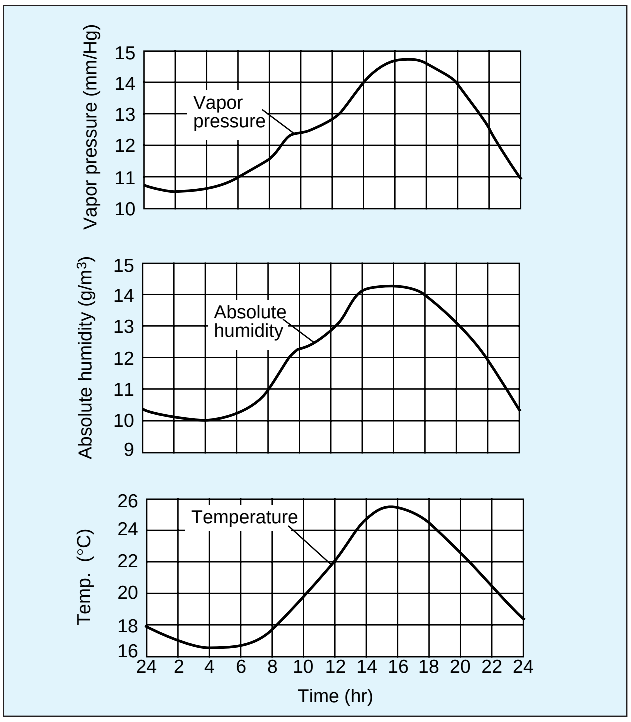

Fig. 3-11 Daily fluctuations (summer) in a warm region (Toronto)

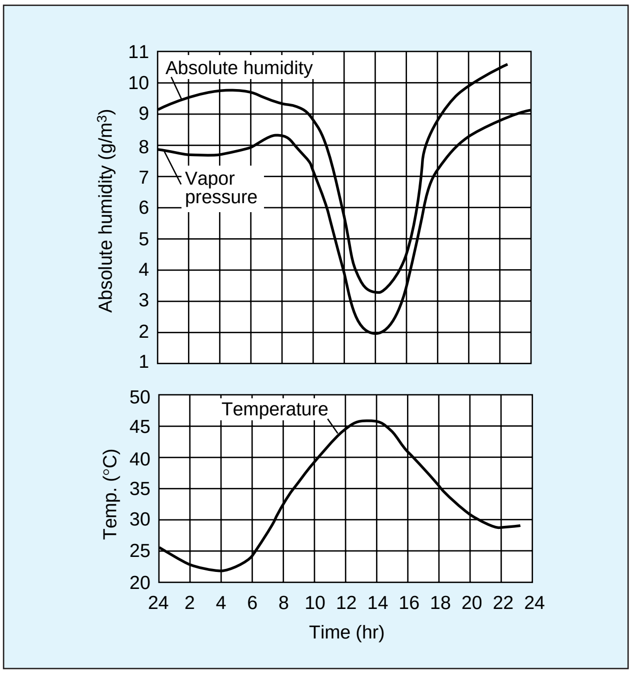

Fig. 3-12 Daily fluctuations (summer) in a desert region

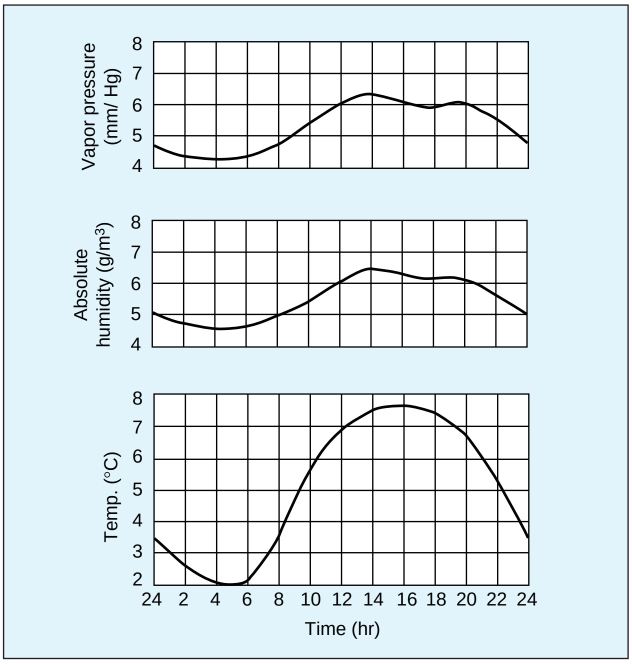

Fig. 3-13 Daily fluctuations (summer) in a polar region

3-2-4 Effects on electrical and electronic parts and materials

The failure rate due to natural temperature and humidity for equipment normally operated while set up on land is high compared to other normal environments. The problem is how water vapor is involved in the high failure rate sustained by these parts. If we assume that electrical and electronic parts are to be placed in a high-humidity environment, we can expect the following three phenomena to occur.

(1) If electromagnetic energy is present, it will be absorbed by the surrounding water vapor.

(2) An extremely thin film of water from condensation will form on the parts.

(3) Ensuing from a variety of weather changes, water vapor will penetrate the parts.

These phenomena produce the following changes in electrical characteristics.

1. The forming of a water film on parts and materials creates an electrostatic capacity effect due to electrical circuits forming and to a high dielectric factor. These effects change such values as Q, inductance, capacitance, loss factor, insulation resistance, and surface resistivity, and also serve to lower surface arc resistance.

2. When the materials are used for insulation, the internal loss of the volume resistivity is changed. When the materials are dielectrics, other complex changes are produced.
3. In particular, in dielectrics in a high-humidity atmosphere, the loss factor varies according to the frequency.
4. The dielectric factor of moist items increases with temperature.

Specific examples
1. In such phenomena as carbon film resistance, the limits of electrical resistance are exceeded if approximately 2 percent of that weight is moisture absorption
2. Most capacitors are unable to maintain necessary performance in regard to the dielectric constant if absorption exceeds 0.1 percent of that weight.
3. Quartz crystals are particularly sensitive to moisture, and failure may result from water vapor penetration totaling 0.004 percent of the volume of a sealed package.

4. *Mechanisms of water penetration*

I would like to organize the mechanisms of moisture penetration into an object.

Moisture penetration mechanisms can be broadly classified in the following two types:
(a) Diffusion through the materials (bulk) making up the parts or equipment, and
(b) Penetration through equipment seals.

Water vapor can only penetrate by diffusion through the materials when the molecular space of the component materials is greater than the diameter of the water molecule, which is 3.4×10^{-10} m (approximately 3.4 Å). The amount of diffusion of water vapor through the molecular space of the material is proportionate to the surface area of the aperture and the direction of flow of the pressure gradient of the water vapor.

Water vapor also has characteristic mechanisms for moving into the material, and a material penetration factor can be identified corresponding to the mechanism for the movement of vapor through the materials. For example, in a material with a diffusion factor of 10^{-7} g/cm^2/sec, moisture requires approximately 10 hours to permeate 1 mm and stabilize. Then, water vapor flows into the material until a steady state is created, and the quantity is determined by the penetration factor of the material existing along the route. In other words, even in substances in which sealing is mechanically complete, vapor will penetrate the material through further diffusion.

Even if we hypothesize a special condition of an environment of 100 percent water vapor, the water vapor penetration mechanism through leakage sites, we must not forget the existence of air together with the water vapor. In the market, there is an environment composed of air and water vapor as a composite gas, and in this situation penetration normally occurs through leakage sites. In general, the following two composite gas conditions can be found in the atmosphere.

(1) With low-pressure water vapor, the condition is mostly air.
(2) With high-pressure water vapor, the condition is mostly water.

Characteristic penetration mechanisms exist for a variety of situations found in these conditions.

Low pressure mechanisms are suited to conditions with less than 50 percent water vapor, and high-pressure mechanisms are suited to conditions from this point to conditions of 100 percent water vapor. In environments of saturation at 80°C or greater, the air:water ratio is 50:50. Thus, (1) the low-pressure water-vapor penetration process normally applies to saturation below 80°C, and (2) the high-pressure water-vapor penetration process applies to environments with saturation above 80°C. The penetration rates for each of those cases can be calculated as in Fig. 4-1.

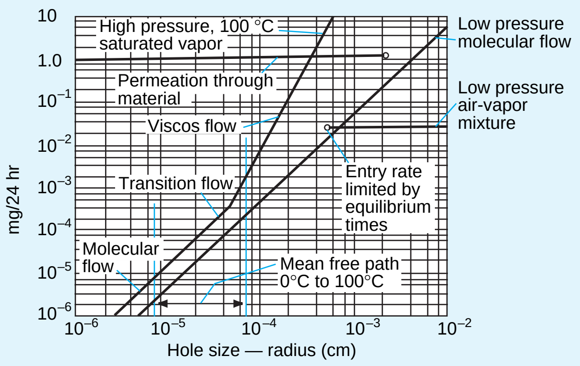

Fig. 4-1 Penetration characteristics of water vapor

4-1 Low pressure mechanisms (mostly air)

The mechanisms can be classified in two different types. Assuming that temperature, water-vapor pressure, and atmospheric pressure are constant:
(1) Water vapor penetrates and passes through by diffusing into air pockets along the route. In this case, the size of the air resistivity (penetration factor) along the route determines the amount of penetration. The penetration ratio varies according to the diameter of the holes.
(2) When a temperature cycle exists at this point, the pressure fluctuations extending along the route aid the passage of the air and water-vapor combination. The amount of water penetration is controlled by the partial pressure of the water vapor (i.e., the ratio of the air: water mixture) and the diameter and resistivity of the route.

The penetration mechanism varies according to the size and diameter of the holes. However, in penetration at low pressure, the variance is slight for small holes, but clearly appears in larger holes.

4-2 High pressure mechanisms (mostly water vapor)

When high temperature occurs simultaneously with high water-vapor pressure, three penetration mechanisms can be identified according to differences in the leakage sites or the diameters of the holes.

(1) When the hole diameter is smaller than the mean free path (7×10^{-5} cm), the amount of influx varies according to the resistance of the route and water-vapor pressure. When flow resistivity is compelled to change directions, the rate will be determined by the diameter and length of the route, and by the penetration factor in the air along the route. (Molecular flow)

(2) When the hole diameter is larger than the mean free path, the amount of influx is proportionate to the square of the pressure and resistance of the route. In this case, resistance is determined by the fourth power of the diameter, the length of the route, and the viscosity of the water vapor. (Viscous flow)
The amount of penetration is proportionately larger with large leakage rather than with small.

(3) When the hole is about the same size as the mean free path at the transition point between the above two types of flow, the amount of penetration is proportionate to somewhere between the first to second power of the water-vapor pressure, creating a mixture of both currents. Leakage in a closed box with remaining air affects the amount of influx when there is a temperature cycle, but that case is rare. (Transition flow)

4-3 Liquid phase penetration

In a water vapor test, just as in a penetration test in liquid, influx is possible in the liquid phase as shown in Fig. 4-2. When the diameter of the hole is at least 2×10^{-3} cm, liquefaction (capillary condensation) depends on the pressure and the resistance of the route, and the influx then occurs in the liquid phase. Resistance is determined by the fourth power of the diameter, the viscosity and density of the water, and the length of the route. In that case, the penetration pressure can be seen as simple water pressure or a pressure differential due to the difference in temperature.

When the diameter of the hole is smaller than 2×10^{-3} cm, surface tension obstructs the flow of water within a temperature range considered likely. The route of leakage is probably filled, but water vapor occurs from the leading edge of water facing this route. Vapor penetration depends on thermal conditions, route diameter, and the penetration factor of the air along the route. When the route becomes smaller, the vapor that evaporates from the leading edge surface diffuses through the route. The water-vapor pressure in this case causes saturated water vapor at the temperature that corresponds to the water temperature.

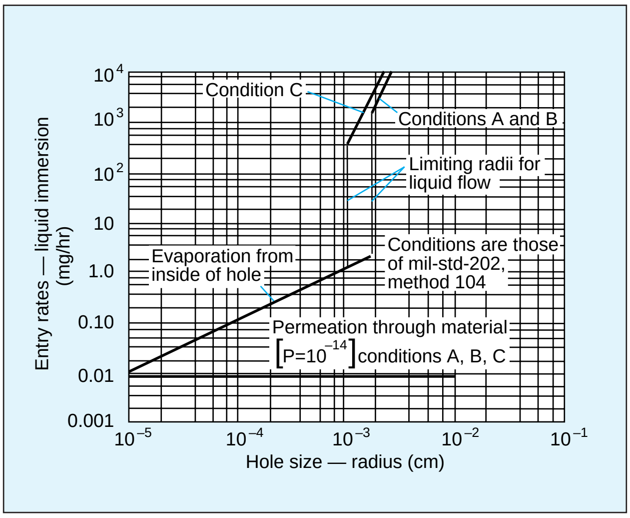

Fig. 4-2 Characteristics of water penetration

5. Summary

In this article, we have looked at the conditions of standard environments that form the basis for all environmental testing. In all public test standards and private standards as well, these conditions always form the basis for individual tests. Although special exceptions exist, efforts are being made unify standard values in the near future for each standard that now has differences due to use in different fields, and all standards are to be based on the IEC/ISO standards.

We have shown that physical concepts aid in understanding the phenomena caused by thermal stress and its relationship to products, which forms the basis for environmental testing. Physical concepts are also crucial to understanding humidity stress and the moisture penetration mechanisms. As a result, I believe you have seen that detailed, wide-ranging physical analysis to understand the minute phenomena. In general, chemical concepts are required subsequent to this. For example, chemical concepts are required to from the time during moisture penetration that contamination occurs, and from the point that moisture reaches the electrical circuits in the parts and units. Mastering these fundamentals at the outset provides the understanding that principles are fundamental and general, and that the failure phenomena of actual products are not unique and special occurrences. Based on acquiring these fundamentals together with lots of experience, one can look at and handle actual test specimens and without hesitation plan what should be done, and perhaps even predict the results before testing.

*Fig. 3-2 to 3-9 and Fig. 4-1 to 4-2 are reproduced from the following document.
International Series of Monographson Electronics and Instrumentation Volume 5
Environmental Testing Techniques and Material 1962
Pergamon Press

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