Report 1

Humidity Measurement and Control in the HAST

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HAST stands for Highly Accelerated Temperature and Humidity Stress Test, a test with environmental parameters of temperature and humidity. HAST is also called the Pressure Cooker Test (PCT) or the Unsaturated Pressure Cooker Test (USPCT). The major differences in testing methods from general evaluation tests for resistance to humidity are first that the temperature and humidity environment are set above 100℃, and second that the test is performed in an atmosphere with a high density of water vapor.

The purpose of HAST is to accelerate moisture penetration into the internal parts of the specimen by raising the water vapor pressure inside the test chamber to a level that is drastically higher than the water vapor pressure inside the specimen, and then to evaluate the specimen's resistance to humidity.

In this article, we shall look at environmental factors such as temperature and humidity that are related to testing in this type of special environment. I shall also discuss the current state of actual testing equipment and test standards, as well as the methods of measuring and controlling humidity at temperatures exceeding 100℃.

1. Environment During Testing

1-1 Relative Humidity in HAST

The relative humidity dealt with in HAST differs from the concept of relative humidity as defined under atmospheric pressure. Relative humidity under atmospheric pressure is defined as "the amount of water vapor actually contained in a constant volume of air, compared to the maximum (saturation) amount of water vapor possible to be contained in that air at that temperature", based on the assumed relationship that from the standpoint of pressure that the dry air pressure + the water vapor pressure = the total pressure. This total pressure value is normally in the vicinity of the atmospheric pressure, and the water vapor pressure is controlled by the atmospheric pressure, since the vapor pressure cannot rise above the atmospheric pressure. However, here we shall consider the atmospheric pressure in HAST as isolated within a completely sealed container in an atmosphere made completely of water vapor without air.

First, let's hypothesize the existence of dry air and water vapor under atmospheric pressure in the enclosed space of volume V at temperature T as in Fig.1.

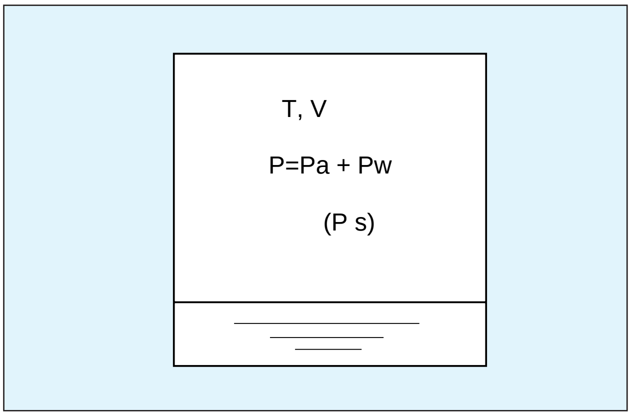

Fig. 1 Enclosed space under atmospheric pressure

The relative humidity ψ is defined by the following formula, given that the various partial pressures occurring at temperature T are Pa, the dry air pressure, Pw, the water vapor pressure, and Ps, and the saturation pressure of water vapor.

$$\psi = \frac{Pw}{Ps} \times 100 \ (\%RH)$$

At this time, we need to carefully note that ψ is calculated as unrelated to total pressure P and the dry air partial pressure Pa.

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Next, if we hermetically seal this space and somehow expel the dry air Pa, the space will be filled only by the water vapor, so the relationship becomes

P = Pw = Ps.

Therefore, within this space the water vapor can be treated as an independent ideal gas, and by setting either the temperature or the pressure automatically determines the other. In other words, PV = nKT (K = the Boltzman constant) or PV = RT. However, in reality this type of linear form doesn't hold true. Instead:

PV = RT + Pf (P.T)

P: pressure
V: volume
R: gas constant
T: temperature
f (P.T): correction term for pressure and temperature

This type of correction term becomes part of the equation. Including the compensation of this correction term, HAST uses the water vapor table (compiled by the Japan Society of Mechanical Engineers) based on the K function showing the relationship between temperature and saturation water vapor. (This is the case within Japan.)

Within a hermetically sealed space as in Fig. 2, if we posit a saturated water vapor environment in the temperature occurring at that time, and we heat up a partial area (the area enclosed by the dotted line) within that space, then if we say that T' > T, we can regard that space as a region of unsaturated water vapor. Then, if we set Ps' as the saturated water vapor pressure corresponding to temperature T' in this partial area, and we have Ps' as the saturated water vapor pressure for the peripheral space, we can define this as

$$\psi' = \frac{\text{Peripheral space saturated water vapor pressure (Ps)}}{\text{Saturated water vapor pressure at the temperature in the partial area (Ps')}} \times 100\ (\%\text{RH})$$

this is called the relative humidity occurring in HAST.

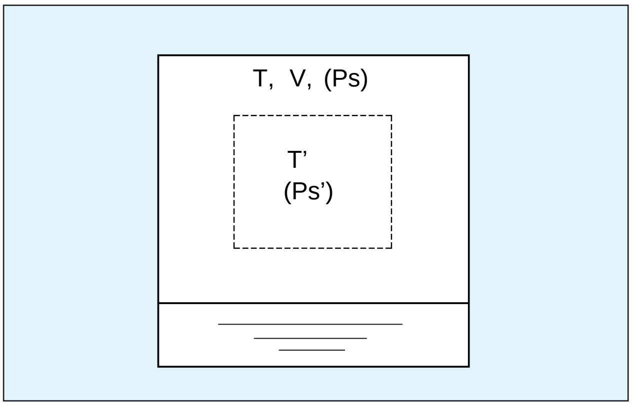

Fig. 2 Hermetically sealed space

How to read the steam table (next page)

The steam table can be used as follows.
For example, when the temperature within the sealed space is 130°C, and the RH is at 90%, the pressure becomes 0.2431 MPa abs., and the saturation temperature becomes 126.5°C.

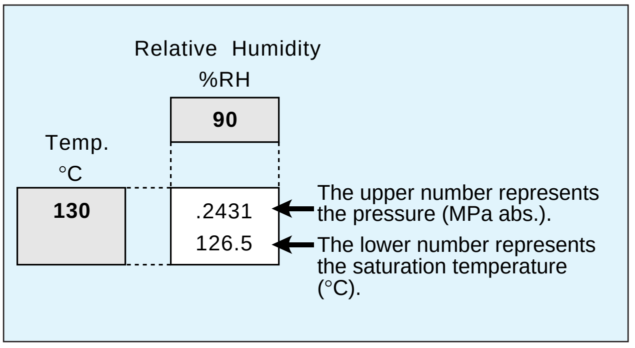

Fig. 3 How to read the steam table

*** K function (equivalent saturation pressure)**

The constant shows the saturation line, and this curved line is also the boundary of the partial region. The formula showing the equivalent saturation pressure β_k as the function of the equivalent temperature θ is as follows:

$$\beta_k(\theta) = \exp\left[\frac{1}{\theta} \cdot \frac{\sum_{\nu=1}^{5} k_\nu (1-\theta)^\nu}{1+k_6(1-\theta)+k_7(1-\theta)^2} - \frac{1-\theta}{k_8(1-\theta)^2+k_9}\right]$$

For the value of the constant included in the K function

$k_6 = 4.167\,117\,320 \times 10^0$
$k_7 = 2.097\,560\,760 \times 10^1$
$k_8 = 10^9$
$k_9 = 6$

The source: 1968 JSME STEAM TABLES

The steam table created from the above formula is shown in Table 1 (next page).

Table 1 Steam Table (Dry-bulb temperature 100 to 141 °C)

Pressure . MPa abs . / Saturation Temperature (°C)												
Temp. °C	Relative Humidity %RH											Temp. °C
	100	95	90	85	80	75	70	65	60	55	50	
100	.1013 100.0	.0963 98.6	.0912 97.1	.0861 95.5	.0811 93.9	.0760 92.1	.0709 90.3	.0659 88.4	.0608 86.3	.0557 84.1	.0507 81.7	**100**
101	.1050 101.0	.0997 99.6	.0945 98.1	.0892 96.5	.0840 94.8	.0787 93.1	.0735 91.2	.0682 89.3	.0630 87.2	.0577 85.0	.0525 82.6	**101**
102	.1088 102.0	.1033 100.6	.0979 99.0	.0925 97.5	.0870 95.8	.0816 94.0	.0761 92.2	.0707 90.2	.0653 88.1	.0598 85.9	.0544 83.5	**102**
109	.1385 109.0	.1316 107.5	.1247 105.9	.1177 104.3	.1108 102.5	.1039 100.7	.0970 98.8	.0900 96.7	.0831 94.5	.0762 92.2	.0693 89.7	**109**
110	.1433 110.0	.1361 108.5	.1289 106.9	.1218 105.2	.1146 103.5	.1074 101.7	.1003 99.7	.0931 97.7	.0860 95.5	.0788 93.1	.0716 90.6	**110**
111	.1481 111.0	.1407 109.5	.1333 107.9	.1259 106.2	.1185 104.5	.1111 102.6	.1037 100.7	.0963 98.6	.0889 96.4	.0815 94.0	.0741 91.5	**111**
119	.1923 119.0	.1827 117.4	.1731 115.7	.1635 114.0	.1539 112.1	.1442 110.2	.1346 108.2	.1250 106.0	.1154 103.7	.1058 101.2	.0962 98.5	**119**
120	.1985 120.0	.1886 118.4	.1787 116.7	.1688 114.9	.1588 113.1	.1489 111.2	.1390 109.1	.1291 106.9	.1191 104.6	.1092 102.1	.0993 99.4	**120**
121	.2049 121.0	.1947 119.4	.1844 117.7	.1742 115.9	.1639 114.1	.1537 112.1	.1434 110.0	.1332 107.8	.1229 105.5	.1127 103.0	.1025 100.3	**121**
129	.2621 129.0	.2490 127.3	.2359 125.5	.2228 123.7	.2097 121.7	.1966 119.7	.1835 117.5	.1704 115.2	.1573 112.8	.1442 110.2	.1311 107.4	**129**
130	.2701 130.0	.2566 128.3	.2431 126.5	.2296 124.7	.2161 122.7	.2026 120.6	.1891 118.5	.1756 116.2	.1621 113.7	.1486 111.1	.1351 108.3	**130**
131	.2783 131.0	.2644 129.3	.2505 127.5	.2366 125.6	.2227 123.7	.2087 121.6	.1948 119.4	.1809 117.1	.1670 114.6	.1531 112.0	.1392 109.1	**131**
139	.3513 139.0	.3337 137.2	.3161 135.3	.2986 133.4	.2810 131.3	.2635 129.2	.2459 126.9	.2283 124.5	.2108 121.9	.1932 119.1	.1756 116.2	**139**
140	.3614 140.0	.3433 138.2	.3252 136.3	.3072 134.3	.2891 132.3	.2710 130.1	.2530 127.8	.2349 125.4	.2168 122.8	.1988 120.0	.1807 117.1	**140**
141	.3717 141.0	.3531 139.2	.3346 137.3	.3160 135.3	.2974 133.2	.2788 131.1	.2602 128.8	.2416 126.3	.2230 123.7	.2044 120.9	.1859 117.9	**141**
	100	**95**	**90**	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	

1-2 Humidity Measurement and Control

As temperature and humidity control is naturally based on the presumed ability to measure these factors, in this section we will treat measurement and control as identical.

As previously noted, when relative humidity is mentioned in the context of HAST, we make conversions using the saturation vapor pressure occurring at various temperatures. However, an actual problem in the test space is that since we cannot directly obtain partial area pressure Ps', we measure the temperature and convert it to the pressure. In addition, we are able to directly measure the peripheral space pressure (Ps) using a precise pressure gauge, but it is difficult to obtain a gauge with long-term stability, and so in this case as well it is in actual practice simpler to make a pressure conversion from the temperature.

Fig. 4 shows the principle of the actual test equipment. Furthermore, a chamber with a sealed space uses a pressure vessel since the internal pressure is greater than the atmospheric pressure.

For the working space, a heater for humidifying water is installed at the bottom of the pressure vessel, humidifying water is stored there, and a heater for moisture is installed inside the working space. Temperature sensors are placed at various suitable sites, and the temperature is monitored. A suitable method is used to expel the air from within the pressure vessel, creating a completely water vapor atmosphere.

The required water vapor within the pressure vessel is supplied by heating the humidifying water with the heater for humidifying water. Subsequently, water vapor that enters the working space is reheated with the heater for moisture, becoming hotter than the water vapor in the peripheral space. We can assume that at this time the water vapor atmosphere inside the working space is unsaturated. If we do not reheat, the test space will become the saturated atmosphere at the peripheral space temperature.

Water vapor that has left the working space radiates heat onto the walls of the pressure vessel and cools, finally condensing and returning to humidifying water. This type of moisture circulation creates and sustains the testing environment.

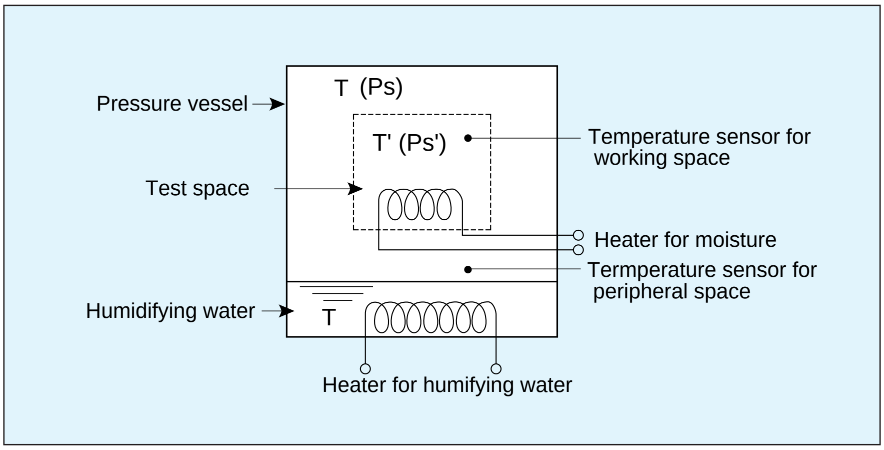

Fig. 4 Principle of the test equipment

2. Actual test equipment

The HAST equipment currently being used can be classified as follows.

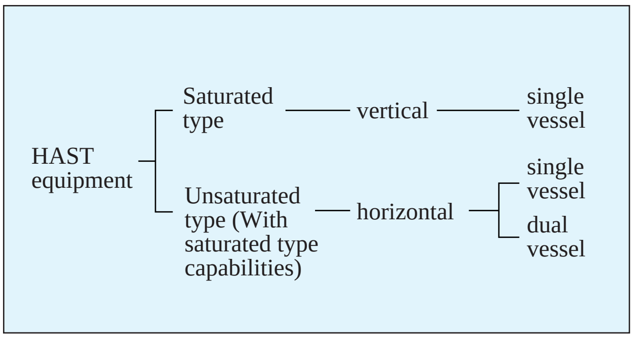

Fig. 5 Classification of HAST equipment

By function, the equipment can be classified as either the saturated type that can’t create an unsaturated environment, or as the unsaturated type able to create both the saturated atmosphere as well as the unsaturated environment. The unsaturated type is constructed as either a single vessel type set horizontally with a single pressure vessel, or as a dual vessel type with the humidifying water inside a separate vessel from the test vessel. Theoretically, it is possible to build a single vessel, vertical unsaturated type, but in reality the vertical type has a variety of drawbacks making it difficult to use, and almost all vertical equipment is of the saturated type.

Originally, HAST equipment was built based on remodeling medical autoclaves, and was mostly of the vertical type. The principle of that structure is shown in Fig. 4. This system is easy to understand, but in actual practice there is a tendency for condensation to form on the ceiling of the pressure vessel and to drip on the specimens during testing, making it difficult to maintain test reproducibility. In such an environment, it isn't possible to include electrical tests such as bias impression, so this arrangement has gradually been falling out of favor. However, this type is still used at times when importance is attached to connection with past tests.

Meanwhile, the manufacturers developed a horizontal model of the unsaturated type in an attempt to make improvements. The horizontal model retained the functions of the vertical model, but got rid of its drawbacks. In addition, a number of new functions were added, stimulating a rush of new applications. In particular, this model is becoming established as equipment for official reliability evaluation. In fact, IEC Pub. 60068-2-66 takes up test standards for HAST.

At this point, I would like to give a simple introduction of the structure and system of the mainstream horizontal equipment.

The horizontal model can be either single vessel or dual vessel, but both types employ essentially the same system. While there are no major differences, some differences appear due to the developmental approaches taken by individual manufacturers, for example whether there is a vapor circulation fan system, as well as differences in methods of measuring temperature and humidity.

The single vessel type horizontal equipment shown in Fig. 6 has the pressure vessel divided into the working space and the peripheral space.

The key feature of this type is the use of a circulation fan. The water vapor current circulated by the fan inside the working space corresponds to the flow of natural currents, so it averages about 0.3 m/s. The water vapor is generated from the humidifying water at the bottom of the working space, then is reheated by the heater for moisture just before being sucked into this fan, and so becomes hotter than the water vapor in the peripheral space as it is circulated into the working space. After the water vapor has gone through the working space, it reverses course in the area of the front door area, then is cooled as it returns through the space between the working space partition and the pressure vessel inside wall, and some of the vapor condenses and returns to the humidifying water. The shortage is resupplied from the humidifying water and takes the circulation loop. In this way, the specimen can be continuously supplied with a new and uniform environment.

The actual test equipment includes several types of auxiliary equipment for testing and safety.

Also, voltage impression terminals are provided in the unsaturated atmosphere for electrical testing such as bias impression testing done in the unsaturated atmosphere.

Furthermore, there is one temperature sensor inside the working space and one more in the humidifying water, but the newest equipment uses a system with a wet and dry bulb method installed, and is able to provide graded control for raising and lowering temperature and humidity.

The humidifying water can also be considered as one part of the equipment, and either distilled water or high quality deionized water is used. This is to avoid adversely affecting the specimens even in the HAST region with highly activated moisture. In particular, water with a high chlorine content such as tap water should never be used, nor should well water. Furthermore, most of the equipment parts, including the pressure vessel and most of the structural parts, are made of stainless steel to resist corrosion and degradation.

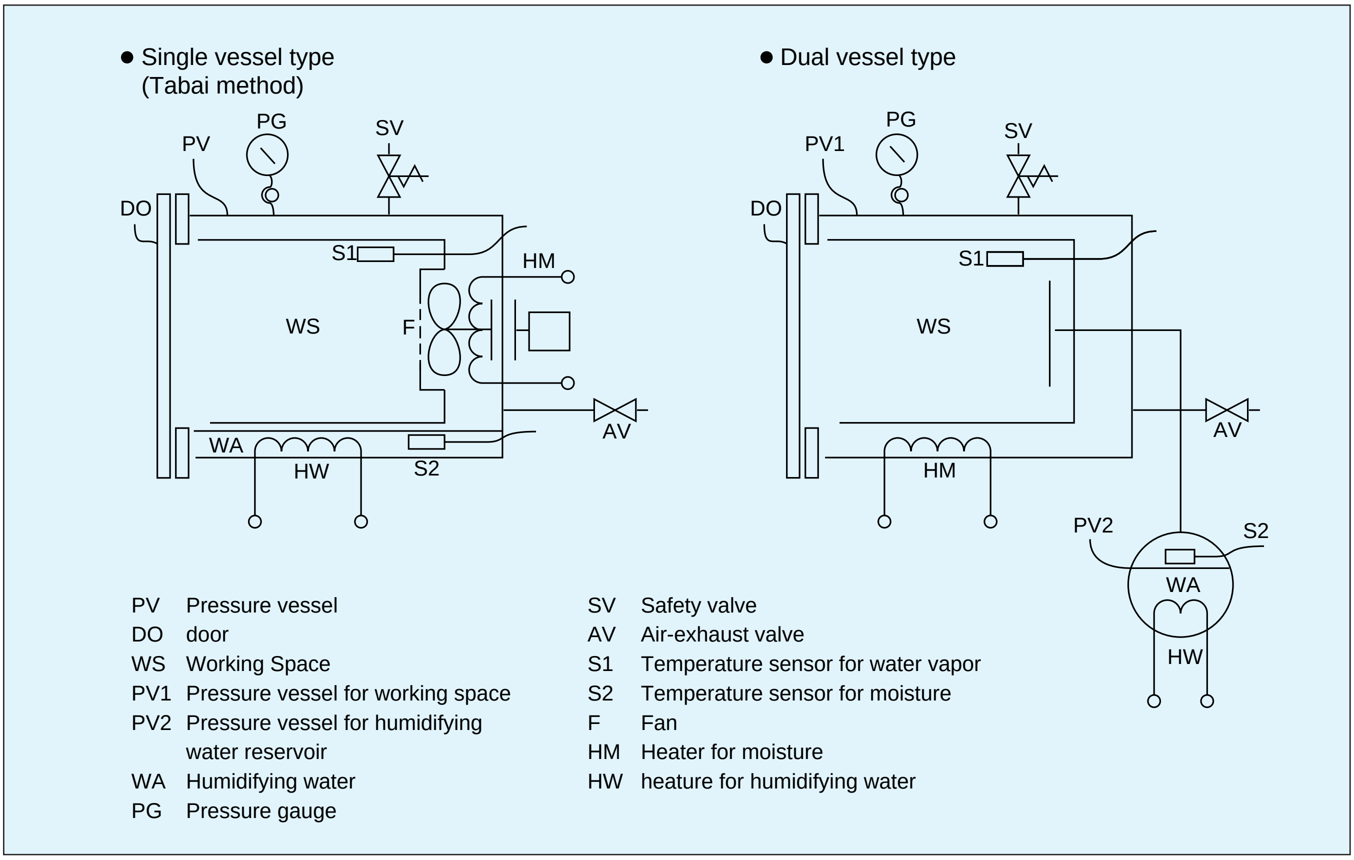

Fig. 6 Actual structure of test equipment

Photo 1 TABAI HAST CHAMBER
Model: EHS-411MD (Dual vessel)

3. Test Standards

The following are official test standards that apply to HAST.

International standards

(1) IEC Pub.60068-2-66 (1994-6) Environmental testing. Part 2: Test Methods-Test Cx; Damp heat, Steady state (unsaturated pressurized vapor)

(2) IEC Pub.60749 AMMENDMENT 1 (1991-11)
Semiconductor devices
Mechanical and climatic test methods
5C Damp heat, steady-state-highly accelerated

National standards

(3) JEDEC (Joint Electron Device Engineering Council) STANDARD (1988-6) No.22-110 (U.S.A.)
Test Method A110
Highly-Accelerated Temperature and Humidity Stress Test (HAST)

(4) EIAJ (Electronic Industries Association of Japan) ED-4701 (1992-2) (Japan)
Environment and Duration test methods for Semiconductor Devices
Method B-123 Unsaturated vapor pressure test

The most recent among these is IEC Pub. 60068-2-66 dealing with special standards for HAST serial test methods. This publication is found in Part 2 dealing with test methods. The annex, in particular, is quite substantial, and contains a detailed explanation of HAST. The annex presents a summary of such areas as the physical meaning of HAST, explains how humidity is measured and how the equipment is maintained, and offers a representative test equipment system. In addition, the steam table in the annex is positioned as a section of the main document, and the annex gives binding force to the regulations on temperature and humidity presented in the main document.

To unify IEC standards on test severity (test conditions), this publication conforms to Pub. 60749. The essentials of this standard constitute the first time that a comprehensive proposal created in Japan has been adopted internationally for official standards.

At this point I would like to describe the test procedure (the temperature and humidity sequence) in these regulations. (This explanation corresponds to Fig. 7.)

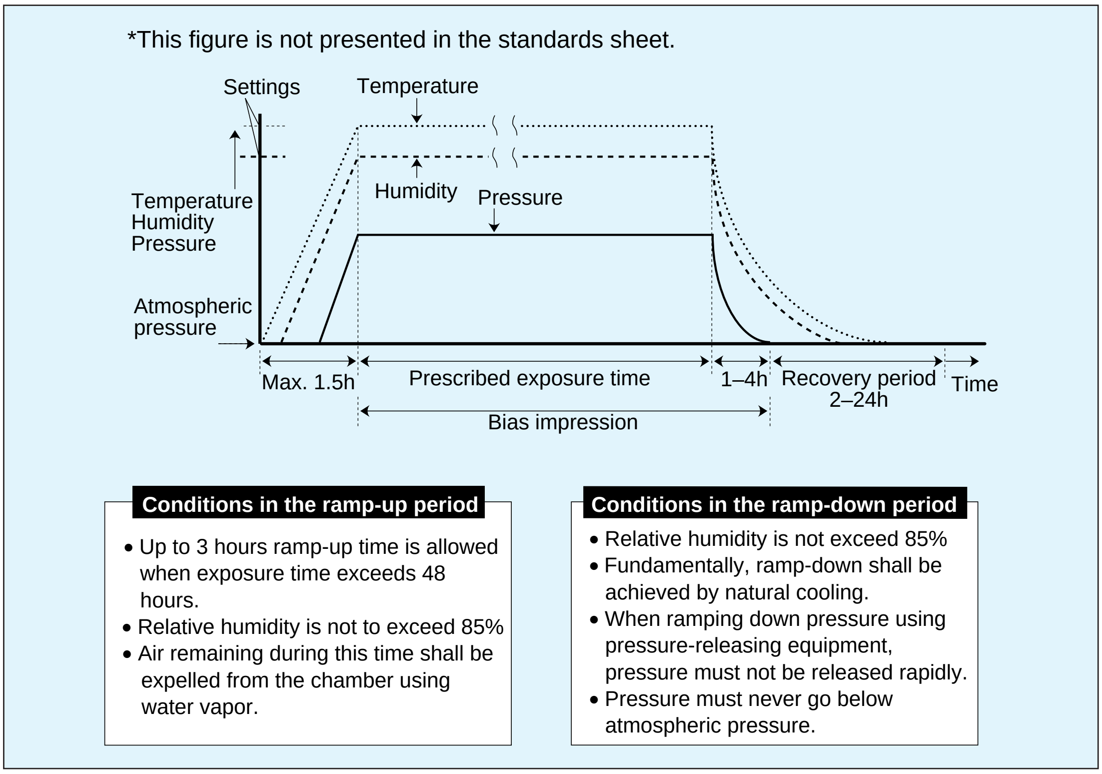

Fig. 7 Outline diagram of test procedure

(1) Initial measurements

A pre-test inspection is to be performed to confirm that each specimen conforms to the relevant specification, and shall include such areas as dimensions, functions, and a visual check.

(2) Testing

Specimens at room temperature shall be placed into the test equipment (hereafter, test chamber) at the same room temperature, and then necessary activities such as hooking up electrical wiring shall be done.

Test chambers that supply humidifying water shall then have the door closed and be heated to the temperature and humidity settings. After heating to around 100°C, the air-exhaust valve (AV in Fig.6) shall be opened and the air remaining in the chamber shall be expelled along with part of the vapor. When the atmosphere inside the chamber becomes completely water vapor at around 100°C, the valve shall be closed and heating shall continue to the target values for temperature and humidity. From this point the pressure (vapor pressure) inside the chamber shall be gradually ramped up until reaching the setting conditions. The test time count shall begin at the point at which the setting conditions have stabilized, and the specimens shall be left in this environment for the prescribed time. When required, electrical tests such as bias impression shall be performed simultaneously.

(3) Intermediate measurement

Requested measurements of the specimens (mainly electrical measurements) shall be allowed, but the test environment must not be disturbed. Therefore, the provisions stipulate that the operation of the chamber may not be stopped at an intermediate point, and specimens may not be removed.

(4) Recovery

After the prescribed test time is up, the test chamber shall cool down naturally or shall be gradually cooled down under control that approximates natural cooling, the pressure shall be ramped down, and the chamber shall return to its original condition.

After the pressure has been ramped down to the vicinity of atmospheric pressure, specimens shall be removed from the chamber and final measurements shall be made within 24 hours.

The procedure detailed above gives a rough outline of the test sequence including the control pattern for the test equipment. Fig.7 describes this process with extremely ideal straight lines, but in reality the temperature levels do not move so evenly during ramp-up and ramp-down of the temperature and humidity. However, large fluctuations in test conditions are not recognized. This unevenness occurs because the pressure vessel has an extremely large heat capacity. This uneven temperature occurs for a very short period compared to the length of the test and occurs at comparatively low temperature and humidity (below 100°C), so in actual practice we can ignore the effect on the specimens.

4. Problems in measurement and control

Humidity in HAST is handled in a simple environment composed of a nearly ideal water-vapor atmosphere after the air has been expelled. Therefore, in principle we can look at this theoretically as an ideal gas.

When problems occur in measurement and control, they result inevitably from the fact that each part in the equipment, including the temperature sensor, must be made using state of the art technology.

Since HAST is basically a highly accelerated test that works by strengthen environmental stress to extreme levels, there is a possibility of degradation of the precision of the measuring equipment due to the equipment's ability to withstand the environment or deterioration or problems with cleanliness. I believe we must consider these points when attempting to maintain precision.

The following points in particular are important for measurement control.

(1) Degradation from the protective cover in storage of the measurement element due to material quality and processing method
(2) Smudging or corrosion of the measurement probe due to substances emitted from the specimens
(3) Smudging or endurance of the gauze for the humidity bulb when using the dry bulb method

These items also hold true when performing humidity testing under normal atmospheric pressure.

However, these phenomena occur very quickly in the HAST environment, i. e., a high pressure vapor atmosphere above 100°C. Therefore, the primary factor is the dulling of the sensitivity of the temperature sensor, resulting in control errors and instability.

These problems are difficult to resolve, and the most effective means of handling them is to clean and maintain the parts inside the test chamber every day.

In addition to such problems originating from the hardware, we must also recognize non-hardware problems. For example, current equipment is not constructed to directly expel the remaining air just before starting the test, and each equipment manufacturer sets the timing for closing the air-exhaust valve from the actual test values. Because of this, a very slight difference occurs in the amount of air that is expelled in a cold start (a start with the test chamber cold) and a hot start (a start with the test chamber warmed up). Another problem comes from the gas emitted from the specimens and the air dissolved in the humidifying water that are gradually released into the test chamber during the test, making it difficult to strictly say that the environment is completely a water vapor atmosphere. If this amount is large enough, it is likely to bring on the problems already discussed early on, and the presence of oxygen will cause the new problem of oxidation of the equipment inside the chamber as well as the specimens themselves. In such a case, the natural result is that the temperature and humidity values based on the steam table will not be correct.

To resolve this problem, some might believe that a vacuum pump should be used before starting the test, and gas should be released by baking the specimens and the humidifying inside the test chamber to forcibly extract the dissolved oxygen. However, if this is done after the specimens are placed in the chamber, it would—if even temporarily—expose the specimens to an unnecessary environment, ruining the basis for evaluation.

From a practical standpoint in testing, these problems are not currently seen as being especially important.

However, to maintain high precision and reproducibility in testing, it is vital for the user to always perform the test under identical conditions.

5. Summary

The HAST test method is “the measurement and control of humidity above 100°C”. Moreover, the environment is essentially obtained by creating a saturated water-vapor atmosphere. This is based on not having any gas present other than the water vapor.

In this sense, I must reemphasize that the definition of relative humidity is fundamentally different than relative humidity under atmospheric pressure. In other words, it is based on the definition explained in item 1, “Environment During Testing”, and the RH is found by making conversions according to the steam table using the K function. Several equipment systems are in use, but all are designed and produced in accordance with this definition (in Japan). As I stated before, the test standards have already been put in order and put into practical service, being actually applied in a multitude of ways. However, even in this type of situation we cannot say that no problems stem from the severity of the environment. To avoid even a few of these problems, we are currently supervising the equipment daily, in particular in regards to the all-important cleanliness. It is difficult to claim that the equipment has been perfected, as a number of problems (areas for improvement) still remain.

From a practical point of view, these equipment problems are not really very important when compared to the amount of stress in the test. However, we believe it is vital that we as the manufacturer renew our efforts to resolve these problems.