3.4 Humidity

Humidity is the amount of water vapor in the air, which is expressed by various indexes depending on the study objectives. These indexes are mutually convertible, although additional data including those on temperature and atmospheric pressure are required. It should be noted that technical terms used for some types of humidity differ slightly between academic disciplines (Appendix 3.4-1).

Types of instruments

The following are the main types of hygrometers that are used in most observations. With the aim of avoiding radiation effects, as in temperature measurement, a shelter is used for all hygrometers except infrared ones. Usually, a thermometer and a hygrometer are placed in a shelter.

Wet and dry bulb thermometers

One of the two juxtaposed thermometers is used as the dry bulb thermometer. The other is used as the wet bulb thermometer. This one is kept wet with gauze applied to a sensing unit and fed with water from a tank. Evaporative heat loss causes the wet bulb to cool. There is a relationship between the amount of water vapor in the air and the temperature marked by a wet and dry bulb thermometer. This relationship is used to determine the humidity.

To automatically observe the vertical distribution (profile) of temperature and humidity, platinum resistance thermometers and sheathed thermocouple thermometers are most commonly used. The Assman ventilated psychrometer incorporates a mercury thermometer, which makes the unit portable. It also has high measurement accuracy. For these reasons, it is used as a handy calibration instrument.

Dew-point hygrometers

Taking advantage of the electric conductivity of lithium chloride, which is highly hygroscopic, this hygrometer indicates the resistance value in response to the dew-point temperature. Under high-humidity conditions, it is capable of continuous measurement with high accuracy. This makes it well-suited to observation in snowy areas. However, it cannot function in low humidity, where the equilibrium temperature is below the atmospheric temperature. Dew-point hygrometers of a cooling type are relatively expensive. In this instrument, a mirror placed in the air is cooled and temperature is measured when frost forms on the mirror surface.

Polymeric humidity sensors

Moisture sensors made of polymeric organic substances measure humidity by detecting changes in electrical properties of polymer membranes in response to changes in atmospheric water content. The leading instruments are those in the HMP45 series (discontinued model, replaced by HMP155) marketed by Vaisala, Oyj., Finland (Photo 3.4-1). Although requiring an external energizer, they are small enough to be equipped in a radiosonde. Because of their easy maintenance in comparison with that for wet and dry bulb thermometers, they are used for continuous observation. There are a few things that need to be kept in mind: the sensor response time of about 15 seconds is slightly longer than that of other sensors; the sensor reads "100 %" continuously and takes time to recover once condensation forms on the sensing unit.



Photo3.4-1 A thin-film polymeric humidity sensor and a platinum resistance thermo sensor in HMP45D (Pt100).

Infrared hygrometers

The hygrometer operates by sensing the infrared absorptivity of water vapor, which gives it a fast response time. The instrument needs to be maintained and calibrated frequently, as its cell is prone to smudging during the observation of high-humidity air. (See Section 2.2 "Open-path CO_2/H_2O gas analyzers" and 2.3 "Closed-path CO_2 gas analyzers" for details.)

Measuring method

As dirt on the web bulb of a wet-and-dry-bulb thermometer prevents water from evaporating evenly, which causes large errors, the gauze needs to be changed periodically. In preparing gauze for a wet-and-dry-bulb thermometer, it has to be boiled well enough to remove accretions such as starch and oil, and then it has to be dried cleanly. The use of distilled water is desirable to moisten the gauze, and the wet bulb should always be kept wet with a thin film of water. The wet bulb sensing unit is positioned approximately 2 cm above the tank water surface, and the water level is maintained constantly. Periodical maintenance is also required to keep the dry bulb from collecting dirt and water droplets.

The polymeric humidity sensor has its sensing unit stored in a resin case which is equipped with a dust filter to protect the sensor. Attention should be paid to dirt on the dust filter and the sensor. Distilled water can be used to remove stubborn dirt. A humidity measuring chip is particularly fragile, and it has to be handled with great care.

As is true for temperature measurement, dirt caught in the shelter should be removed regularly.

The cell of an infrared hygrometer has to be kept clean with regular maintenance using a sponge and 50 % ethanol. If a closed-path hygrometer is connected with a tube to intake air samples, the tube needs to be regularly inspected, cleaned and replaced to prevent leakage, staining, internal condensation and intrusion of rainwater.

Instrumental errors between hygrometers are more pronounced than those between thermometers. To measure the vertical distribution of average humidity, it is recommended that air samples be collected from each elevation and measured with the same analyzer. This method, however, has the disadvantage of not being able to carry out continuous measurement at one point. Also, it is relatively difficult to provide maintenance in a remote place. For these reasons, more than one instrument in the HMP45 series, which is easy maintain, is placed and regularly calibrated at the same elevation.

† Tips!

For a ventilated psychrometer, enough gauze should be prepared for frequent replacement. A wash bottle with a capacity of 500 ml may be useful for cleansing gauze and supplying water to the tank.

Tips 3.4-1

Tips!

For easy replacement of the sensory unit, the HMP45 series is designed to be insertable. Structurally, as the cable disconnects when tensed, special care should be directed to wiring. The cable near the sensor may be wound into one or two loops and then fixed.

Tips 3.4-2

Calibration

Active sensors need to be periodically corrected using a reference instrument placed at the same level. Sensors, packing materials and joints that have deteriorated over time must be replaced. To calibrate the reference instrument, a chloride-saturated solution is poured in a test chamber, which is then covered with a lid and left at room temperature for at least one hour so that the test can be carried out under the condition of fixed relative humidity (Appendix 3.4-2). The test chamber used for the calibration of the HMP45 series is commercially available. With it, instrumental outputs can be adjusted. A humidity-measuring chip and a module can be replaceable.

Appendix 3.4-1: Definitions of humidity

Name [unit]	Conversion	Definition		
Water vapor pressure e [Pa]	e.g., Sprung Equation 1)	The partial pressure of water vapor in the humid atmosphere		
Saturation vapor pressure e_s [Pa]	e.g., Goff-Gratch Equation 2)	The maximum water vapor pressure the air can hold at a given temperature		
Saturation deficit $e_{\rm d}$ [Pa]	$e_{s}-e$	The difference between the saturation vapor pressure and the water vapor pressure		
Relative humidity $\phi_{\rm r}[\%]$	$\frac{e}{e_{\rm s}}$	Vapor pressure as a percent of the saturation vapor pressure		
Specific humidity q [kgkg ⁻¹]	$\frac{x}{1+x}$ or $\frac{\varepsilon e}{p-(1-\varepsilon)e}$	The mass of water vapor per unit mass of moist air ε : ratio of molecular weight of vapor to that of dry air, ≈ 0.622		
Mixing ratio x [kgkg ⁻¹] Absolute humidity in some engineering fields [kgkg ⁻¹]	$\frac{\mathcal{E}e}{p-e}$ or $\frac{q}{1-q}$	The mass of water vapor per unit mass of dry air ε : ratio of molecular weight of vapor to that of dry air, ≈ 0.622		
Absolute humidity ϕ_a [kgm ⁻³] Vapor density in some engineering fields [kgm ⁻³]	$\frac{0.00794e}{1 + 0.00366(T_{\rm a} - 273.15)}$	The mass of water vapor per unit volume of moist air		
Percentage humidity ϕ_p (saturation) [%]	$100 \frac{x}{x_{\rm s}}$	The ratio of the absolute humidity in moist air to the mixing ratio in saturated air (x_s) , expressed as a percentage		
Dew point temperature C_{dp} [°C]	Approximation 3) (Hayashi, 1988)	The temperature at which cooled moist air becomes saturated (i.e., condensation starts)		

1)
$$e = e_s - \frac{j(C_d - C_W)p}{755}$$

Where C_d : dry-bulb temperature [°C], C_W : wet-bulb temperature [°C], p: total atmospheric pressure [Pa], e_s : Saturation vapor pressure [Pa] at a wet-bulb temperature C_W and j: constant (0.5 when the wet bulb is not frozen and 0.44 when the wet bulb is frozen).

2) above water surface

$$\log_{10} e_{s} = 10.79574 \left(1 - \frac{T_{1}}{T_{a}}\right) - 5.02800 \log_{10} \left(\frac{T_{a}}{T_{1}}\right) + 1.50475 \times 10^{-4} \left\{1 - 10^{-8.2969 \left(\frac{T_{a}}{T_{1}} - 1\right)}\right\} + 0.42873 \times 10^{-3} \left\{10^{4.76955 \left(1 - \frac{T_{1}}{T_{a}}\right)} - 1\right\} + 0.78614$$

above ice

$$\log_{10} e_{s} = -9.09685 \left(\frac{T_{1}}{T_{a}} - 1 \right) - 3.56654 \log_{10} \left(\frac{T_{1}}{T_{a}} \right) + 0.87682 \left(1 - \frac{T_{a}}{T_{1}} \right) + 0.78614$$

Where T_a : absolute air temperature [K] and T_1 : triple-point temperature of water (273.16 K).

3)
$$C_{dp} = -c_2 \frac{\ln\left(\frac{e}{6.1078}\right)}{\ln\left(\frac{e}{6.1078}\right) - c_1}$$

Where c_1 and c_2 : constants ($c_1 = 17.2693882$ and $c_2 = 237.3$ above water surface, and $c_1 = 21.8745584$ and $c_2 = 265.5$ above ice).

Appendix 3.4-2: Equilibrium relative humidity of air with chloride-saturated solution

	0 °C	5 °C	10 °C	15 °C	20 °C	25 °C	30 °C
KNO ₃	97	96	95	95	94	93	92
KCl	88	87	86	86	85	84	-
NaCl	76	76	75	75	75	75	75
MgCl ₂ ·6H ₂ O	34	33	33	33	33	33	32

(unit: %)

(Japanese Industrial Standards Committee, JIS Z 8806:2001, Humidity measurement methods)