White Paper

rotronic
MEASUREMENT SOLUTIONS

WATER ACTIVITY

The measurement of water activity (aw) or equilibrium relative humidity (ERH) is a key parameter in the quality control of moisture sensitive products and materials. Water activity is defined as the free or non-chemically bound water in foods, pharmaceutical, cosmetics and other products.

Fresh apple and dried apple rings (different levels of water activity).

Content

Theory

What is water?

Water (H_2O) is a transparent liquid found throughout the planet. Awater cycle exists: evaporation of water from streams, lakes, rivers and oceans, then condensation of the water vapor in the atmosphere followed by precipitation with rain falling back down to earth.

Evaporation occurs based upon the saturation pressure of water. The vapor pressure of water, or saturation vapor pressure, indicates the amount of water vapor that can exist as gas mixed in the air and is very temperature dependent:

Temperature (°C)	Water Vapor Pressure (kPa)
0	0.61
10	1.23
20	2.34
30	4.24
40	7.37
50	12.33
60	19.92
70	31.18
80	47.34
90	70.11
100	101.33 = 1 atm

Saturation vapor pressure at different temperatures

Relative humidity is the amount of water vapor pressure present in the ambient atmosphere compared to the saturation vapor pressure.

Condensation occurs when the relative humidity is above 100%. Water vapor will condense from the air and water droplets will appear.

Water is the major component of most living organisms. From a biological standpoint, water has many distinct properties that are critical for the proliferation of life. It carries out this role by allowing organic compounds to react in ways that ultimately allow replication. All known forms of life depend on water.

What products contain water?

Two broad categories exist:

- Hygroscopic: substances that absorb water from their surroundings
  - Salts
  - Vegetal fibres (wood, paper, produce…)
  - Meat products
- Hydrophobic: substances that don't absorb water from their surroundings
  - Gases
  - Sand, glass in powder form
  - Metals in powder form

What is water activity (aw)?

Water activity is often described as a measure of the “free” or “non-chemically bound” water. These terms might be easy to understand, but do not cover all aspects of water activity.

The correct definition is: “The water activity (aw) of a food is the ratio between the vapor pressure of the food itself, when in a completely undisturbed balance with the surrounding air media, and the vapor pressure of distilled water under identical conditions. Awater activity of 0.80 aw means the vapor pressure is 80 percent of that of pure water. The water activity increases with temperature. The moisture condition of a product can be measured as the equilibrium relative humidity (ERH) expressed in percentage or as the water activity expressed as a decimal.” (Source: U.S. Food and Drug Administration)

The formula for aw is: **aw = p / ps**

Where **p** is the water vapor pressure above the product surface and **ps** the water vapor pressure above a surface of pure water. Both are measured at the product temperature and as a ratio the value is always between 0…1. Both parameters in the aw formula are temperature dependent and as such aw is temperature dependent. This is because temperature changes how water interacts with the product being tested.

Why measure water activity?

Water activity plays an important role in product quality in various fields, including:

- Food industry
- Pharmaceutical industry, Cosmetic industry
- Seed storage
- Tobacco industry
- Industrial manufacturing

As explained previously, all forms of life depend on water. Water activity indicates the amount of water which is biologically available to microorganisms. Each species of microorganism (bacteria, yeast, mould...) has a minimum water activity value below which growth is no longer possible.

Water activity	Contaminant
aw = 0.91...0.95	Many bacteria
aw = 0.88	Many yeasts
aw = 0.80	Many mildews
aw = 0.75	Halophile bacteria
aw = 0.70	Osmiophile yeasts
aw = 0.65	Xerophile mildew

Contaminants at different water activities

The US Food and Drug Administration (FDA) has adopted the concept of water activity for establishing limits beyond which certain types of foods are considered susceptible to mold and bacteria and have set the following regulations: The water activity level of 0.85 aw is used as a point of definition for determining whether a low-acid canned food or an acidified food is covered by the regulations. Low-acid canned foods can be preserved by controlling water activity at levels above 0.85 aw. The minimum aw level for the growth of C. botulinum is approximately 0.93 aw. Depending on various product characteristics this minimum level can be as high as 0.96 aw. The regulations (21 CFR 113.3(e) (1) (ii)) state that commercial sterility can be achieved by the control of water activity and the application of heat. The heat is generally necessary at aw levels above 0.85 aw to destroy dormant cells of microorganisms of public health significance (e.g. staphylococci) and spoilage microorganisms which can grow in a reduced aw environment. See also the following other sections of the regulations which deal with aw controlled products:

21 CFR 113.10

Attendance at an approved school giving instruction appropriate to the preservation technology involved.

21 CFR 113.40(i)

Equipment and procedures for thermal processing of foods where critical factors such as water activity are used.

21 CFR 113.81(f)

Additional factors to be controlled to prevent the growth of microoganisms not destroyed by the thermal process.

21 CFR 113.100(a) (6)

Record keeping requirements for aw determinations.

Some examples of water activity controlled low-acid canned foods, that may have an aw of greater than 0.85 aw, are: canned cake, bread, bean paste, some chutney, salted vegetables, salted fish, guava paste, lupini beans, syrup, toppings, puddings, and some oriental specialty sauces. Water activity is usually controlled by the use of salt or sugar. There are situations where routine aw determinations need not be made during production. For example, if salt is the preservative, percent salt determinations alone may be sufficient to document control of water activity and commercial sterility. However, the processor or the processing authority would need to have datawhich consistently relates salt levels in the particular product to aw levels. Water activity could also be controlled by formulation as long as the formulation is related to a given aw level by sufficient data. Since changes in ingredients suppliers may change the aw of the finished product, periodic aw determinations by the processor would be appropriate. (Source: U.S. Food and Drug Administration)

Water activity (aw) of some common foods

Liver Pate: 0.96
Cheese Spread: 0.95
Red Bean Paste: 0.93
Caviar: 0.92
Fudge Sauce: 0.83
Salami: 0.82
Soy Sauce: 0.80
Soft Moist Pet Food: 0.83
Peanut Butter 15% total moisture: 0.70
Dry Milk 8% total moisture: 0.70

Water can have different effects in various products and is recognized in the food industry as being critical for the microbiological, enzymatic, chemical and composition stability of most products. Variations in water activity can significantly affect:

- Color
- Taste
- Nutritional value
- Protein and vitamin content
- Shelf life
- Storage and packaging
- Solubility

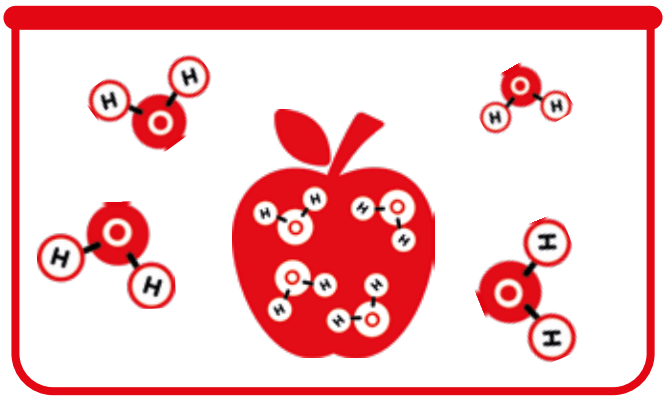
Water migration within a product

The water activity of a product will always try to reach equilibrium with the surrounding atmosphere. Free water will migrate from a region within a product with a high water activity to regions of low water activity. Water will migrate until equilibrium is reached. Equilibrium relative humidity (ERH) = 100 x aw.

What is static equilibrium?

Static equilibrium is a set of conditions under which a product and the surrounding atmosphere have the same water activity levels.

- Product and environment are at the same temperature
- The partial pressure of water vapor in the environment is the same as in the product.



Static equilibrium where there are the same amount of free water molecules in the product and in the surrounding air.

How to control water activity

The water activity in products can be controlled by using various additives (humectants), by using satisfactory packaging materials or by maintaining favourable maturation and storage conditions.

How can water activity measurements be applied in the real world?

Water activity provides better information than the total moisture content regarding:

- Microbial, chemical and enzymatic stability of perishable products such as foods, seeds and pharmaceutical goods
- Cohesion and flow properties of hygroscopic powders
- Adherence of coatings
- Control of caking and compaction properties
- Dimensional stability of materials such as paper
- Tensile strength and elastic recovery
- Yield pressure and compaction

Total water in a product

So we have seen that the water activity is part of the total water in a product; specifically it is the free water. However, there also exists bound water within a product. The bound water is usually measured by infrared or loss on drying: this is known as the moisture content!

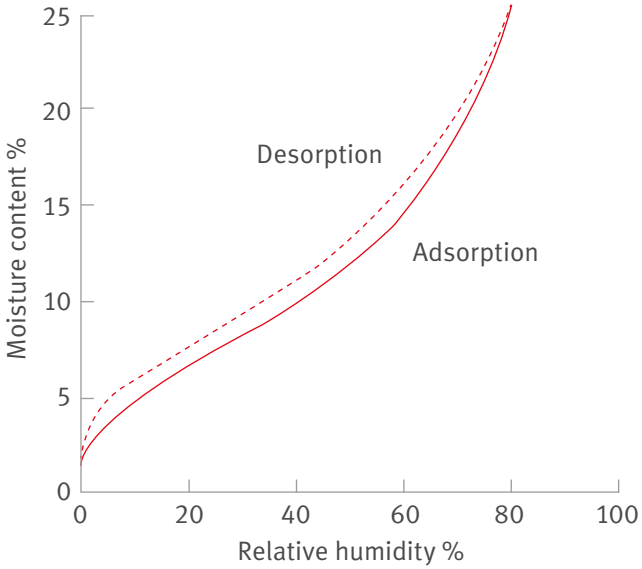
What is moisture content?

Moisture content is the percentage of water by weight in the product compared to the dry or wet weight of the product and includes both the bound water plus the free water. Moisture content is often confused with the water activity.

Is it possible to correlate water activity and moisture content?

At equilibrium, the relation between the percentage of water and the water activity of a hygroscopic material can be graphically represented by a curve: the sorption isotherm. For each water activity value, the sorption isotherm shows the corresponding moisture content at a given constant temperature. Each product has its own sorption isotherm.

With the help of a sorption isotherm, the moisture content of a product can be determined by measuring water activity. This is beneficial as water activity measurements are quick and non-destructive. The sorption isotherm (usually non-linear) is determined by experiment for each different product and at different temperatures.



Sorption isotherm

What should I measure: water activity or moisture content?

Both measurements have advantages and disadvantages. The disadvantages of measuring moisture content:

- Moisture content does not tell you how much free water is available to microorganisms
- Provides no information regarding how water will migrate in or out of a product
- Measuring the moisture content destroys the sample
- Moisture content alone may not mean anything
- Measurement techniques are either costly or time-consuming
- Moisture content is unaffected by sample preparation

Measuring water activity, however, provides many benefits:

- Directly measures free water
- Non-destructive
- Quick and simple measurement
- Measures differences in sample preparation (vital for products affected by external spoilage such as tablets, most food products and seeds)

How to carry out a test procedure

However, since water activity is a qualitative measurement, used alone it does *not* define:

- shelf life
- growth potential of specific organisms
- physical properties (clumping etc.)

In order to carry out a meaningful measurement for water activity, it is also important to check the actual parameter that you are looking to control.

1st test: Actual parameter and water activity

- Shelf life tests
- Presence of spoilage organisms
- Physical properties
- Taste tests
- Efficacy of products (drugs, cosmetics)
- Costly tests
- Long time required
- Often required for compliance

Initial tests provide the detailed information on the parameter you are aiming to control. The tests may take more time with greater costs. They will provide details that allow you to relate, for example, shelf life to water activity for your specific product. At the same time you can test the water activity of raw ingredients and mid-production samples.

This means, moving forward, subsequent water activity measurements alone can be used as an indicator of shelf life for end products, but also as a check on raw ingredients and processes to catch deviations before they can impact products. As water activity measurements are faster and available at lower cost this reduces overall costs and testing times.

2nd test: Test for water activity only

- Raw ingredients (check consistency)
- Production processes (do recipes remain the same)
- End products (for shelf life and quality)
- Quick and easy
- Performed on site/in field
- Lower cost

Example: using water activity for shelf life testing

For unique food products where published water activity data is not available shelf life cannot be assessed accurately by testing water activity alone. Also, where production processes can vary it may be interesting to refine the process to provide the best compromise between product costs and shelf life. In this example, Product Awas produced in four batches, each was immediately tested for water activity and then subsequently underwent a long-term shelf life test.

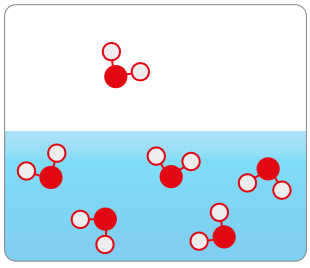
Product A	Shelf Life	Water Activity
Batch 1	9 months	0.83 aw
Batch 2	5 months	0.85 aw
Batch 3	3 months	0.88 aw
Batch 4	2.5 months	0.90 aw

Testing demonstrates that to meet a three-month shelf life products should be produced with awater activity reading equal to or below 0.88 aw. Quick and easy water activity measurements can therefore be used alone moving forward to confirm that products meet this specification. When can water activity measurement be used alone? This can be carried out on known products with defined standards:

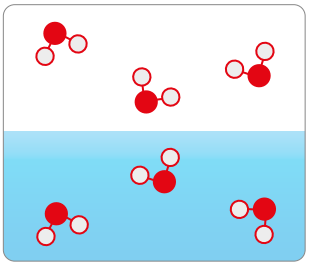
- Grains, cheese, salami…

For these products, health organisations or industrial bodies have already performed detailed testing and defined standard water activity limits for specified products. Water activity measurements can also be used alone to simply monitor product changes. The water activity provides a quick way to determine if an end product has changed:

- Processing change (drying time, particle size)
- Raw ingredient change (supplier inconstancy)
- Contamination (chemical or organic)



Measurement sample not yet in equilibrium



Measurement sample in equilibrium

How to carry out awater activity measurement

1. As a qualitative measurement it is important that variables are eliminated when performing measurements. This includes temperature and sample preparation.

2. Place a sample of the product to be measured into a Rotronic sample cup (14 or 40 mm deep).

   Recommendation: fill up to within 3 mm of the rim if possible. The less air in the container, the faster the time to achieve equilibrium.

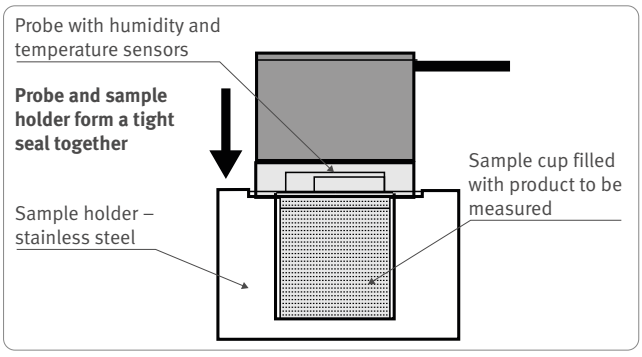
   Important: Do not allow the sample to touch the measurement probe head! Contamination of the measurement head will falsify all subsequent measurements made with other product samples.

3. Place the sample cup into the sample holder.

4. Close the lid or place the measurement head on the sample holder.

   Important: the probe and sample holder must form a tight seal. Only then is the system closed and equilibrium can be achieved. A clamp is available.

5. Water activity can be measured in two ways: either via a predictive model or by waiting until the water vapor pressure and the temperature have reached equilibrium within the measurement chamber. Rotronic devices have embedded Aw Quick software to perform this process quickly and repeatedly.



Cross section HC2-AW with WP-40

Temperature control

Water activity is sensitive to temperature. Measurements can only be made when the product sample, sample holder and measurement sensors are at stable temperatures. Many standards require measurements to be made at a specific temperature.

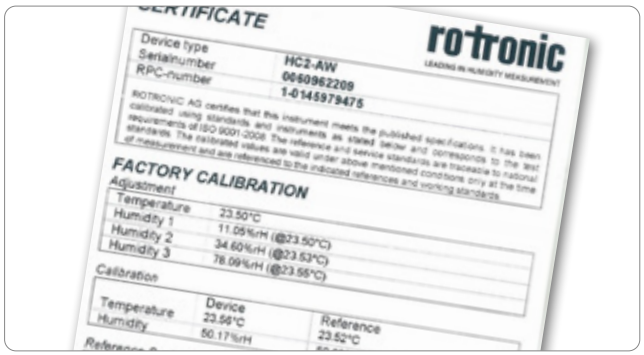
In situations where ambient temperature cannot be controlled or where you wish to test samples at temperatures away from ambient, a temperature controlled system should be used. Rotronic provides measurement solutions for both applications. In each case, Rotronic instruments are designed to maintain stable temperature through the use of large thermal mass or active thermal control for the AwTherm.

What measurement principle is used?

Rotronic measures water activity with a thin film capacitive sensor. The capacitance of the sensor changes based upon the number of water molecules in the air. Rotronic uses the same principle for relative humidity measurement as 0...1 aw = 0...100 %RH. The HygroMer WA1 humidity sensor has excellent long-term stability and accuracy.

How can I be sure that my measurements are correct?

All Rotronic probes are delivered with a factory calibration certificate. The probes are adjusted at three relative humidity points and at one temperature point. They are then calibrated at one humidity and one temperature point. The calibration/adjustment reference is ISO 17025 certified. Further calibration can be requested pre-delivery to ISO 17025 standards.


CERTIFICATE

rotronic

Device type HC2-AW
Serialnumber 0050962209
RPC-number 1-0145979475

FACTORY CALIBRATION

Adjustment

Temperature	23.50°C
Humidity 1	11.05%rH (@23.50°C)
Humidity 2	34.60%rH (@23.53°C)
Humidity 3	76.09%rH (@23.55°C)

Calibration

	Device	Reference
Temperature	23.56°C	23.52°C
Humidity	50.17%rH	

Rotronic factory calibration certificate

How long is the calibration certificate valid?

Rotronic recommends calibrating probes every 12 months, but depending on customer-specific standard operating procedures (SOP) each customer will define their own calibration interval. ISO 21807 states that a calibration is required before each measurement or series of measurements, at least once a day.

Calibration and adjustment options

In order to carry out calibrations and adjustments (if found to be necessary) during usage, Rotronic offers various solutions:

- EAxx-SCS salt solutions, available at the following relative humidity values: 0.5, 5, 10, 11, 20, 35, 50, 60, 65, 75, 80 & 95 %RH. The Rotronic salt solutions are all delivered with an ISO 17025 calibration certificate.

Rotronic traceable salt solutions

- HG2-S & XL temperature and humidity generators, which can generate temperatures between 0...60 °C and relative humidity values between 5...95 %RH. The HG2-S & XL is delivered with an ISO 17025 accredited HC2-S reference probe. The major advantage of the HG2-S & XL is that you have the possibility to calibrate your probe at the exact temperature and relative humidity levels that you require.
- ISO 17025 calibration: Rotronic can provide ISO 17025 accredited calibration for temperature and relative humidity. ISO 17025 certificates are often required by regulatory bodies and for company Quality systems.

The Rotronic range of water activity analysers can be calibrated and adjusted via various display units (bench top, handheld, PC).

Is there any way to accelerate the measurement if it takes too long?

Rotronic offers two integrated modes:
AwE and Aw Quick

AWE mode is the conventional aw measurement with automatic detection of equilibrium. The natural (or static) equilibration of most products typically varies from 30 to 60 minutes.

The Aw Quick function allows water activity measurement results in typically four to six minutes by using an algorithm to predict the full equilibrium value (water activity) of the measured product. The function is very nearly as precise as the regular measurement method, typically within 0.005 aw of the value obtained conventionally.

Both methods require a stable temperature.

Depending on the instrument being used it is possible to switch the mode via the touch pad or by using the Rotronic HW4 software.

What does the Rotronic HW4 software offer?

Via the software, it is possible to:

- Choose the measurement mode: Aw Quick or AwE
- Set the relative humidity and temperature stability tolerance
- Input a batch number, product name and comments for a report
- Run multiple aw tests with different parameters or control temperatures (AwTherm only)

It is also possible to calibrate and adjust the probes with the HW4 software, also generating the necessary reports.


AW Report

AwQuick Mode
Batch Number: 1443
Product Name: Cereals
Comments: Cereals stored in ambient conditions

Dwell Time: 4[min]
Temperature stability: 0.04[°C/min]
Date: Dienstag, 22. November 2016
Time:09:11:04

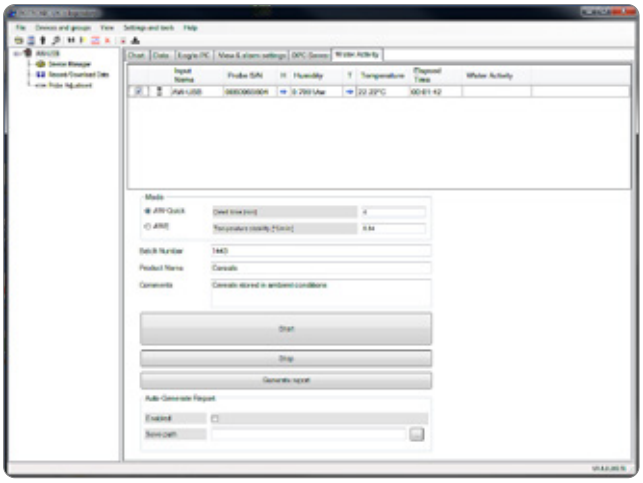
Input Name: AW-USB
Probe S/N: 006098604
Elapsed Time: 00:04:27
Water Activity: 0.7375Aw
Temperature: 22.43°C

Configured by
HW4 User name: Rico Hasler
User description: Admin
User ID number: 1453247

HW4 Information
Version:V3.8.0.16151
HW4 ID:01 33818116

User Events File
c:\users\rico.hasler\appdata\roaming\rotronic_hw4\event\HW4USER_2016.evt

PDF with reports generated.



Screenshot – HW4 Software

Products

Rotronic offers a complete range of products for the measurement of water activity. The instruments are accurate and provide high efficiency, compatibility and easy calibration. Combine the measurement heads, insertion probes, benchtop display units and handheld instruments as you need to meet your requirements.

Product overview	AwTherm	HygroLab	HP23-AW-A	HC2-AW-USB	HC2-AW-USB-SW	HC2-AW	HC2-P05	HC2-HP28
Measurement unit	✔			✔	✔	✔	✔	✔
Display unit	✔	✔	✔					
AwQuick function	✔	✔	✔		✔			
HW4 compatibility	✔		✔	✔	✔	✔	✔	✔
Stationary	✔	✔		✔	✔	✔		
Portable			✔				✔	✔
Interchangeable probe connector		4	2					
Probe connector fitted						✔	✔	✔
USB port/connector	✔	✔	✔	✔	✔			
Ethernet interface		✔						
Includes PC software HW4-P-Quick	✔				✔			
Dew and frost point calculation			✔	✔	✔	✔	✔	✔
Temperature controlled	✔							

Want to stay up-to-date with the latest products? Looking for software updates?

On our website www.rotronic.com you can find the latest Rotronic product information, software downloads, and videos on the measurement of various parameters.

Rotronic water activity video

Simply scan the QR code, alternatively visit the Rotronic website www.rotronic.com/aw

Related documents

Product information

- HC2-AW
- HC2-AW-USB
- HC2-P05
- HC2-HP28
- AwTherm
- HygroLab
- HP23-AW-A

Accessories

- WP-14-S
- WP-40
- PS-14
- PS-40
- AW-KHS

Download the Rotronic water activity brochure here:
www.rotronic.com/aw

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