



Water Activity Tools

How to Profit from Proven Product-Quality Techniques in Five Quick Lessons

aw

Safety & Profitability Intersect
Grocery Distribution & Shelf Life
Caking & Clumping
The Power of Isotherms
Moisture Migration

AQUA[®]
LAB
BY DECAGON

The Importance of Understanding Water Activity

It doesn't cost much to add water to your product. Unless you add the wrong amount, then water can get very expensive.

Add too much and your product will mold on the shelf.

Get the proportions wrong, and your product could lose its characteristic texture.

Combine two ingredients with incompatible water levels and you might get a clumpy mess that gums up the factory machinery.

Store a combination of ingredients at unstable moistures and you'll possibly end up with an ingredient so hard and dried up that it breaks a customer's tooth and causes a lawsuit.

For a cheap ingredient, water can cause a lot of expensive headaches.

Many manufacturers try to get a handle on the problem by measuring moisture content. They burn up a lot of product to get a measurement that can't answer their questions. That's because quantity doesn't tell you much about quality.

Water activity measures the energy status of the water in the product. Moisture content merely tells you how much water is in the product--water activity tells you what that water is doing and what it will do as the product sits on the shelf.

When you measure water activity, you get a fast, accurate, and powerful measure of water quality. You start to see the whole picture.

And when you see the whole picture, water once again becomes the cheapest ingredient in your product.

The scenarios included in this booklet are real stories. The names have been changed to protect the individuals and the businesses and are shared with permission.

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Finding the Moisture Super-Spec

QA/QC Specs are a critical part of every operation. Where do you set the standard?

How much of a safety margin do you need?

Scenario

Too many manufacturers measure moisture content and use a by-guess-and-by-golly standard. For example, a pet food manufacturer we know was producing to 8% moisture content. Why? Because at that level, he had never had spoilage problems or shelf life concerns. He had a safe product. But he discovered that he was over-drying, producing a less-appreciated and less profitable product.

Science

Many manufacturers have decreased costs and increased profits using water activity. You can make good operating decisions based on water activity, because safety information is contained in the actual water activity number.

By reducing water activity, you can rule out the growth of certain classes of microorganisms. At low water activities, you can preclude the growth of microorganisms completely.

Water activity is the only moisture related measurement that is an accepted HACCP critical control point. It is particularly important in intermediate moisture shelf stable food products. In combination with pH, water activity determines which of these intermediate-moisture foods are considered potentially hazardous by the FDA.



Critical control point for stable shelf life



Solution

When he decided to switch to a water activity spec, he discovered the power of a moisture number tied to both quality and safety.

The water activity of his product as originally produced was 0.50 a_w . He needed to stay below the mold growth limit of 0.65 a_w to produce a quality shelf stable product. Making the product moister also increased its palatability to pets.

Without knowing his exact costs, we can still infer the profit margin represented by a difference in 0.50 a_w and 0.65 a_w . If he produced 20,000 pounds of product per hour, operating sixteen hours a day five days a week, and sold the product for forty cents a pound, raising the target a_w level would allow him to produce an additional 1,877,314 pounds of product per year and would generate an additional \$750,925 in revenue. Even better, much of that would be profit since this change would reduce utility costs while keeping man hours, raw material costs, and wear and tear on equipment the same.

Keeping the Cake Fresh

Measuring water activity can predict shelf life. Managing it can increase shelf life—and market success.

Scenario

MOM & POP Bakery baked exceptional cakes. Local demand was high. Mom and Pop wanted to increase sales by expanding. Unfortunately, their delicious cakes had a shelf life of three days. A three-day shelf life left no time to ship the cakes. How could they keep their quality and simultaneously get longer shelf life?

Science

Once again, water activity to the rescue. Water activity is a well known predictor of microbial growth. A simple chart shows water activities below which certain molds will not grow. And there's just one chart (right). These values are the same whether you are measuring the water activity of brie or dog food. They don't change when you change your recipe.

Why is water activity the better predictor? Water content measures quantity. It tells you how much water is in the product. Water activity measures quality because it tells you what the water is doing inside the product. Some water is "bound"—tied up chemically within the product. The rest is "free." The free water may be used by passing microbes—but only if there is enough available.

Some microorganisms need more water while others need less, but all need a certain amount of free water. Moisture content tells only how much water there is, not how much is available. If you measure the water activity of your product, you will know which bacteria, molds, or fungi can grow on and in it. By reducing the water activity, you can rule out the growth of whole classes of microbes. At low water activities (<0.60), you can preclude the growth of anything at all.

You can reduce your product's a_w in several ways. Adding humectants like salt and sugar "binds" the water in the product. You haven't reduced the water content, but you have reduced the water activity. You can dry the product in a number of ways; air drying, vacuum drying, freeze drying, and osmotic dehydration all reduce water activity. You can also lower water activity by lowering the temperature of the product. In many cases, a minor recipe change can bring water activity to a safe and shelf-stable level.

Water Activity & Growth of Microorganisms in Food*

Range of Water Activity	Microorganisms Generally Inhibited by Lowest Water Activity in This Range	Foods Generally Within This Range
1.00-0.95	<i>Pseudomonas</i> , <i>Escherichia</i> , <i>Proteus</i> , <i>Shigella</i> , <i>Klebsiella</i> , <i>Bacillus</i> , <i>Clostridium perfringens</i> , some yeasts	Highly perishable (fresh) foods and canned fruits, vegetables, meat, fish and milk
0.95-0.91	<i>Salmonella</i> , <i>Vibrio parahaemolyticus</i> , <i>C. botulinum</i> , <i>Serratia</i> , <i>Lactobacillus</i> , <i>Pediococcus</i> , some molds, yeasts (<i>Rhodotorula</i> , <i>Pichia</i>)	Some cheeses (Cheddar, Swiss, Muenster, Provolone) and cured meat (ham)
0.91-0.87	Many yeasts (<i>Candida</i> , <i>Torulopsis</i> , <i>Hansenula</i>), <i>Micrococcus</i>	Fermented sausage (salami), sponge cakes, dry cheeses and margarine
0.87-0.80	Most molds (mycotoxigenic penicillia), <i>Staphylococcus aureus</i> , most <i>Saccharomyces (bailii) spp.</i> , <i>Debaryomyces</i>	Most fruit juice concentrates, sweetened condensed milk and syrups
0.80-0.75	Most halophilic bacteria, mycotoxigenic <i>aspergilli</i>	Jam, marmalade, marzipan and glacé fruits
0.75-0.65	Xerophilic molds (<i>Aspergillus chevalieri</i> , <i>A. candidus</i> , <i>Wallemia sebi</i>), <i>Saccharomyces bisporus</i>	Jelly, molasses, raw cane sugar, some dried fruits and nuts
0.65-0.60	Osmophilic yeasts (<i>Saccharomyces rouxii</i>), few molds (<i>Aspergillus echinulatus</i> , <i>Monascus bisporus</i>)	Dried fruits containing 15-20% moisture, some toffees, caramels and honey
0.60-0.50	No microbial proliferation	Dry paste and spices
0.50-0.40	No microbial proliferation	Whole egg powder
0.40-0.30	No microbial proliferation	Cookies, crackers and bread crusts
0.30-0.20	No microbial proliferation	Whole milk powder and dried vegetables

Solution

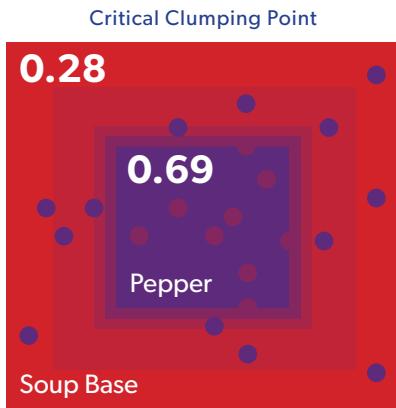
Mom & Pop solved their problem with a minor change. They manipulated their recipe while keeping an eye on the changing water activity. The final product kept all the tastiness of the original but with a lower water activity. Their new 9 to 12 day shelf life made shipping—and successful expansion—possible.

A Soup Mix Story

How to mix ingredients without making a mess.

Scenario

A small dry soup manufacturer was determined to avoid clumped-up soup base. One day he was processing a base with 3% moisture content. He measured some newly received pepper and found it to also have 3% moisture content. Sure that it was safe to mix the two components, he did so and headed out to lunch. The manufacturer returned from lunch, flipped on his processing machinery, and discovered that the whole batch had clumped. He had to throw away the lot. His loss felt even worse as he spent considerable time cleaning up his equipment.



Caking and clumping are ubiquitous problems in the food and pharmaceutical industries. Predicting—and avoiding—the problem means paying attention to three things: time, temperature, and water activity. Over time, free flowing powders will move through the stages of caking. The particles within the powder will get wet, then sticky. Sticky particles will agglomerate, compact, and finally reach the liquefaction stage. The process is affected by particle shape and size, temperature, moisture available within the system, applied pressure, and chemical composition. The problem can be avoided by keeping the powder below a certain water activity.

The soup manufacturer thought he had the process under control. His soup base was dry, the temperature and relative humidity in his processing plant were fine, so why did he end up with a mess?

Science

This manufacturer was distracted by moisture content numbers. Just like the fruitcake producer on page 12 he thought he had his eye on the ball, but he was actually out of the game completely.

He assumed that soup base at 3% moisture and pepper at 3% moisture would be at equilibrium. However, moisture content numbers don't contain information about equilibrium. To understand the energy of water, and predict whether and in which direction it will move, you have to measure water activity.



Had he measured water activity, he would have found that the soup base had a water activity of 0.28, while the freshly ground pepper measured 0.69 a_w . When he combined the two and allowed the mixture to sit over lunch, water moved from the pepper to the soup base and the water activity of the mixture rose above the critical clumping point.

Solution

The critical point at which a product will cake or clump is product-specific. It can be determined by creating a high-resolution moisture sorption isotherm for the product. Maintain the product below that value, and you will avoid clumping. As the soup manufacturer discovered, adding ingredients at higher water activities can change the water activity of the product. In addition, high ambient humidity and increases in temperature can raise the water activity of the product.

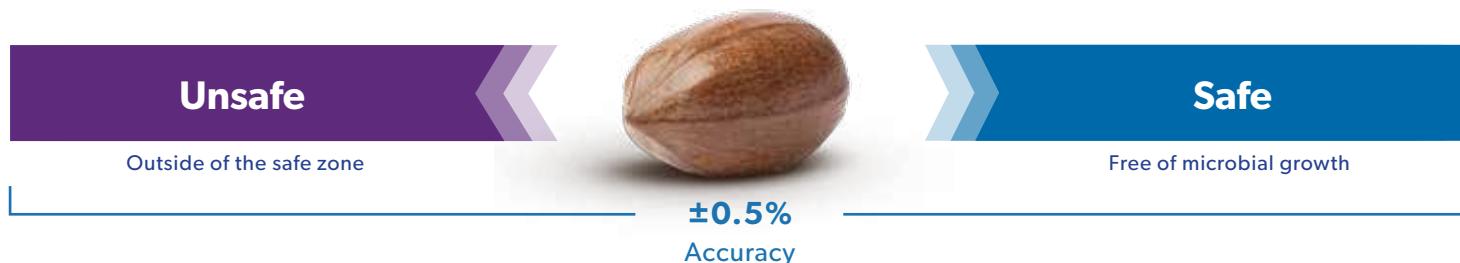
Water activity does not perfectly describe the chemical processes occurring during clumping and caking. Some products, like milk powders, may contain amorphous crystalline compounds. These products are subject to a phenomenon known as “glass transition.” When processed or stored above the glass transition temperature, T_g , these powders show stickiness, collapse, crystallization due to the viscosity decrease above T_g and the increased plasticization by water. During collapse, moisture moves from the crystallized to the amorphous regions, leading to the formation of inter-particle liquid bridges, causing particles to stick together. There is no routine method currently available to monitor glass transition during processing. However, a high-resolution isotherm can pinpoint the transition point. By keeping the product below that water activity spec, caking and clumping can be avoided even in glassy products.

Pecans & Airbags

How a “loss-on-drying” method failed to predict spoilage.

Scenario

Many manufacturers use the “loss-on-drying” method to measure water content. They weigh the original product, dry it out, and weigh again. A pecan grower sold pecans to a school fundraising organization. Ever year he dried his pecans to a moisture content of 4%. For thirteen years, the method worked perfectly. Year fourteen could have been titled “The Return of the Moldy Pecan.” Misleading because when you measure moisture content, you need to know how dry is “dry enough.”



Science

Moisture content measurements can be imprecise and misleading. That’s because when you measure moisture content, you need to know how dry is “dry enough.” But the water content of a safe product varies from product to product and from recipe to recipe. In corn seeds, safe storage means a water content of 12.5% while in mustard seeds, it’s 7.5%.

The water activity of a safe product is universal. A simple chart shows the water activity values below which certain molds do not have enough “free” water to grow. For example, below 0.6 a_w , water is so tightly “bound” that it is unavailable to even the most xerophytic fungi. That number is the same for every product, ingredient, and substance.

Moisture content measurements are also imprecise.



The pecan producer found this out when he checked the water activity of his pecans. A 4% moisture content relates, in pecans, to $0.68 a_w$. That's pretty safe. Anything under $0.60 a_w$ will be totally free from microbial growth. In pecans, that relates to 3.8% moisture content. Unfortunately, the moisture content measurement was only accurate to $\pm 0.5\%$. That means his fourteenth year pecan shipment had probably closer to 4.5% moisture content and was outside the safe zone.

In fact, the better accuracy, speed and easy measurements of water activity are attractive even to people who need to measure water content. An airbag manufacturer needed to control water content in the chemical propellant (cupric oxide) used in the airbags. He needed a tight control. If the cupric oxide's water content wasn't within spec, the airbag wouldn't inflate. Cupric oxide has a water content of about 0.05%— so low that measurements were hard to make. They required a high precision moisture balance and scrupulous attention to scientific technique. Even under the best conditions, readings were hard to get.

Solution

After finding the relationship of water content to water activity for cupric oxide, the manufacture found that a change as small as 0.02% moisture content related to a variation of 0.2 a_w . The a_w meter accuracy of $\pm 0.003 a_w$ let them measure to tighter controls—and made the measurements much easier to get.

Fruitcake & Fruit Cereal Surprise

Every producer needs to know what will happen to their product as it sits on the shelf.

High Activity

Lower Activity

Direction of water movement

Scenario

Shelf stable can mean “won’t get moldy,” but it covers a lot of other food qualities as well. Take, for example, a well known raisin bran manufacturer. Both the manufacturer and the consumer of the raisin bran expected crunchy flakes and chewy raisins. The consumer got a surprise when he bit into a rock hard raisin and broke a tooth. Soon after, the manufacturer got a surprise in the form of a lawsuit.

Fortunately, not all moisture migration problems end up in a court of law. But if you produce and sell products that contain discrete ingredients, you need to know where the moisture will go as the product sits on a shelf.

A fruitcake manufacturer wants to predict conditions over time in her fruitcake. She doesn’t want the cake to get soggy as the fruit pieces get dry and hard. So she measures moisture content. The cake contains 30% water, while the fruit pieces have 50% water. She knows that water wants to come to equilibrium. Therefore, she assumes that water will migrate from the wetter ingredient (the fruit) into the drier ingredient (the cake). Unfortunately, she has her eye on the wrong ball.

Science

While she’s watching the water content and feeling confident of the score, a whole different game is going on at the water activity level. If she continues without knowing the score of that game, she’ll suddenly be confronted with a surprise ending—in this case, dried up cake and soggy fruit, because the cake had a higher water activity than the fruit pieces at these moisture contents.

Unless acted on by other forces, water does want to come to equilibrium. But equilibrium occurs when the partial specific Gibbs free energy is the same everywhere in a system. Water activity is a measurement of Gibbs free energy. Moisture content has nothing to do with the energy of the water.



To understand this concept better, think of two tanks of water. One is almost full at 10,000 gallons. The other huge tank is nearly empty, containing only one gallon. Which way will water move? Knowing the water content of the tanks is completely misleading. The volume of water is irrelevant. Water moves from higher pressure to lower pressure, not from full to empty. If we raise the pressure of the nearly empty tank by putting it on top of the almost full tank, that last gallon of water will quickly leave its spacious tank.

Water activity, not moisture content, predicts how water will migrate within a product. The fruitcake manufacturer can develop a recipe in which cake and fruit pieces both have the same water activity. No moisture surprises when this cake is stored and sold--it is a safe, palatable, and shelf-stable product.

Solution

Knowing the water activity of discrete ingredients can help you decide how to process them. One solution to a moisture migration problem is to lower or raise the water activity of discrete components until they have the same water activity value. You can also retard the diffusion process within a component by increasing its viscosity. An edible barrier, like chocolate coating on the inside of an ice cream cone, can prevent moisture migration. Sometimes a_w differences that can't be equalized require separate packaging.

4TE DUO



Sensor Types: Chilled-mirror dew point, Infrared temperature

Accuracy: $\pm 0.003 a_w$

Range: 0.030 to 1.000 a_w

Repeatability: $\pm 0.001 a_w$

Resolution: $\pm 0.0001 a_w$

Measurement Time: Less than 5 min (most samples)

Operating Environment: 5 to 50 °C (39.2 to 122 °F) 20 to 80% Relative Humidity (non-condensing)

Temperature Control: 15 to 50 °C (± 0.2 °C)

Universal Power: 110 V to 220 V AC, 50/60 Hz Less than 0.4 amps

Data Interface: RS232A Compatible

Test Result Memory: 8,000 readings (each reading includes water activity, temperature, time, date, operator, and sensor used)

Program Identification: Alphanumeric; Programmable to display product name, lot, or product ID number

Certifications: CE; AOAC Approved Method for Measurement of Water Activity

For Volatiles try the AquaLab TDL Water Activity Meter

The TDL is the First Water Activity Meter COMPLETELY Unaffected by Volatiles

The newly released AquaLab Tunable Diode Laser (TDL) uses a finely-tuned laser beam to precisely measure the presence of water vapor. The laser beam width--which is less than one nanometer wide--is specific to the commonly occurring isotope of water.

Other vapor molecules--propylene glycol, alcohols, even different isotopes of water--do not affect the reading. The sensor is capable of measuring the water activity of previously impossible to measure samples, including soy sauce, ethanol, even gasoline.



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AquaLab by Decagon
509-332-2756
Fax: 509-332-5158
info@aqualab.com
www.aqualab.com



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