What is the water activity?

17 de junio de 2004

Summary

The water activity of foodstuffs is a very important aspect of food preservation. The growth of the various microorganisms stops at a given level of water activity and a comprehensive knowledge of these levels is essential for food processors as well as for research purposes.

Water activity is simply the ratio of the water vapor pressure in any kind of food system to the water vapor pressure of pure water.

aw = P product / Pwater

This simple mathematical equation has a very important meaning in food technology and in many biological areas. In this article three aspects of the application of water activity in food preservation are discussed.

1. The relationship between water activity and food preservation from the point of view of microbial growth, one of the most important aspects of food preservation.

2.Water activity prediction using theoretical equations.

3.Experimental determination of water activity using the measuring Instrument.

A number of food processing operations involve the transfer of water from one point to another. Effective dehydration, for example, is contingent on a knowledge of the water activity in food.

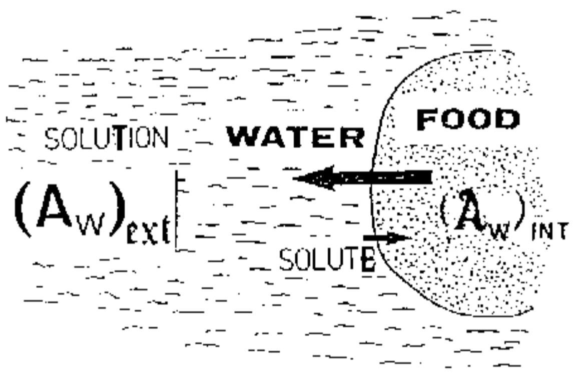
A further point of significance is moisture gain and loss in packaged foods. In order to predict the shelf life of foods the water activity also has to be predicted.

Finally, food processing in the form of salting or sugaring also depends on a knowledge of water activity.

This example (**Fig. 1**) illustrates "osmotic dehydration", the moisture transfer process which occurs during the salting of fish or cheese, etc. The food with its specific water activity is surrounded by a solution with lower water activity. The driving force between the internal and external water activity produces water flow which is known as osmotic dehydration. There is also a certain amount of solute diffusion into the food resulting in a reduction of water activity to a level sufficient to prevent microbial growth and hence to preserve the food .

Moisture migration in a dry food mix is also a very important problem and a good example of the application of water activity (**Fig. 2**). in a dry soup containing dried chicken pieces, beef, carrots, potatoes and rice, for example, and packed in a moisture proof package, water transfer takes place between the different ingredients. If all the ingredients have different moisture contents and levels of water activity, the water transfer will continue until a state of equilibrium is reached, i.e. until all ingredients have the same water activity levels, but not necessarily the same moisture content.

A major application of water activity concerns the control of microbial growth. Other aspects such as quality or organoleptic properties are important, but safety in food is the first and most significant criterion, and this means the control of microbial growth. The lowest limit for growth in foods or any other item is around aw 0.6. I n the narrow range between aw 1 and aw 0.6 a large number of microorganisms can grow which are potentially dangerous to food. As a result, the regulatory agencies in many countries are now beginning to define water activity standards for processed foods.



$$N_{H_2O} = K\,(A_{W_i} - A_{W_e})$$

Fig.1

The most important microorganism in this context is Clostridium botulinium which stops growing at aw < 0.95. All other microorganisms have defined growth limits. Yeasts and molds tend to be more resistant to water activity than bacteria Most pathogenic bacteria in food can be stopped by water activity of around aw 0.90, but to stop yeasts and molds it is necessary to lower activity to as little as aw 0.7 to 0.75. Staphylococcus aureus, Clostridium perfringens, Bacillus cereus and Clostridium botulinium are all very dangerous pathogenic bacteria in food. With the exception of Staphylococcus aureus, most pathogenic bacteria in food can be inhibited by water activity levels of less than aw 0.92 to 0.80. Staphylococcus aureus is inhibited at around aw 0.85.

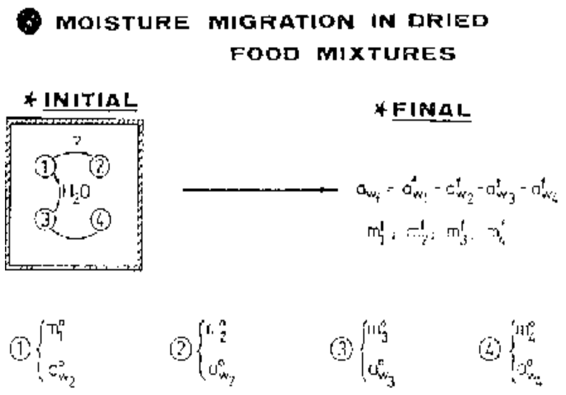


Fig. 2

When a bacterial cell is placed in a solution with low water activity, the cell dehydrates and bacterial growth is inhibited. According to the principles of thermodynamics, water activity is the driving force behind dehydration, which explains why water activity and not moistu re content influences microbial g rowth .

The ancient Egyptians practiced meat preservation in the form of mummification. Research has been carried out using the measuring instruments to explain the microbial stability of mummies. The specimens involved were embalmed some 2,000 years before

Christ and provide very good illustration of the way water activity is used to prevent microbial growth.

The embalmers used natron (natural soda) found in large quantities in the dry beds of the lakes of Egypt. Natron is a mixture of sodium carbonate with 10 molecules of water (Na2CO3 10H2O) and 10 to 30% sodium chloride (NaCI). Herodotus, the Greek historian, described the embalming process as follows: "the embalmers removed most viscera and plunged the body in a concentrated solution of natron for 70 days". it may be assumed that after this long time the body found an equilibrium with the saturated solution of natron. Recent measurements of the water activity of natron produced a reading of about aw 0.71. This means that if a fresh body with water activity of about aw 0.99 is put in this solution, the level at which equilibrium is reached is low enough to inhibit almost all kinds of microbial growth.

The picture of Ramses II shows the dehydrated body with lost water in the concentrated solutions of natron and added salt with lowering effect on the water activity aw (**Fig. 3**).

The second point to be considered is the prediction of water activity in foods, specifically semi-moist food with aw > 0.6, such as processed cheese, bologna sausage, leberwurst, ham, etc. It is possible to predict the water activity in these items by theoretical means. The main reason for the decrease in water activity is the dissolution of the solutes in the aqueous phase. The water activity can be easily calculated by physiochemical means with knowledge of the relation between this activity and the osmotic coefficient, a thermodynamic parameter which can be obtained from tables or by mathematical equation. If the solutes dissolved in, say, tomato ketchup - sugar (sucrose and glucose) and salt - and the modality (number of solute moles per 1000 g solvent) are known, it is possible to calculate the osmotic coefficient and to make theoretical predictions of the water activity.

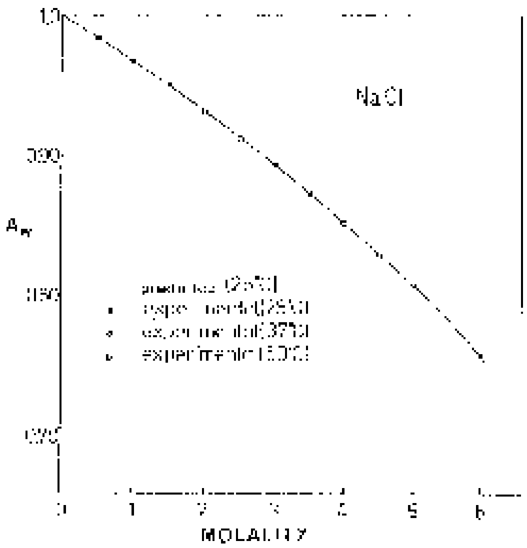


Fig. 4

Figure 4 shows the relationship between water activity and concentration (molality) of common salt (NaCI). The points were experimentally determined and the full line predicted theoretically using available mathematical equations. The correlation between prediction and reality is very high. The graph also shows another very interesting property of sodium chloride, namely the complete independence of water activity from temperature, which makes NaCI solutions excellent for calibrating water activity measuring equipment.

The following table lists the theoretically predicted and experimentally determined water activity values of different sausages:

NaCl	NaCl	Aw	Aw
	molal	exper.	pred.
leberwurst	0.656	0.97	0.978
bologna	0.778	0.97	0.974
longaniza	1.90	0.97	0.935
salami	1.75	0.97	0.953

Here again, the very good correlation between theoretical and empirical results is illustrated.

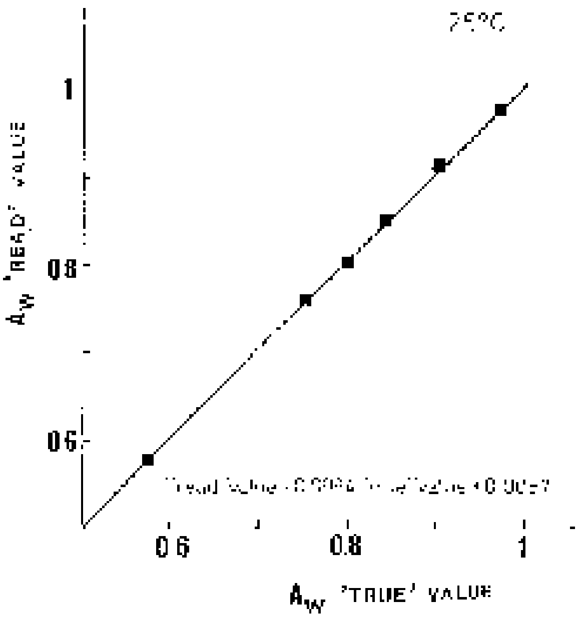


Fig. 5

For quality control, of course, it is not sufficient to rely on theoretical predictions, as the determination of NaCI water content or modality would be too time-consuming. A quick method is required of measuring water activity.

This leads into the third consideration to be discussed in this article, namely the experimental determination of water activity. The measuring instrument measures the relative equilibrium humidity in %rh which is directly correlated with the water activity in accordance with

the following formula:

aw = ERH / 100

To measure the water activity of food or other biological products an accurate and high-speed precision instrument is required which is capable of giving reproducible results, although speed of measurement is not as important in academic research as it might be in food quality control where 30 or 50 samples per day need to be inspected. Low cost is a further obvious criterion as is convenient handling - it is possible that the end user might not be a highly skilled technician. In industry the major considerations are speed, accuracy and precision.

As can be seen from from **Figure 5**,the accuracy of the measuring instrument meets all requirements in this respect. The vital significance of this high accuracy can be appreciated by considering a specific and dangerous bacteria. The water activity level for Clostridium botulinium is aw 0.95. Given an error of just 2% a reading of aw 0.95 could correspond to a real value of aw 0.93 or 0.97. At the latter level, Clostridium botulinium is toxic. With discrepancies of this nature, an accuracy level of + 2% is simply unacceptable.

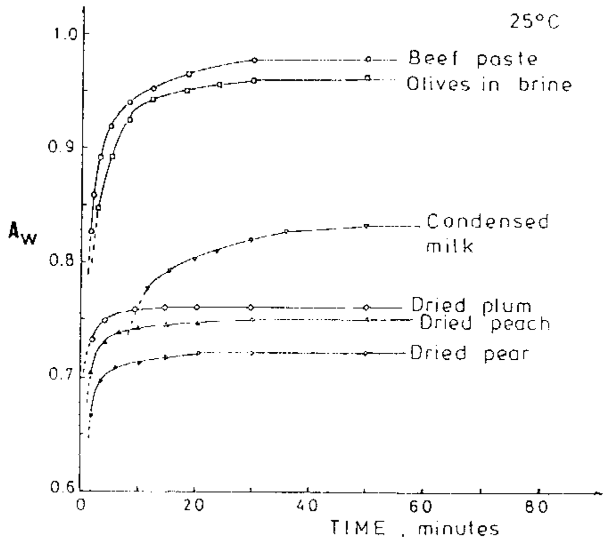


Fig. 6

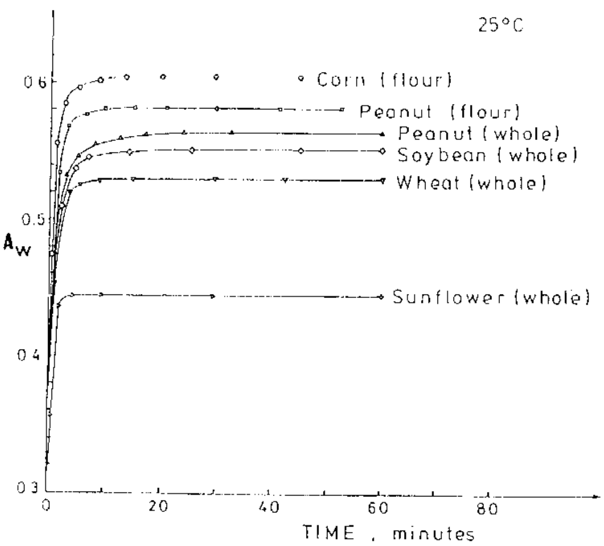


Fig. 7

For food manufacturers, the speed at which equilibrium is reached between the sensor and the food is also of importance. **Figures 6 and** 7 show the rates achieved with the measuring instrument. Water activity was plotted against time for different semi-moistfoods. Under normal circumstances, equilibrium is achieved more rapidly when the water activity is low. The equilibration times plotted here adequate for the food industry.

A further problem which might be encountered is one of volatile elements in food. The flavor of most foods is made up of hundreds of different chemical components such as alcohols or acids and so on. These volatile ingredients may interact or be absorbed in the sensor, producing contamination of some sort or another. This problem does not arise when measuring water activity in dry items such as grain, wheat, flour, corn flour, some biscuits, soluble coffee or dried milk. In semi-moist foods, however, it is possible for the volatile component to interfere with the reading. Acetic acid in tomato ketchup is one such example. Some foods also contain a small amount of alcohol which will also contaminate the sensor.

Figure 8 shows the calibration curve of the measuring instrument before and after contamination. The experimental sausage had a very strong aroma which did not produce any kind of problem.

In the American market one of the most important aw-controlled products is semi-moist pet food (which usually contains around 3% propylene glycol). PG is a volatile ingredient which contaminates the sensors of most types of electronic water activity hygrometers. The curve in **Figure 9** shows how the PG has interacted with the sensor to distort the reading.

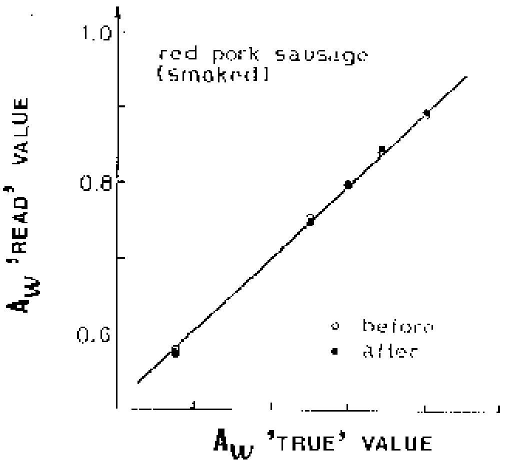


Fig. 8

Sensor contamination on the measuring instrument was studied using different filters placed between the sensor and the food. Several types of semi-moist food with strong aroma were taken into consideration. Ten consecutive readings of each type were taken after which a standard deviation S was calculated. In almost all cases with the exception of pet food containing PG no discernible contamination was measured and the sensor was effectively screened **(Fig. 10)**. A new "micropore" filter is also being studied at the moment. The problem with any filter is that it lengthens the equilibration time. Figure 1 1 shows the comparative times for the sensor alone and protected with a micropore filter. At the same time, however, the micropore filter appears to solve the problems caused with propylene glycol. An experiment was conducted using a modeS system consisting of water, sodium chloride and propylene glycol . The aw for water was predicted theoretically to be 0.90. The experiment was then conducted as follows (**Fig. 12**):

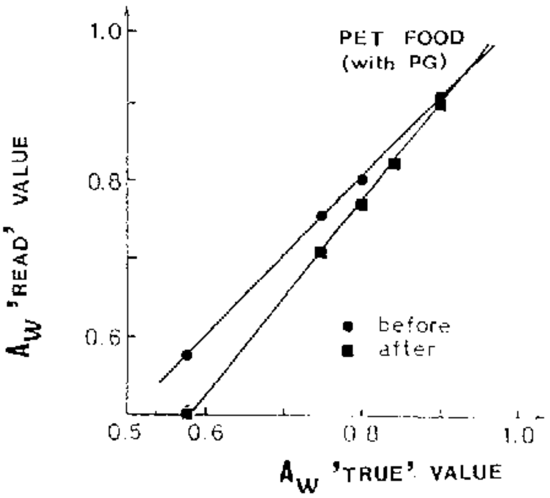


Fig. 9

In the first run the water activity of the propylene glycol model was measured and the reading found to correlate exactly with the theoretical calculation. Then barium chloride, which has a similar aw, was substituted. After two hours the PG model, now supposedly contaminated, was measured a second time. The correlation between the theoretical value and the measured value was again very close, and similar results were also achieved with barium

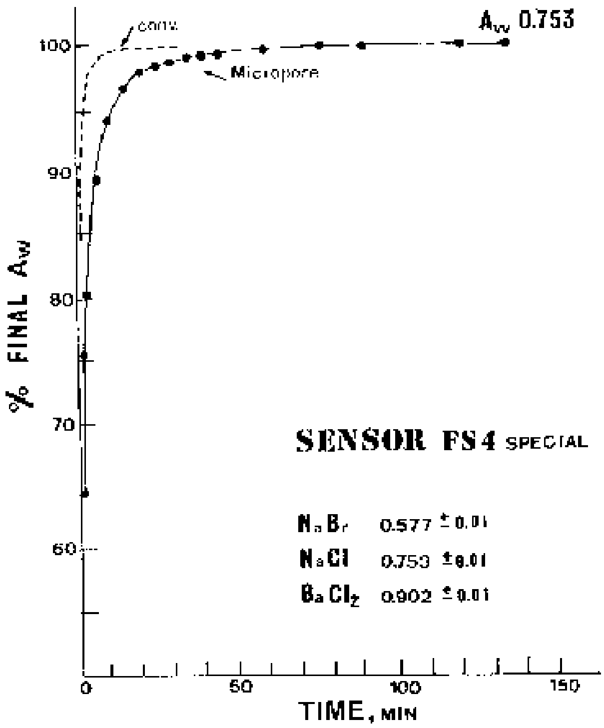


Fig. 11

chloride. The second run produced comparable findings, in other words the reading with the Thermoconstanter tended to correspond with the theoretical prediction.

The preliminary results with the micropore filter are extremely promising, but these findings have still to be verified through additional experiments with other volatile substances such as alcohol, aseptic acids and the like.