1.5. WET SOLID–HUMID GAS EQUILIBRIUM · WATER ACTIVITY

1.5.1. Definition

The background of water activity and the definition from its themodynamic concept was reported by several authors (Van den Berg, 1986; Vega-Mercado and Barbosa-Cánovas, 1994). All those works stated the importance of water activity (a_w) upon the preservation of food by lowering the availability of water to microorganisms and chemical reactions.

To our convenience, water activity is important for the kinetics of drying through the relationship between water content and vapour pressure. Vapour pressure gradient is considered to be the driving force of dehydration.

When a system consisting of several phases and components is in thermodynamic equilibrium, molecules are interchanging continuously between phases. The rates of interchange of molecules from all species between the phases is equal and there is no net change in the mass of various phases. Therefore, there is no net change in free energy between the phases, and the chemical potentials of all components within the phases are equal. The chemical potential can not be determined directly that is to say, it is expressed, for gases, in terms of an auxiliary function, named fugacity. Fugacity has the dimensions of vapour pressure, and represents the tendency of the molecules of a substance to escape. For an ideal gas in a mixture, it is identical to partial pressure. For real gases, as total pressure decreases, fugacity approaches vapour pressure, since all gases tend to exhibit ideal behaviour at zero pressure. Water activity from its thermodynamic concept is defined as the ratio of fugacities:

$$a_w = \frac{f}{f_0} \approx \frac{p}{p_0}$$

1.5.1

The water activity of a system is closely equivalent to the relative vapour pressure (RVP) of water over that system, although it is not identical to it in theory. Van den Berg (1986) reported from other authors that the numerical difference between water activity and RVP at ambient conditions (below 50ºC, at pressure of 1 bar) is less than 0.2%. This difference may be neglected for practical purposes, and justifies what is often stated: that water activity equals relative vapour pressure.

The sorption isotherm is defined as the relationship between the water activity (or the relative humidity of the surrounding air) and the moisture content of the material at equilibrium in constant temperature. The typical shape of an isotherm reflects de manner in which the water is bound to the system. Up to a water activity of about 0.30 water is considered to be held on polar sites of relatively high energies (Figure 1.5.1). This is called the monolayer. The a_w in the range of 0.30 to 0.70 is referred to as multilayer water. It consists of layers of water which are adsorved onto the first layer by hydrogen bonds (multi-layer region). Above water activity of 0.7 the water approaches the condition of "condensed water"; it is relatively free and the isotherm reflects solution and surface capillary effects (Wolf *et al.*, 1972).

Desorption isotherms are obtained when the equilibrium process departs from wet samples and allows them to equilibrate with the surrounding air by loosing moisture, and adsorption isotherms are obtained when the equilibrium process departs from dry samples. Depending on whether the process is of adsorption or desorption, the amount of water at any water activity may be different. This difference between desorption and adsorbtion is called hysteresis (Figure 1.5.1) (Wolf et al., 1972). Hysteresis is generally observed in most hygroscopic products (Okos *et al*., 1992). The hysteresis phenomenon has also been studied for meat and meat products. The results of those studies are contradictory. For instance, Wolf *et al*. (1972) found a hysteresis effect on freeze-dried meat and showed that hysteresis

decreased by increasing temperature. Lioutas *et al*. (1982), showed that samples containing no salt gave similar adsoption and desorption isotherms. However, the addition of salt in the meat mixture led to strong hysteresis which increased by increasing salt content. Mujica *et al*. (1987, 1989) did not find any hysteresis effect on porc meat sausages and dry-cured ham respectivelly.
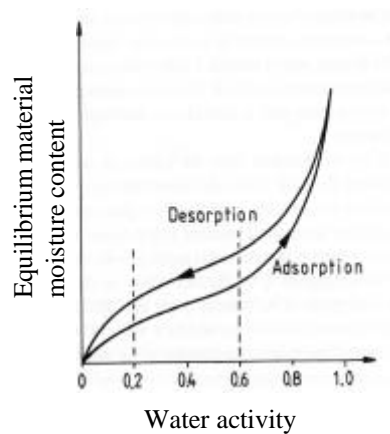

Figure 1.5.1 Schematic representation of sorption isotherms

Figure 1.5.2 presents three basic shapes of sorption isotherms which characterize the material in reference to water adsorptivity. Food is considered hygroscopic material.
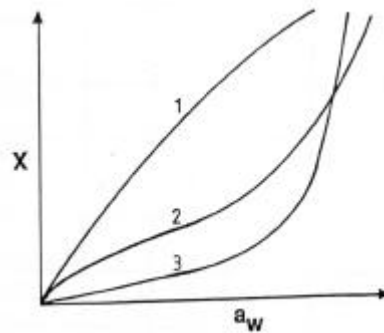

Figure 1.5.2 Basic shapes of sorption isotherms. 1. Highly hygroscopic; 2. Medium hygroscopic; 3. Low hygroscopic, sensitive to high air humidity (Abdula, 1993).

1.5.2. Measurement of water activity

There are mainly two ways of obtaining a sorption isotherm. One is the direct measurement of the water activity in samples of different moisture contents. They can be categorized into four groups:

1. The material vapour pressure measurement.

2. The relative humidity of air in equilibrium with the material measurement.

3. Freezing point depression or boiling point elevation measurement.

4. Isopiestic method.

The other method used to determine a sorption isotherm is the gravimetric method. It consists of placing the material, dried (adsorption) or fresh (desorption), in atmospheres of known, different relative humidities. Depending on their initial moisture content the samples will gain or loose moisture until they reach equilibrium. In equilibrium, characterized by constant weight, the moisture content of the samples is determined either by the calculation of the water uptake during the sorption process or the moisture content analysis.

Different techniques can be used to regulate the relative humidity. The relative humidity can be adjusted with the help of salt or sulphuric acid solutions at different concentrations or also with the help of different saturated salt solutions. Another possibility is to vary the saturation pressure or the saturation temperature. These techniques are referred to as two-pressure and two-temperature systems, respectively. In short, these methods consist of saturating the air at pressures or temperatures different from the one experienced by the sample in the experimental chamber. Depending on the saturation pressure or temperature, different relative humidities are obtained. Another possibility is to mix dry and saturated air streams in different proportions.

The sorption measurements can be performed under different conditions: static or dynamic. In a static system the air surrounding the sample is stagnant. In a dynamic system the air is stirred or blown over the sample. The dynamic system has the advantage of short equilibration time which is often very important in measuring the sorption isotherms of foodstuffs. To shorten the equilibration time it is also possible by working under vacuum conditions.

Measurements of the sorption isotherm differ on one additional point. This is the weighing method. This can be continuous or discontinuous. Discontinuous weighing is convenient because it enables working simultaneously with many samples. It also allows observations to be made on the physical changes of the material. Continuous weighing is convenient because it allows the recording of weight changes without interrupting the sorption process. The major limitation of this system is that only one sample can be handled at a time (Motarjemi, 1988).

1.5.3. Sorption isotherm model

The food isotherm is first obtained in a graphical form from experimental data. These water sorption isotherm data has almost always been fitted in one or more theoretical, empirical or semi-empirical equations. No single equation has been found to depict accurately the sorption isotherms of all types of food in the entire range of water activity. Such being the case, isotherm data is studied individually and the model that describes the behaviour the most accurately is used to report the water activity and moisture content for a specific food (Okos *et al.*, 1992).

A model can be based on different theories (kinetic, capillary-condensation, potential, polarisation theory…), although a model based on just one of the suggested theories can not predict the sorption isotherm in the whole range of water activity (Langmuir, BET (Brunauer, Emmet and Teller), Halsey, Bradley equations…). Therefore, several models based on a combination of the above theories have also been proposed (Smith, 1947; Ngoddy and Bakker Arkema, 1970;…) and semi-empirical (Hendersson model) and empirical models (Oswing, Mujica *et al.*, 1989) have taken a big interest. Usually the model

that describes the behaviour of the sorption isotherm more accurately is the one used to report the water activity and moisture content of the food.

Bradley's equation has been reported to fit the experimental data for proteins such as myosin, ovalbumin etc. (Palnitkar and Heldman, 1971). The BET equation is used most frequently to characterise the monolayer water and the GAB (Guggenheim, Anderson and Brunauer) equation is considered one of the best equations for fitting isotherms of many food materials. It does require five experimental data points, but is good up to a_w 0.94. Oswin's equation is a series expansion for S-shaped curves. Henderson's equation is good for describing globular proteins (Okos *et al*., 1992). Ferro Fontan *et al*., (1982) investigated the Hailwood and Horrobin isotherm equation, which was applied to collagen and fish protein concentrates.

An additional point, that makes differences between the sorption models, is the number of parameters that are necessary to construct the model. Most of the models are built with two to four parameters, and models containing up to seven parameters have also been suggested.

1.5.4. Sorption isotherms of solid mixtures

Sorption isotherms of individual solids and solid mixtures can be experimentally measured and suitable equations fitted to the experimental results. However, a question arises: knowing the isotherms of each mixture component (in terms of dry mass content) how can one predict the solid mixture isotherm?

Many tried to answer this question. Lang and Steinberg (1981) and Boquet *et al.* (1978) quoted and reviewed several papers (e.g. Ross, 1975; Chirife *et al*., 1978; Lang and Steinberg, 1980; among others). Since then, several others were published, which present applications of earlier reported methods rather than the developed new ones (Welti *et al*., 1994).

In equilibrium each mixture component will come to equilibrium with the atmosphere and the other components of the mixture. This situation is analogous to equilibrium of a

multiphase liquid system with vapour phase. The chemical potentials of each component moisture in the atmosphere, will be therefore equal. Calculation of this equilibrium is relatively simple in solutions, however, molar masses of each component and methods for calculating activity coefficients in the liquid phase are necessary. In the case, where solid components have unidentified molar masses, the task becomes difficult. Still several researchers propose mixing rules based on the theory of solutions. It follows a short review of the most important methods. Many attempts were undertaken to predict sorption isotherm of a mixture from sorption isotherms of individual components and their weight fractions in the mixture. The most important methods are:

1.5.4.1. Linear mixing rule

The linear mixing rule (Briggs, 1932; Labuza, 1968), which was experimentally verified by Lang and Steinberg (1980), is based on the assumption that the resulting equilibrium moisture content is a product of mass fractions and equilibrium moisture contents of each component at the same a_w i.e. it assumes no interactions among the solid components of the mixture. It has been verified in mixtures of insoluble solids as well as in mixtures of soluble and insoluble solids. Contrarily to other methods, this method doesn't allow direct calculation of a mixture water activity.

1.5.4.2. Salwin and Slawson method

Salwin and Slawson method (Salwin and Slawson, 1959) is based on linearization of sorption isotherms in a narrow range of water activities. It applies well only to mixtures of similar solids in a narrow range of a_w. It was verified by mixing insoluble solids (several foods).

1.5.4.3. Ross's method

It is derived from Gibbs-Duhem equation for solutions (Ross, 1975). It assumes no interactions between solids present in the mixture. Applicable both to mixtures containing only soluble components or mixtures composed of soluble and insoluble components. It gives good results at small concentrations of soluble parts. At higher concentrations deviations increase significantly.

1.5.4.4. Chuang and Toledo method

This method (Chuang and Toledo, 1976) is based on the approximation of sorption isotherms by Norrish's equation. Suggested by insoluble-soluble solid mixtures but proved successful only in starch-wheat mixture. It is uncertain whether the predicted water activity depends on the fact of how the total moisture in the mixture is initially distributed among the components.

1.5.4.5. Lang and Steinberg method

It is based on the application of the linear mixing rule to solids which sorption isotherms are approximated to Smith's equation (Lang and Steinberg, 1981; Chinachoti, 1990).
This allows a direct evaluation of a_w of the mixture. It has been verified by soluble-insoluble solid mixtures for a_w in the range 0.30 to 0.95 (starch-sucrose, starch-sucrose-NaCl, Lang and Steinberg, 1981) and for a_w in the range 0.949 to 0.990 (starch-sucrose-salt, Chinachoti, 1990).

To be able to apply this predictive methods, information about the solid sorption isothem equation is required. It is also necessary an equation that relates the water activity of the saturated solution with temperature and an equation that relates the water activity to the concentration of the diluted solution. This diluted solution can be predicted theoretically,

however in practical applications several semiempirical or empirical equations can be used. Among them come,

1. Norrish equation (Norrish, 1966) - Norrish equation coefficients in water solutions at room temperature are reported by e.g. Sloan and Labuza (1976), Bussiere and Serpelloni (1985).

2. Chuang and Toledo equation (Chuang and Toledo, 1976) - It is a modified Norrish equation. Coefficients of Chuang and Toledo equation in water solutions at room temperature are reported by Sloan and Labuza (1976).

3. Chen equation (Chen, 1989) - It is developed from Raoult's law. He fitted coefficients to several compounds.

4. Rotstein and Cornish equation (Crapiste and Rotstein, 1982) - He reported some coefficients in water solutions at room temperature.

All above equations require the knowledge of the solute molecular mass. This may become a serious trouble if the organic components are of unknown molecular masses. A way out can be the following equation:

5. Smith sorption isotherm. Using the Smith's isotherm with water content (X) expressed as dry basis was suggested by Lang and Steinberg (1981) and with X (wet basis) by Chinachoti (1990). Coefficients of Smith's in water solutions at 20 ºC was reported by Lang and Steinberg (1981).

1.5.5. Factors affecting water activity

1.5.5.1. Temperature

The sorption characteristics of meat can be changed by different factors. One factor involved in determining the shape of the curve is temperature. The effect of temperature on sorption isotherms has been largely studied and usually increasing temperature decreases the moisture content (Okos *et al.*, 1992).

The temperature effect on isotherms follows the Clausius-Clapeyron equation:

$$\left[\frac{\partial \ln a_w}{\partial (1/T)}\right]_x = -\frac{Q_s}{R}$$

1.5.2

where Q_s is the heat of sorption of water in J/mol and *R*, the gas constant (8.31441 J/mol K). The binding energy is defined as the difference between the heat of water adsorption and its latent heat of condensation.

The heat of sorption Q_s is higher at lower moisture contents as well as at lower temperatures. Also, the binding energy tends to zero at high moisture contents since water eventually behaves as free water.

Among the numerous models which have been advanced, several include the temperature as a parameter of the equation and allow in this way the calculation of the sorption isotherms at the desired temperature.

Chirife and Iglesias (1978) suggested in their review that the Halsey's modified equation could be used to predict reasonably well the effect of temperature on water sorption isotherms of some kinds of meat (chicken, fish protein concentrate). Motarjemi (1988) used BET, GAB, Halsey and Oswin equations to model minced meat isotherms at different temperatures. The best fit was observed in GAB model, followed by Oswin model. She

reported the work of Lomauro (1985) in which GAB model gave the best fit, although Boquet *et al*. (1978) got the best results using Halsey model. The same author also reported other studies in beef, where Halsey model was also applied considering the effect of temperature.

1.5.5.2. NaCl

In addition to the physical factors in sorption isotherms, chemical factors like dissolved solutes influence water activity. Differences between electrolytic and non-electrolytic solutions as well as amount of positively and negatively charged ions play a roll in the sorption process (Okos *et al*., 1992). The effect of solutes has been studied by several authors, Ross (1975) used Raoult's law to explain the dependence of water activity on the solute level and the moisture content of a food system. Bone (1987) gave some example of Salwin equation for the determination of water activity of a mix of two components. In literature several water activity values in meat and meat products with NaCl have been reported (Leistner *et al*., 1981; Gauthier *et al*., 1986; Lin *et al*., 1990). Some other authors have also considered the effect of NaCl on the water activity (Demeyer, 1979; Palmia, 1982; Gauthier *et al*., 1986). The equations given by those authors take into account the NaCl content of the water phase of the meat. Chuang and Toledo (1976) derived an equation that predicted accurately the equilibrium water activities in two solid mixtures (NaCl and dehydrated meat). Lioutas *et al*. (1984) obtained in their results an important effect of the NaCl on the sorption isotherms of salted meat at water activity values above 0.75. Within this range ($a_w > 0.75$), the water activity decreases when the NaCl content of the meat is increased. In contrast, in water activity values under 0.75, the NaCl does not affect the sorption isotherms. He suggested the application of Smith's model for salt meat mixtures. Mujica *et al*., (1989) found a similar effect on dry cured ham, although Mujica *et al*., (1987) did not find significative differences between isotherm for dry sausages of different composition considering NaCl content.

Johnston and Duckworth (1985) reported that macromolecular solids dominate the sorption pattern at low water activity and the soluble components exert their effects largely through their colligative properties when a_w is higher than 0.75.

Motarjemi (1988) observed a deviation between the experimental values and the predicted values, by the principle of the sorption isotherms additivity. She suggested that the deviation could be due to the "salting-in" effects of the sodium chloride at low concentrations, (reported previously by studies of Bone (1969) and Chou and Morr (1979)).

1.5.5.3. Heat treatment and freeze storage

Motarjemi (1988) found differences between the sorption isotherms of raw minced meat and heat treated minced meat, the latter being less hygroscopic. The difference found was observed in the whole range of water activity. She suggested that structural changes occured in meat due to the heat treatment.

In the same manner, her studies on the sorption isotherms of raw and frozen-stored minced beef was observed at intermediate and low water activities. At high water activities the sorption isotherms were not affected by freeze storage. She assumed that the macrostructure of the minced beef was not altered, and just the number of available sorption sites decreased by the denaturation of the protein during frozen storage.

In her work of heat treated minced beef, she proposed the temperature dependence using the parameters of the Oswing model.

1.5.5.4. Composition

The composition also affects the water sorption properties. The basic components of the meat usually include proteins, lipids and water. The water-protein interaction is influenced by the amino acid composition of the proteins and their ionic strength. However, this can be considered at low and at intermediate water activity range, because of the influences of molecular structure and the conformational features at high water activity. (Wolf *et al*., 1972, Okos *et al*., 1992). Motarjemi (1988) reported from other studies that the denaturation

of protein (tropocollagen and collagen) decreased the sorption capacity, and that lyophilized tropocollagen was more hygroscopic than air-dried.

The effect of the fat content of the meat on the water activity is unclear. Mujica *et al*. (1987) observed in dry sausage (salami) that the sorption isoterms were not affected by the fat content of the sausage. On the contrary, Konstance *et al*. (1983) in bacon and Mujica *et al*. (1989) in dry-cured ham, found that the equilibrium moisture content at any water activity decreased with increasing fat content. Motarjemi (1988) reported the work of Nemitz (1963) and Mittal and Usborne (1985) in which they found the same behabiour.

Motarjemi (1988), presented the sorption isotherm of lard, which shows a very low sorption capacity. She also showes that the equilibrium moisture content decreases with the fat content at the different water activities. Her results agrees with the results obtained by Iglesias and Chirife (1977), which, the authors concluded that the equilibrium moisture contents of minced meat with different fat contents can be adequately compared if this is expressed on a fat-free basis.

Rödel (1989) stated from his previous studies that the addition of fat indirectly influences the water activity level of meat products, since fat contains very little water in comparison with lean meat. He also reported that the meat products that are very rich in fat contain relatively little water, so if NaCl is added to these products, the water activity will be lower than in products with a greater lean portion if the NaCl is in the same amount.

Motarjemi (1988) among others, tried to reconstruct the sorption isotherm of the foodstuff or mixture from knowledge of the sorption isotherm of individual components. In her study, the prediction of the sorption isotherm, considering the effect of fat, minced meat mixture and potato starch, added to minced meat was considered acceptable. Other authors (Palnitkar and Heldman, 1971) tried also to predict the sorption isotherm of whole beef from the knowledge of the sorption isotherms of individual components, although the final result was not very successful.

1.5.6. Data of water activity and sorption isotherms in meat

1.5.6.1. Reported data

Data reported by some of the studies stated previously are shown in Table 1.5.1.

Table 1.5.1 Water activity values in meat and meat products.

			a_w
Fresh Meat[1]			0,99
Bologna Sausage[1]			0,97
Liver Sausage[1]			0,96
Blood Sausage[1]			0,96
Raw Ham[1]			0,92
Dried Beef[1]			0,9
Fermented Sausage[1]			0,91
Meat Products[2]			0,99-0,70
Pork Sausages[3]			0.99-0.97
Cured Ham[4]		1,65%NaCl	0,967
		4,24%NaCl	0,938
Muscles of spanish dry-cured ham[5]			
Semimembranosus	65.3%H_2O	7.06%NaCl	0.983
Semitendinosus	72.9%H_2O	0.79%NaCl	0.995
Biceps femoris muscle	71.1%H_2O	1.06%NaCl	0.995

[1]Leistner *et al*. (1981); [2]Gauthier *et al*. (1986); [3]Fett (1973); [4]Lin *et al*. (1990); [5]Sayas-Barberá *et al*. (1998).

1.5.6.2. Reported models

Mujica *et al*. (1987) fitted the Oswin model to the isotherms of dry sausages (equation 1.5.3),

$$X = a \left(\frac{a_w}{1 - a_w} \right)^n$$

1.5.3

where *a* is 0.223 and *n* is 0.868.

Oswin model was also used by Motarjemi (1988) where the temperature in minced beef meat (I) and heat treated beef (II) was considered. Parameter *a* is described by:

(I)

$$\ln a = -0.007T + 4.61$$

1.5.4

(II)

$$\ln a = -0.0059T + 4.02$$

1.5.5

and *n* is the constant value:

(I)

$$n = 0.548$$

(II)

$$n = 0.562$$

Halsey's modified equation has been used to predict reasonably well the effect of temperature on water sorption isotherms of some kinds of meat (minced beef, heat treated beef, chicken, fish protein concentrate):

$$a_w = \exp(a'' X^{-r})$$

1.5.6

The following relations for *a"* and *r* were reported in minced beef below 40ºC by Motarjemi (1988) (III), in heat treated beef by Skjöldebrand, (1979) (IV) and chicken by Chirife and Iglesias (1976) (V):

(III)
$$a" = \exp(-0.023T + 9.23)$$
1.5.7

(III)
$$\ln r = 0.0045T - 1.51$$
1.5.8

(IV)
$$a" = \exp(-0.029T - 2.16)$$
1.5.9

(IV)
$$r = 0.0067T - 0.091$$
1.5.10

(V)
$$a" = \exp(-0.011T + 2.466)$$
1.5.11

GAB equation was also used by Motarjemi (1988) to model the isotherm of minced beef considering the effect of temperature:

$$X = X_m \frac{C_B \ K \ a_w}{(1 - K \ a_w)[1 + (C_B - 1) \ K \ a_w]}$$
1.5.12

Below 40ºC the GAB constants change according to:

$$\ln C_B = \frac{1279.3}{T} - 1.966$$
1.5.13

$$X_m = -0.054T + 22.54$$
1.5.14

$$\ln K = 0.0012T + 0.377$$
1.5.15

BET has been used to determine the amount of monolayer water and the sorption heat in beef:

$$X = X_m \frac{C_B a_w}{(1 - a_w)[1 + (C_B - 1)a_w]}$$

1.5.16

Monolayer water in minced meat beef (Motarjemi, 1988):

$$X_m = -0.043T + 18.92$$

1.5.17

Monolayer water in raw beef (Iglesias and Chirife, 1984):

$$\ln X_m = -0.0176\,t + 2.39$$

1.5.18

Note that in last relation, the temperature is expressed in degrees Celsius in contrast to the former ones where the temperature is expressed in degrees Kelvin.

Sorption heat (Q_s) is calculated by BET equation using the constant C_B:

$$C_B = k\,\exp\frac{Q_s}{R\,T}$$

1.5.19

The sorption heat can be also calculated using the Clausius-Clayperon equation (section 1.5.5.1) and GAB model. Table 1.5.1 shows some values reported in literature.

Table 1.5.1 Heat of sorption for adsorption process of some protein foods.

Product		BET equation (kJ/mole)	Clausius-Clayperon (kJ/mole)	GAB equation (kJ/mole)
Chicken[1]	Raw	6.44	15.76	-
	Cooked	6.56	21.82	-
Trout[1]	Raw	4.93	15.76	-
	Cooked	7.74	16.39	-
Fish protein conc.[1]		7.74	13.46	-
Minced beef meat[2]	Raw	5.69-6.74	8-10	10.6

[1]Chirife and Iglesias (1976). [2]Motarjemi (1988).

Some equations have also been reported for salted products. For instance, Mujica et al. (1989) used the following empirical equation to model the isotherms of cured ham (equation 1.5.20):

$$X = \left(\frac{1}{a - b\, a_w} \right)$$

1.5.20

where *a* and *b* were:

	Temp (ºC)	$a_w < 0.75$	$a_w > 0.75$
a	20	26.02	5.42
	30	25.61	4.23-4.77
	40	59.46	5.22
b	20	32.81	5.32
	30	32.55	4.16-4.63
	40	78.91	5.20

1.5.6.3. Predictive methods for solids mixtures

Chuang and Toledo (1976) derived an equation that predicted accurately the equilibrium water activities of mixtures of two solids. The form of the equation was (equation 1.5.21):

$$\text{Log} \frac{a_w}{X_1} = -\left[(-K_{12})^{0.5} X_2^2 + (-K_{13})^{0.5} X_3^2\right]^2 + \frac{X_2}{X_2 + X_3} b_{12} + \frac{X_3}{X_2 + X_3} b_{13}$$

1.5.21

where the constants of some solutes and solid mixtures used for evaluating a_w at 25ºC are shown in Table 1.5.2:

Table 1.5.2 Constants for NaCl and dehydrated meat used for evaluating a_w at 25ºC of solid mixtures (Chuang and Toledo, 1976).

	Concentration (wt % solids)	Slope k	Intercept b
NaCl	0-7.5	0.0002063	-0.7417
	7.5-17.3	0.00002975	-0.7308
	17.3-26.4	-0.00003039	-0.7118
Dehydrated meat	50-89.8	-0.0000805	-0.6705
	89.8-95	-0.000123	0.9466

1.5.6.4. Water activity and sorption isotherms in fat

Some authors studied the water activity of fat. For instance, Rödel *et al.* (1980) measured the water activity of porcine and bovine fat (Table 1.5.3) and Motarjemi (1988) determined the sorption isotherms of lard and mixtures of minced meat and lard at different proportions (Figure 1.5.2).

Table 1.5.3 Water activity of fat (Rödel *et al.,* 1980).

		NaCl (%)	H_2O (%)	a_w
Pork, back fat	Fresh	0,1	9,6	0,991
	Chilled	0,1	6,5	0,982
	Salted and smoked	1,2	2,4	0,724
Beef, tallow	Fresh	0,2	13,6	0,993
	Chilled	0,2	4,2	0,984

Konstance and co-workers (1983) measured the sorption isotherms of bacon. They proposed an empirical equation to correlate the water activity to the fat and moisture contents of bacon (equation 1.5.22).
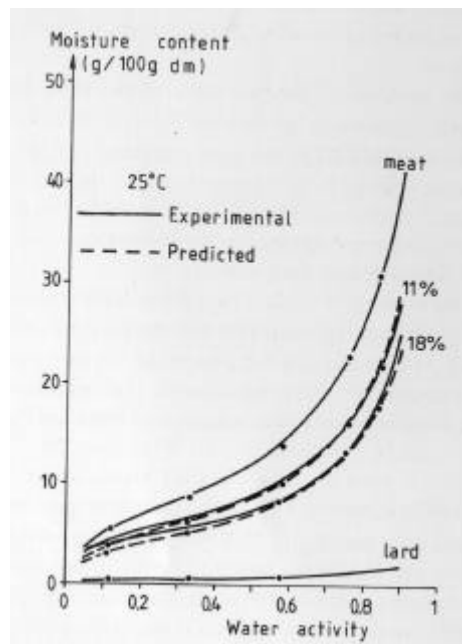

Figure 1.5.2 Sorption isotherms of lard, minced meat and mixtures of minced meat at 11% and 18% lard (Motarjemi, 1988).

$$\text{Ln } [-\ln(1-a_w)] = C_0 + C_1 \text{ fat} + C_2 \text{ Ln moist} + C_3 \text{ fat x Ln moist}$$

1.5.22

Where, fat is expressed in percentage (%), moist as kg H_2O/kg original wet product and constants C_0 , C_1 , C_2 *and* C_3 are shown in Table 1.5.1.

Table 1.5.1 C_0 , C_1 , C_2 *and* C_3 parameters for Konstance and co-workers equation.

	C_0	C_1	C_2	C_3	R
5ºC desorp.	-2.531	10.381	0.437	1.101	0.867
25ºC desorp.	-3.133	3.990	1.171	0.909	0.958
40ºC desorp.	-1.641	8.456	0.314	1.106	0.880
25ºC adsorp.	2.415	-1.150	1.363	-1.428	0.967

R is the coefficient of correlation and C is the regression coefficients. Konstance *et al*. (1983).