
EFFECT OF TEMPERATURE ON DESORPTION ISOTHERMS FOR BEEF

Mewa¹, E.A.; Okoth², M.W.; Kunyanga³, C.N.; Rugiri⁴, M.N

^{1,2} University of Nairobi, Kenya

^{3,4} Egerton University, Kenya

doi: 10.37017/jeae-volume5-no1.2019-7

Publication Date: 30 September 2019

ABSTRACT

Desorption isotherms of beef were determined by the standard static gravimetric technique, based on the use of saturated salt solutions with water activities from 0.05 to 0.9. Equilibrium moisture content of each sample at different temperatures and water activities were determined. The stable moisture content for meat during drying was also established. The GAB, BET and Oswin models were used to fit the experimental sorption data. Non-linear regression analysis was performed to estimate model parameters and fitting quality evaluated using the Coefficient of determination (R^2) and the standard error of estimate (SEE). The equilibrium moisture content decreased with increase in temperature at constant water activity and increased with increase in water activity at constant temperature. The critical moisture was 10-20 % (d.b). The high values of R^2 and low values of SEE for the GAB and Oswin models indicated that these models gave the best fit for the desorption data of beef.

Keywords: Beef, desorption isotherms, equilibrium moisture content, water activity.

INTRODUCTION

Moisture sorption isotherms represent the equilibrium relationship between the moisture content of foods and the water activity at constant temperature and pressure. Equilibrium moisture content (EMC) is defined as the moisture content when vapor pressure of water present in the food material has reached to the equilibrium with its surroundings. It is a thermodynamic entity and has practical significance in both drying and storage of foods. It is affected by both relative humidity and temperature of the surroundings. Water activity is defined as the ratio of vapor pressure of water in the foodstuff to the vapor pressure of pure water at the same temperature. Water activity controls microbiological growth and enzymatic activity of food products.

The knowledge and understanding of moisture sorption isotherms for food products is of great importance in design and optimization of the

drying processing for instance; in assessing packaging problems, for modeling moisture changes which occur during drying, for predicting shelf life stability, for ingredient mixing predictions etc. (Spiess and Wolf, 1983; Gal, 1987). They can also be used for design and optimization of drying equipment and other engineering purposes related to dehydration (Maskan *et al.*, 1998). For food products, the sorption isotherm can be measured by means of three different measuring techniques: gravimetric, manometric or hygrometric (Iglesias and Chirife, 1978). In the gravimetric methods, the weight of the sample is measured with a balance. In the manometric methods, the vapour pressure of water is measured when it is in equilibrium with a sample at given moisture content. In the hygrometric methods, the equilibrium relative humidity with a sample at given moisture content is measured (Iglesias and Chirife, 1978).

Aiming to mathematically express the relation between the water activity of food and its moisture content, diverse models have been developed such as nonlinear, linear, regression models. In many cases, the model that is suitable for certain food product is not suitable for a different one, furthermore, the model only exhibits a suitable predictive ability for certain moisture activity ranges (Ahmat *et al.*, 2014). Several mathematical models have been proposed to describe sorption isotherms. The most common equations that are used for describing sorption in food products are the Langmuir equation, the BET equation, the Oswin model, the Smith model, the Halsey model, the Henderson model, the Iglesias-Chirife equation, the GAB model, and the Peleg model (Sahin and Gülüm, 2006).

Due to the complex composition of meat products a theoretical prediction of sorption isotherms is not possible, and sorption data must be determined experimentally (Adam *et al.*, 2000). In the literature some review papers and compilations about isotherms of different meat products can be found (Iglesias and Chirife, 1982; Lazarides, 1990, 1991). However, information on desorption isotherms of meat at temperatures found during the solar drying process is scanty. Therefore, there is a need to provide information on sorption isotherms of beef at solar drying temperatures of tropical countries in order to better understand the behavior of the product during drying. The objectives of this study were to determine and to model the desorption isotherms for beef at 30-60°C.

2.1. MATERIALS AND METHODS

2.1.1. Sample collection and preparation

Meat (beef) of high microbial quality from the round of the hind quarter of an inspected male carcass was purchased from Dagoretti slaughter house, Nairobi, Kenya. Excess fat was trimmed off to prevent rancidity while drying. It was then cleaned and stored in a cold room at 5°C for 48 h prior to experiments so that the storage conditions would be kept the same for all samples before drying. The meat was cooled overnight at 0°C to obtain enough consistency for cutting and cut along the direction of its fibers into thin strips of 5 cm long, 5 cm wide and 1 cm thickness. Triplicate samples were used for the determination of initial moisture content of beef using the oven method at 105°C for 3 h, (AOAC, 2000) and the average values reported as 328.69 g water/g dry matter.

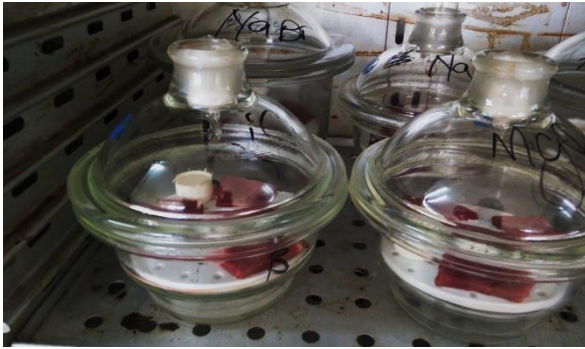
2.1.3. Experimental

Desorption isotherms of fresh meat were determined using the standard static gravimetric technique. This method is based on the use of saturated salt solutions to maintain a fixed relative humidity according to the COST 90 method (Wolf *et al.*, 1985). The salts used with a range of water activity from 0.05 to 0.9 (Greenspan, 1977) are shown in Table 1.

Ten empty desiccators each with an insulated lid containing different saturated salt solutions were placed in a hot air oven adjusted to a fixed temperature for 24 h so as to bring the salt solutions to a stationary temperature.

Table 1 Water activities of the saturated salt solutions at four temperatures used in the desorption experiments

Salt	Water activity			
	30°C	40°C	50°C	60°C
KOH	0.0738	0.0626	0.0572	0.0549
LiCl	0.1182	0.1125	0.1110	0.1073
CH ₃ COOK	0.2160	0.2012	0.1890	0.16
Mg (Cl) ₂ .6H ₂ O	0.3238	0.3159	0.3159	0.2926
K ₂ CO ₃	0.4317	0.4320	0.4322	0.4327
NaBr	0.5602	0.5320	0.5320	0.497
NaNO ₃	0.7312	0.7100	0.7100	0.6735
NaCl	0.7569	0.7540	0.7444	0.743
KCl	0.8362	0.8232	0.8120	0.8030
KNO ₃	0.9188	0.8835	0.8521	0.8478



Triplicate meat samples were placed on the perforated base 5 cm above the surface of the desiccators. A small quantity of toluene was placed in each hygrosat in order to prevent fungal activity (Wolf *et al.*, 1985).

Weight recording of the beef samples was done after every 4 days. This procedure was continued until the weight was constant. The equilibrium moisture content of each sample was determined by a drying oven whose temperature

Nonlinear regression analysis, using Minitab (Version 18.0, Minitab Inc., USA) software package, was used to estimate the model coefficients from the experimental sorption data for all samples. The suitability of the equations was evaluated using coefficient of determination (R^2) Eq. (4) calculated numerically by Excel and the standard error of the regression (standard error of estimate) Eq. (5) generated by Minitab. For goodness of fit of the curve to the equation, a high value of R^2 and a low value of SEE were taken.

Modelling equations

Table 2 Moisture sorption isotherm models

Model	Equation	References
GAB	$X_{eq} = \frac{X_M C K a_w}{(1 - K a_w)(1 - K a_w + C K a_w)}$	(Van Den Berg, 1985)
BET	$X_{eq} = \frac{X_M C a_w}{(1 - a_w)(1 + (C - 1)a_w)}$	(Brunauer <i>et al.</i> , 1938)
Oswin	$X_{eq} = a \left(\frac{a_w}{1 - a_w} \right)^b$	(Oswin, 1946)

Where C, K, a and b are constants; a_w is the water activity; X_{eq} represents the equilibrium moisture content on a dry weight basis (kg water/kg dry matter) and X_M is the monolayer of water (kg water/kg dry matter)

$$R^2 = \frac{\sum_{i=1}^N (M_{p,i} - M_{e,avg})^2}{\sum_{i=1}^N (M_{e,i} - M_{e,avg})^2} \quad \dots(1)$$

$$SEE = \sqrt{\frac{\sum_{i=1}^N (M_{e,i} - M_{p,i})^2}{N}} \quad (2)$$

Where M_e is the experimental EMC value, M_p is the predicted EMC value and N is the number of experimental data.

For the purpose of this work, three models were used to fit the experimental sorption data; the GAB, BET and Oswin (Table 2).

The stable dry matter (moisture content) for meat during drying was also established from the sorption isotherms.

3.1. RESULTS AND DISCUSSION

3.1.1. Effect of temperature and water activity on the equilibrium moisture content

Equilibrium moisture content data obtained for beef at different water activities and temperatures are shown in figure 1. The mean of the equilibrium moisture content of beef ranged from 0.04 to 0.59, 0.03 to 0.42, 0.03 to 0.36 and 0.11 to 0.24 (kg water/kg dry matter) for temperature of 30, 40, 50 and 60°C respectively within the relative humidity range of 5-90%. The desorption isotherms were of sigmoid form (Type II according to the BET classification) which is common for many hygroscopic products.

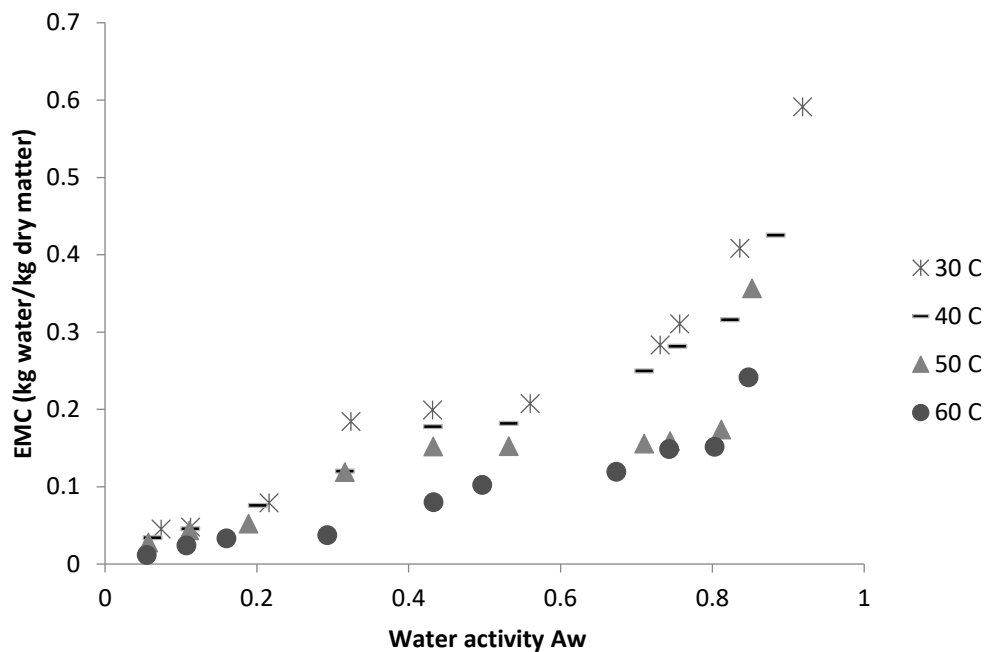


Figure 1: Desorption curves of fresh beef (experimental results): equilibrium moisture content as a function of water activity for different temperatures

Equilibrium moisture content (EMC) for beef increased with water activity at selected temperatures (Figure 1). This may be due to the fact that vapor pressure of water present in foods increases with that of the surroundings. The EMC values decreased with increased temperature at all levels of water activity. The kinetic energy associated with water molecules present in foods increases with increasing temperature. This in turn, resulted in decreasing the attractive forces and consequently, escape of water molecules. This led to a decrease in the degree of water sorption with increasing temperature at a given water activity. Several researchers (Iglesias & Chirife, 1982; Singh *et al.*, 2001) have reported similar trend for different foods.

The critical moisture content for beef (at water activity value of 0.6) within the temperature range of 30-60°C was found to be between 0.1 and 0.2 kg moisture/kg dry matter (Figure 1). Below the water activity of 0.6, microbial growth cannot occur and therefore the equilibrium moisture content found within this water activity can be considered as the stable

moisture content for drying (Ahmat *et al.*, 2015).

Sorption models presented in Table 1 were tested for their effectiveness to describe the desorption isotherms for beef at different temperatures. The coefficient of determination (R^2) and standard error of estimate (SEE) values for each model are reported in Table 2. The highest values and lowest values of R^2 and SEE respectively were found for the GAB and Oswin models, therefore, these two models showed the best fit with respect to R^2 and SEE values. The coefficient of determination (R^2) for GAB and Oswin models was lower than 0.93 at 30, 40 and 60°C. These models were therefore considered as the best to describe the experimental desorption data for beef within this temperature range and water activity between 0.05 and 0.9 (Table 2. This confirms the findings obtained by some authors that the GAB model is the most appropriate for modeling agri-food products (Trujillo *et al.*, 2003; Singh *et al.*, 2006).

Table 3 Estimated parameters and model constants for GAB, BET and Oswin models

Model	Temp. (°C)	Statistical parameters		Model constants				
		R ²	SEE	X _M	C	K	a	B
GAB	30	0.9759	0.0302	0.1144	11.1308	0.8785		
	40	0.9851	0.0177	0.1175	7.6441	0.8209		
	50	0.7823	0.0499	0.0617	29.1549	0.9279		
	60	0.9473	0.0180	0.0484	8.34602	0.9930		
BET	30	0.8919	0.0815	0.0572	5.64802E+17			
	40	0.8991	0.0518	0.0577	221.0820			
	50	0.7872	0.0481	0.0473	141.9250			
	60	0.9421	0.0189	0.0366	19.1733			
Oswin	30	0.9795	0.0262				0.1897	0.4660
	40	0.9857	0.0164				0.1658	0.4586
	50	0.7805	0.0466				0.1249	0.4517
	60	0.9532	0.0167				0.0820	0.5719

Monolayer moisture (X_M) obtained from the GAB model was found to be higher than that obtained from the BET model while the energy constant for the GAB model was lower than that of the BET at the same temperatures (Table 2). The same observations have been made by (Ahmat et al., 2014). In both models, the monolayer moisture content decreases as the experimental temperature increases (Table 2) as has been obtained for most agri-food products (Singh et al., 2001; 2006).

The energy constant representing multilayer water (K) for the GAB model, which ranges from 0 to 1 (Ahmat et al., 2014), was highest at 60°C. Multilayer water is water associated with

neighboring molecules by water-water or water-solid substrate hydrogen bonding. A high value indicates that water is freezable and strongly bound (Timmerman et al., 2001). The value of b in the Oswin model ranged between 0.4660 and 0.5719 and decreased as temperature increased. This indicates that the interaction between water molecules and the solid skeleton decreases with temperature increase. These results are similar to those obtained for other meat products (Singh et al., 2006).

Figure 2 and 3 show the experimental points of desorption isotherms at 40°C by GAB and Oswin models respectively. They represent a visually good fit between the experimental values and those obtained from the models.

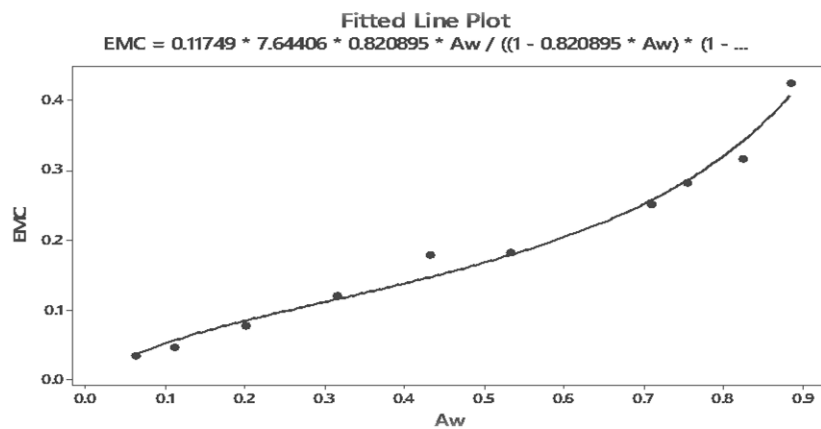


Figure 2: Experimental and predicted values of equilibrium moisture content of fresh beef at different water activities using GAB model

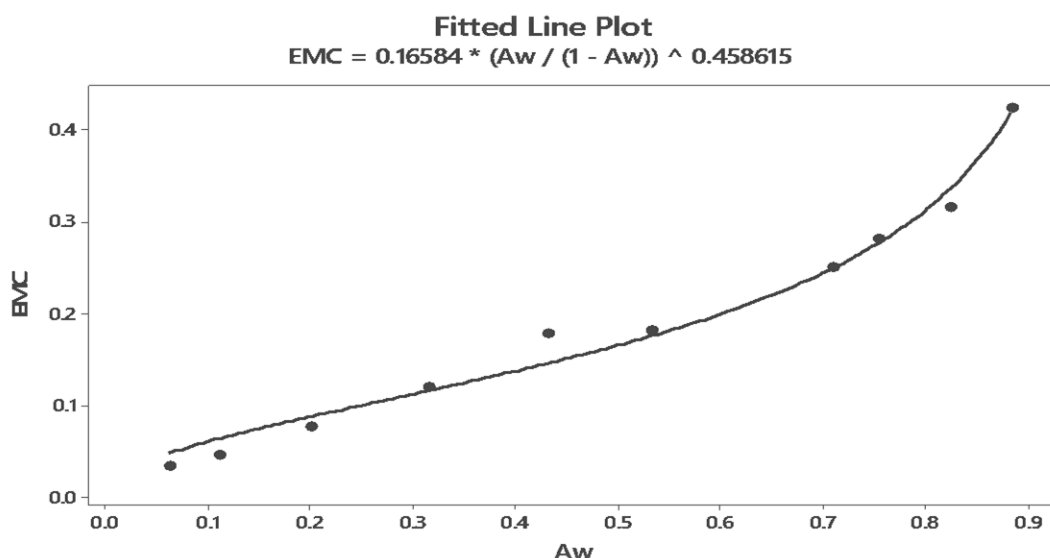


Figure 3: Experimental and predicted values of equilibrium moisture content of fresh beef at different water activities using Oswin model

4.1. CONCLUSIONS

The desorption isotherm of beef at different temperatures and water activities were determined by the standard gravimetric method using various saturated salt solutions. There was a significant effect of temperature on the equilibrium moisture sorption in the range of temperatures studied. The equilibrium moisture content increased with increasing temperature at constant water activity. The critical moisture content for safe drying of beef (at 0.6 Aw) was 10-20 % (d.b). Among the sorption models chosen to test, GAB and Oswin models are suitable for describing the relationship between the equilibrium moisture content, water activity and temperature for beef.

REFERENCES

- Ahmat, T., M. Barka, A. Aregba and D. Bruneau, 2015. *Convective drying kinetics of fresh beef: An experimental and modeling approach*. Journal of Food Processing and Preservation, 39: 2501-2595.
- Ahmat, T., D. Bruneau, A. Kuitche and A.W. Aregba 2015. *Desorption isotherms for fresh*

beef: An experimental and modeling approach. Meat science, 96: 1417-1424.

- Brunauer, S., P.H., Emmet and E.Teller. 1938. *Adsorption of gases in multimolecular layers*. Journal of the American Chemical Society, 60: 309-319.
- Gal, S. 1987. *The need for, and practical applications of sorption data*. In R. Jowitt, et al. (eds). Physical Properties of Foods, 2: 13-25., London: Elsevier Applied Science.
- Greenspan, L. 1977. *Humidity Fixed Points of Binary Saturated Aqueous Solutions*. Journal of Research of the National Bureau of Standards, 81a: 89-112.
- Iglesias, H.A and J. Chirife. 1982. *Handbook of food isotherms. Water sorption parameters for food and food components*. New York: Academic Press.
- Iglesius, H.A. and J. Chiriffe. 1978. *An empirical equation for fitting water sorption isotherms for fruits and related products*. Canadian Institute of Food Science and Technology Journal, 11: 12-15.

-
- Lazarides, H.N. 1990.** *Sorption isotherm characteristics of an intermediate moisture meat product.* Lebensmittel Wissenschaft Technologie, 23: 418–421.
- Lazarides, H.N. 1991.** *Application of the transformed GAB equation to delineate moisture sorption behaviour of an intermediate moisture meat product.* Lebensmittel Wissenschaft and food components. Academic press, New York
- Maskan, M and F. Göğüş. 1998.** *Sorption isotherms and drying characteristics of mulberry (Morus alba).* Journal of Food Engineering, 37: 437-449.
- Oswin, C.R. 1946.** *The kinetics of package life. The isotherm.* Journal of Chemical Industry 65: 419–421.
- Sahin, S and S. Gülüm. 2006.** Physical Properties of Foods, 205, 218 p. Springer; New York, United States.
- Singh, R.R.B., K.H. Rao, A.S.R., Anjaneyulu and G. R. Patil. 2001.** *Moisture sorption properties of smoked chicken sausages from spent hen meat.* Food Research International, 34: 143-148.
- Singh, R.R.B., K.H. Rao, A.S.R. Anjaneyulu and G.R. Patil 2006.** *Water desorption characteristics of raw goat meat: Effect of temperature.* Journal of food engineering, 75: 228-236.
- Spiess, W.E.L. and W.R. Wolf. 1983.** *The results of the COST 90 project on water activity.* In: R. Jowitt et al. (Eds.), Physical properties of foods, pp. 65-91. London: Applied Science Publishers,
- Timmerman, E.D. and J. Chirife 1991.** *The physical state of water sorbed at high activities in starch in terms of the GAB sorption equation.* Journal of Food Engineering, 14: 171-179.
- Trujillo, F.J., P.C. Yeow and Q.T. Pham. 2003.** *Moisture sorption isotherm of fresh lean beef and external beef fat.* Journal of Food Engineering, 60: 357-366.
- Van Den Berg, C. 1985.** *Development of B.E.T. Like Models for Sorption of Water on Foods; Theory and Relevance,* In D. Simatos and J.L. Multon (Eds), Properties of Water in Foods, pp. 119 – 135. Dordrecht: Martinus Nijhoff Publishers
- Wolf, W., W.E.L. Spiess, and G. Jung. 1985.** Standardisation of isotherm measurements (COST-project 90 and 90 BIS). D.Simatos, & J. L. Multon (Eds.). Properties of Water in Foods, p661. Dordrecht: Martinus Nijhoff.