available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/fbp

Experimental and mathematical study of desorption isotherms of Tunisian Sardine (*Sardinella aurita*)

*Bilel Hadrich, Nourhène Boudhrioua, Nabil Kechaou**

Groupe de Génie des Procédés Agroalimentaires de l'Unité de Recherche en Mécanique des Fluides Appliquée et Modélisation - Ecole Nationale d'Ingénieurs de Sfax, B.P 'W' 3038, Sfax, Tunisia

ARTICLE INFO

Article history:
Received 24 September 2007
Accepted 4 January 2008

Keywords:
Desorption isotherms
Gravimetric methods
Isosteric heat of desorption
Modelling
Sardine muscle

ABSTRACT

Desorption isotherms of sardine muscles were determined at three temperatures (25, 35 and 50 °C) for a water activity range varying from 0.10 to 0.75. Gravimetric static methods using saturated salt solutions were used (continuous and discontinuous measurements). Six models were taken from the literature to describe experimental desorption isotherms. The OSWIN model shows the best fit of the experimental data.

The net isosteric heat of desorption and the isosteric heat of desorption were determined by using the CLAUSIUS–CLAPEYRON equation. The isosteric heat of desorption decreases continuously with the increase of the equilibrium moisture content. A mathematical correlation was established between the isosteric heat of desorption and equilibrium moisture content.

1. Introduction

Tunisian sardine (*Sardinella aurita*) has a great importance in Tunisian food customs. In fact, sardine is a cheap source of protein. It can be economically explored in commercial scale. Drying is one of the most common methods of fish preservation. The knowledge of water desorption properties is extremely important in predicting the product behaviour during drying and/or storage at various conditions (Hadrich et al., 2008).

In fact, moisture sorption isotherm is an extremely important tool in food engineering because it could be used to predict changes in food stability and to select appropriate package materials (Simal et al., 2007; Bellagha et al., 2005). Desorption data could be used for the proper choice of the end-point of drying process (Gal, 1987).

Because of the complexity of solid matrice, it is not possible to predict theoretically desorption characteristics based on knowledge of product composition. Experimental data are always required for each material. A number of mathematical equations having two or more parameters have been developed to model isotherm data. Chirife and Iglesias (1978) made a review of the different models appearing in the literature, classifying them in linear and non-linear ones. The BET model (modified form of Langmuir isotherm) was developed by Brunauer et al. (1938) to incorporate multilayer adsorption. This model was further modified by Guggenheim-Anderson-de Boer (Van den Berg, 1981) and it is always used to describe sorption isotherms of several products.

Other types of correlations (logarithmic or power laws) were used to describe sorption isotherms such as Henderson (1952), Chung and Pfost (1967), Halsey (1948) and Oswin (1946) models. These empirical models have also a dependent temperature term and were used to reflect the temperature dependency of equilibrium moisture sorption.

Thermodynamic parameter such as net isosteric heat of sorption could be estimated from the curve of water activity versus temperatures. It is possible to predict the moisture desorption isotherm of a product at other temperature conditions by using the CLAUSIUS–CLAPEYRON equation (Kaya and Kahyaoglu, 2007; Simal et al., 2007; Jamali et al., 2006).

The paramount objective of the work was to establish desorption isotherms for Tunisian sardine (*S. aurita*) muscle at three different temperatures (25, 35 and 50 °C). Experiments

* *Corresponding author*. Fax: +216 74275595.
E-mail addresses: bilelhadrich@yahoo.fr (B. Hadrich), nourhene.boudhrioua@fss.rnu.tn (N. Boudhrioua), nabil.kechaou@enis.rnu.tn (N. Kechaou).

0960-3085/$ – see front matter © 2008 The Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.fbp.2008.01.003

Nomenclature

a_w	water activity
L_v	latent heat of vaporization of pure water (J/mol)
$q_{st,n}$	net isosteric heat of desorption (J/mol)
Q_{st}	isosteric heat of desorption (J/mol)
r	correlation coefficient
R	universal gas constant (J/mol K)
S	standard error
T	absolute temperature (K)
X_{eq}	equilibrium moisture content (kg/kg d.b.)
X_m	monolayer moisture content (kg/kg d.b.)
$\sigma_{relative}$	relative standard deviation $\sigma_{relative} = (100/\bar{X}_{eq})\sqrt{\left(\sum_{i=1}^{n}(X_{eq_i} - \bar{X}_{eq})^2\right)/n-1}$

were conducted using the two static gravimetric methods: discontinuous and continuous. The former, i.e. the discontinuous method, is widely favoured because it has the advantage of not being costly and of being simple to use. The latter, i.e. the continuous method, requires computer acquisition of the sample weight. Although the continuous method allows the use of the desorption kinetics to estimate apparent moisture diffusivity, it was used in this paper only for the purpose of validating the results obtained through the use of the discontinuous method.

Six mathematical models were tested to fit the experimental data.

The variation of the isosteric heat of desorption of sardine was determined as a function of equilibrium moisture content.

2. Material and methods

2.1. *Studied material*

Fresh sardine (*S. aurita*) was purchased from a local market in Sfax (Tunisia) and transported to the laboratory in a few minutes. Sardine was then eviscerated and cleaned. Parallelepiped samples were prepared from the muscles. These samples were used for desorption experiments.

2.2. *Moisture content*

Moisture content was determined by dehydrating the muscle sample during 24 h in an oven at 105 °C (AOAC, 1996). The sample weight was measured by an analytical balance (METTLER-TOLEDO) having a precision of ±0.0001 g. Moisture content was expressed in dry basis (kg/kg d.b.).

2.3. *Desorption isotherms*

2.3.1. *Discontinuous measurement equipment*

Desorption isotherms of sardine were determined by using the gravimetric static method of saturated salt solutions (Spiess and Wolf, 1987) at 25, 35 and 50 °C. Experiments were performed by using the same samples of sardine muscle for all temperatures, in a range of water activity varying from 0.10 to 0.75. The saturated salt solutions were prepared by dissolving, in a jar, an appropriate quantity of salt in distilled water (Motarjemi, 1988). Each salt solution provides a fixed water activity for each temperature and salt concentration (Multon et al., 1991). Table 1 shows water activities of used saturated salt solutions at 25, 35 and 50 °C. The jars were kept 24 h in the oven at a temperature of 25 °C in order to be stabilized. Duplicate samples of 2–4 g of sardine muscle were placed in the hermetically sealed jars which were then placed in a controlled temperature oven (Fig. 1). The samples were weighed at different times. Equilibrium was considered to be reached when the change in weight did not exceed 0.001 g (about 3–4 weeks for every temperature). When the samples reached constant weight, at 25 °C, the temperature of the oven was then increased to the next temperature condition to establish the corresponding desorption isotherms (35 °C then 50 °C). The experiment was stopped when the equilibrium was reached at the temperature of 50 °C and the equilibrium moisture contents of samples were measured.

Table 1 – Water activities of used saturated salt solutions at 25, 35 and 50 °C

Salt	25 °C	35 °C	50 °C
LiCl	0.1105	0.1117	0.1105
CH_3COOK	0.2245	–	–
$MgCl_2$	0.3300	0.3200	0.3054
K_2CO_3	0.4276	–	0.4091
NaBr	0.5770	0.5455	0.5093
$SrCl_2$	0.7083	–	0.5746
NaCl	0.7528	0.7511	0.7484

2.3.2. *Continuous measurement equipment*

The continuous measurement was performed at 50 °C and at a relative humidity of 31% obtained by using saturated salt solution of $MgCl_2$. The equilibrium moisture content was obtained by continuous dehydration of a suspended sample in a drying oven (Fig. 2). The drying oven was equipped with an analytical balance (METTLER-TOLEDO). This balance was related to a personal computer for sample weighting and time acquisition. The experiment was stopped when the equilibrium was reached (weight change less then 0.001 g) and then the equilibrium moisture content of the sample was measured.

2.3.3. *Mathematical treatment*

The experimental desorption isotherms data were fitted by using six mathematical models chosen among the most used models in literature (Kaya and Kahyaoglu, 2007; Jamali et al., 2006; Bellagha et al., 2005; Kaleemullah and Kailappan, 2004;

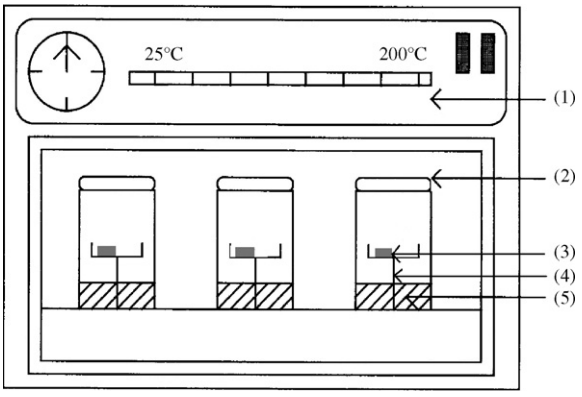

Fig. 1 – Experimental apparatus for measurement of desorption isotherms—Static gravimetric method: discontinuous measurement. (1) Thermostated oven; (2) jar containing salt; (3) sample; (4) sample holder; (5) saturated salt solution.