Moisture desorption isotherms of *Lavandula officinalis* L. flowers at three temperatures

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Abstract

Lavander has been used as a medicinal plant and to treat several diseases. Knowledge of moisture desorption isotherms is useful in food dehydration and drying. The equilibrium moisture content for *Lavandula officinalis* L. flowers were measured by using the gravimetric static method with water activity ranging from 11% to 85% and three temperatures of 30, 40 and 50ºC. Five mathematical models (modified Henderson, modified Oswin, modified Halsey, modified Chung – Pfost and GAB equations) were used to fit the experimental data of desorption. The modified Halsey model was found to be the best model for describing desorption isotherms curves.

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1. Introduction

Lavander is an important medicinal plant of the Labiatae family. Linalool and linalyl acetate are the main component of lavender oils. The relationship between Equilibrium Relative Humidity (ERH) and Equilibrium Moisture Content (EMC) is normally defined by Moisture sorption isotherms (Soysal and Öztekin, 1999). Moisture desorption isotherms help us to determine the maximum moisture that the plant can be allowed to lose during drying. Since all the agricultural products are generally hygroscopic, it is important to determine their equilibrium moisture content for drying, storing, mixing and packaging operations. Having different physical and chemical structures, agricultural crops demonstrate different EMCs under similar conditions (Ahmadi Chenarbon et al., 2010). Medicinal and aromatic plants are used extensively in food, cosmetic, and pharmaceutical industries for the production of spice, essential oils and drugs (Soysal and Öztekin, 2001). Due to their high moisture content and vulnerability to microorganisms, it is very important to provide optimum drying and storage conditions in order to prevent quality spoilage. EMC is defined as the moisture content of hygroscopic material in equilibrium with a particular environment in terms of temperature and relative humidity (Soysal and Öztekin, 1999). In practice, the result of moisture exchange between the product and the surrounding air yields a relative humidity which is known as the Equilibrium Relative Humidity (ERH) (Silakul and Jindal, 2002). The common technique for measuring sorption properties is the static method. This method benefits from the ability to maintain constant conditions (Arnosti et al., 1999; Barrozo et al., 1994). Temperature and relative humidity of the environment in which samples are placed, are adjusted. When sample mass attains a constant level, sample moisture content is measured and adopted as the Equilibrium Moisture Content (EMC) value. Several empirical and semi-empirical equations have been reported to provide a correlation for the sorption isotherm values of agricultural and food products, including aromatic and medicinal plants (Belghit et al., 2000; Park et al., 2002). However, no single equation is comprehensive enough to predict the relationship between the EMC of agricultural and food products and the relative humidity over a wide range of temperature (Lahsasni et al., 2004; Park et al., 2002). The objective of this study was to determine the desorption isotherms of *Lavandula officinalis* L. flowers at relative humidity and temperature levels ranging from 11 to 85% and from 30 to 50ºC, respectively. Five popular models (modified Henderson, modified Oswin, modified Halsey, modified Chung – Pfost and GAB equations) in the literature were fitted to the experimental data in order to verify their adequacy to describe the EMC of the *Lavandula officinalis* L. flowers (Chung and Pfost, 1967; Halsey, 1985; Oswin, 1946).

2.Materials and Methods

2.1. Experimental procedure: The *Lavandula officinalis* L. fresh flowers used in desorption experiments have been grown in the Institute of Medicinal Plant of Iran in 2010. After harvesting, the flowers were cut from stems immediately. 1g (±0.0001) samples of fresh flowers for desorption experiments were weighed and placed into the glass jars. The equilibrium moisture content of *Lavandula officinalis* L. flowers were determined by using the static gravimetric method at 30, 40 and 50°C. These temperatures are often used for drying of medicinal plants. In this method, seven saturated salt solutions (LiCl, CH_3COOK, $MgCl_2$, K_2CO_3, $NaNO_2$, NaCl and KCl) with relative humidities ranging from 11 to 85% were used to maintain relative humidities in the jars (Greenspan, 1976). Table1 gives the equivalent relative humidities for the selected salt solutions at three temperatures.

Nomenclature

C_1 , C_2 , C_3 , C_4 C_5 , C_6 and C_7	equation coefficients	RSS	Residual Sum of Square
T	Temperature, ° C	SEE	Standard Error Estimation
Ta	absolute temperature. K	MRD	Mean Relative Deviation
R	universal gas constant, kJ/kmol k	df	degrees of freedom
R^2	determination coefficient	EMC	Equilibrium Moisture Content
ERH	Equilibrium Relative Humidity (decimal)	d.b	dry basis
i	sample number	m	Number of samples

Table1. Saturated Salt solutions and Equilibrium Relative Humidities at different temperatures

Salt type	Equilibrium Relative Humidity (ERH)		
	T=30˚C	T=40˚C	T=50˚C
LiCl	0.113	0.112	0.111
CH_3COOK	0.216	0.204	0.192
$MgCl_2$	0.324	0.316	0.305
K_2CO_3	0.432	0.432	0.433
$NaNO_2$	0.643	0.616	0.597
NaCl	0.751	0.747	0.744
KCl	0.836	0.823	0.812

Samples were weighted every three days until constant weight was reached. Crystalline thymol was used in the jars to prevent microbial spoilage. Constant weight was reached after about 3 weeks in different levels of temperature and relative humidities. The moisture content of each sample was determined in a drying oven at 105°C for 24h (Anon1996; AOAC, 1990).

2.2. Data analysis: Five models, namely, modified Henderson, Oswin, Halsey, Chung – Pfost and GAB equations were used for correlating and defining the relationship between the equilibrium moisture content data and relative humidity at three temperatures (Table 2).

Table 2. Mathematical relationships applied for desorption modeling of *Lavandula officinalis* L.

Model name	**Model expression**	**References**
Modified Henderson	$EMC = \left(-\frac{1}{C_1(T+C_2)}Ln(1-ERH)\right)^{1/C_3}$	(Thompson *et al*. 1968)
Modified Halsey	$EMC = \left(\frac{-\exp(C_1+C_2T)}{Ln(ERH)}\right)^{1/C_3}$	(Iglesias and Chirife 1976)
Modified Oswin	$EMC = (C_1 + C_2T)\left(\frac{ERH}{1-ERH}\right)^{1/C_3}$	(Brooker *et al*. 1974)
Modified Chung-Pfost	$EMC = \frac{1}{C_1}Ln\left(Ln(ERH)\frac{(C_2-T)}{C_3}\right)$	(Chung and Pfost 1967)
GAB equation	$EMC = \frac{C_1C_2C_3(ERH)}{[1-C_2(ERH)][1-C_2(ERH)+C_2C_3(ERH)]}$	(Van den Berg and Bruin 1981)

C_2 and C_3 in the GAB equation were determined by using the following equations (Arabhosseini et al., 2005).

$$C_2 = C_4 exp\left(\frac{C_6}{RTa}\right) \quad (1)$$

$$C_3 = C_5 exp\left(\frac{C_7}{RTa}\right) \quad (2)$$

Nonlinear regression analysis was used to estimate the constants of models in desorption experiment (Chen, 2002; Peleg, 1993). Mean relative deviation (MRD), determination coefficient (R^2), residual sum of squares (RSS), and standard error estimation (SEE) were used to evaluate the fitting quality of models.

$$SEE = \sqrt{\frac{\sum_{i=1}^{m}(EMC - \overline{EMC})^2}{df}} \quad (3)$$

$$MRD = \frac{1}{m}\sum_{i=1}^{m}\frac{|EMC - \overline{EMC}|}{EMC} \quad (4)$$

$$RSS = \sum_{i=1}^{m}(EMC - \overline{EMC})^2$$

3. Results and discussion

3.1.Experimental Results: Fig.1, 2 and 3 illustrates desorption isotherms of *Lavandula officinalis* L. flowers obtained at various water activities for three temperature levels of 30, 40 and 50ºC. As shown, S- shaped curves were found for all three temperatures similar to the most biological products (Ait Mohamed et al., 2005; Kouhila et al., 2002; Lahsasni et al., 2003). On the other hand the full range of water activities and temperatures had a significant effect on EMC and with decreasing temperature in a constant relative humidity, the EMC was increased (Fig.1-3). Such behavior may be explained by considering the excitation state of molecules. At high temperatures, molecules are in an increased state of excitation, leading to weaker attractive forces. This in turn, results in a decrease in the degree of water sorption at a given relative humidity with increasing temperature (Kouhila et al., 2002).

3.2.Fitting of the desorption models to equilibrium moisture data: Desorption curves of *Lavandula officinalis* L. were fitted to five isotherm models. The results of non- linear regression analysis at the three temperatures are listed in Tables 3 and 4. As inferred from the tables, parameters were found to be temperature dependent for all the models. The modified Halsey equation provided the best fit to experimental data of desorption isotherms with the maximum $R^2 = 0.99$ and the lowest MRD = 0.101and SEE=0.081, respectively.

Table3. Model parameters, determination coefficients and mean relative errors in fitting of desorption isotherms at three temperatures

parameters	Estimated values and the variance of the equations and statistical parameters			
	Henderson	Halsey	Oswin	Chung – pfost
C_1	0.243 ± 0.013	- 2.202 ±0.052	1.422 ± 0.083	6.652± 0.384
C_2	279.18 ± 21.00	$-3.82 \pm 0.38 \times 10^{-4}$	$-5.82 \pm 3.14 \times 10^{-3}$	20.02 ± 11.33
C_3	2.011±0.061	2.18 ± 0.14	6.182 ± 0.032	83.53± 62.00
RSS	0.0431	0.0301	0.044	0.0320
MRD	0.375	0.101	0.221	0.187
SEE	0.120	0.081	0.107	0.094
Residual	Systematic	Random	Systematic	Systematic

Table4. Coefficients and error parameters of the GAB equation fitted to desorption isotherms at three temperatures

parameters	Estimated values and the variance of the equations and statistical parameters
	GAB
C_1	4.352 ± 0.062
C_4	3.305 ± 0.087
C_5	$3.23 \pm 2.201 \times 10^{-4}$
C_6	654 ± 31
C_7	493
RSS	0.045
MRD	0.237
SEE	0.108
Residual	Systematic

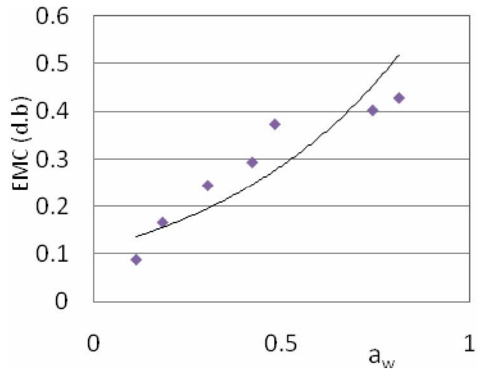

Figure 1. Desorption isotherms data of *Lavandula officinalis* L. flowers at 30ºC and fitted curve of the Halsey model

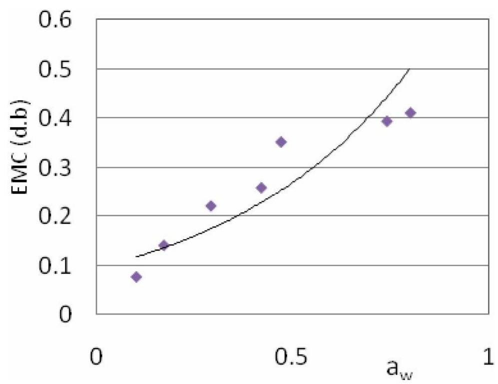

Figure 2. Desorption isotherms data of *Lavandula officinalis* L. flowers at 40ºC and fitted curve of the Halsey model

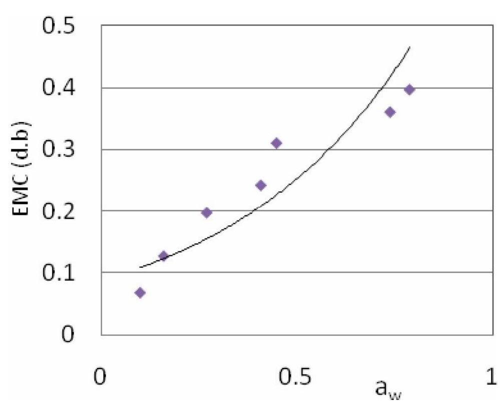

Figure 3. Desorption isotherms data of *Lavandula officinalis* L. flowers at 50ºC and fitted curve of the Halsey model

4. Conclusions

Moisture desorption curves of *Lavandula officinalis* L. flowers were obtained at three temperatures (30, 40, 50ºC) and relative humidity levels ranging from 11 to 85%. Statistical analysis was used to determine the best equation for predicting the desorption curves of *Lavandula officinalis* L. flowers. Halsey equation was the best fit with lowest error.

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