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MOISTURE ADSORPTION 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 adsorption isotherms is useful in storage condition. 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 adsorption. The modified Chung - Pfost model was found to be the best model for describing adsorption isotherms curves.

Keywords: *Lavandula officinalis*, adsorption, equilibrium moisture content.

Nomenclature

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

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 adsorption isotherms data can be used for establishing a storage method. 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 micro organisms, 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 adsorption 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).

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MATERIALS AND METHODS

Experimental procedure

The *Lavandula officinalis* L. fresh flowers used in adsorption experiments have been grown in the Institute of Medicinal Plant of Iran in 2010. After harvesting, the flowers were cut from stems immediately. 50g fresh flowers were used for adsorption tests. First the flowers were stored in room condition to reach low moisture content. Then the dry materials were dehydrated in a desiccators contain of blue silicagel at room temperature for two weeks. The moisture content of the samples was less than 4% at the end of this period. 1g (±0.0001) samples of fresh flowers for adsorption 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, Mg Cl_2, K_2CO_3, $NaNO_2$, NaCl and KCl) with relative humidity ranging from 11 to 85% were used to maintain relative humidity in the jars (Greenspan, 1976). Table-1 gives the equivalent relative humidity for the selected salt solutions at three temperatures.

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 humidity. The moisture content of each sample was determined in a drying oven at 105°C for 24h (Anon1996; AOAC, 1990).

Table-1. Saturated salt solutions and equilibrium relative humidity 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

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 adsorption 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).

$$C_2=C_4exp\left(\frac{C_6}{RTa}\right)$$

$$C_3=C_5exp\left(\frac{C_7}{RTa}\right)$$

Nonlinear regression analysis was used to estimate the constants of models in adsorption 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.

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

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

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

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RESULTS AND DISCUSSIONS

Experimental Results

Figures 1, 2 and 3 illustrates adsorption isotherms of *Lavandula officinalis* L. flowers obtained at various water activities for three temperatures levels of 30, 40 and 50ºC.

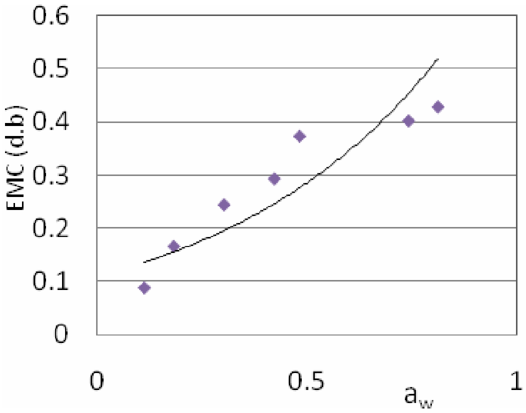

Figure-1. Adsorption isotherms data of *Lavandula officinalis* L. flowers at 30ºC and fitted curve of the Chung - Pfost model.

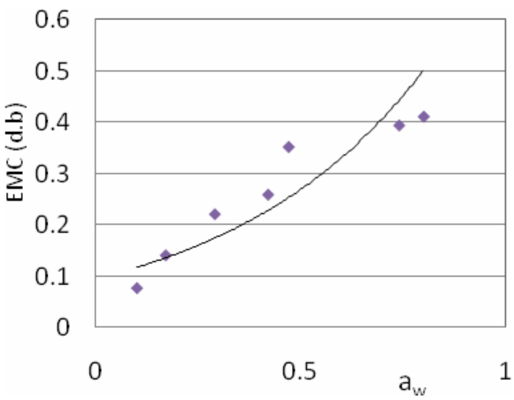

Figure-2. Adsorption isotherms data of *Lavandula officinalis* L. flowers at 40ºC and fitted curve of the Chung - Pfost model.

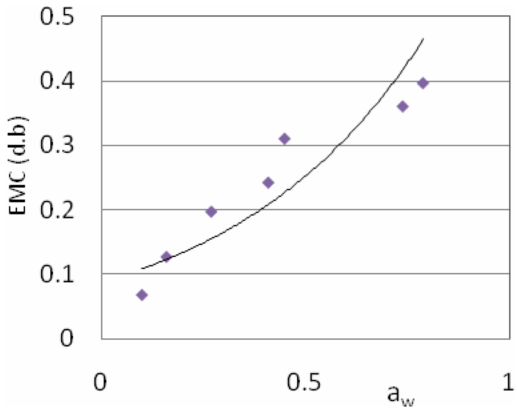

Figure-3. Adsorption isotherms data of *Lavandula officinalis* L. flowers at 50ºC and fitted curve of the Chung - Pfost model.

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 (Figures 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).

Fitting of the adsorption models to equilibrium moisture data

Adsorption 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 Chung - Pfost equation provided the best fit to experimental data of adsorption isotherms with the maximum $R^2 = 0.99$ and the lowest MRD = 0.112 and SEE = 0.107, respectively.

Table-3. Model parameters, determination coefficients and mean relative errors in fitting of adsorption isotherms at three temperatures.

parameters	Estimated values and the variance of the equations and statistical parameters			
	Henderson	Halsey	Oswin	Chung – Pfost
C_1	0.231 ± 0.011	- 3.11 ±0.02	2.345 ± 0.1	5.421± 0.21
C_2	151.15 ± 11.00	$-2.47 \pm 0.2 \times 10^{-3}$	$-3.67 \pm 2 \times 10^{-4}$	18.11 ± 10.01
C_3	1.547±0.02	1.11 ± 0.2	5.252 ± 0.01	65.22± 31.00
RSS	0.261	0.351	0.345	0.233
MRD	0.245	0.133	0.145	0.112
SEE	0.167	0.109	0.117	0.107
Residual	Systematic	Random	Systematic	Systematic

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Table-4. Coefficients and error parameters of the GAB equation fitted to adsorption isotherms at three temperatures.

parameters	Estimated values and the variance of the equations and statistical parameters
	GAB
C_1	3.451 ± 0.07
C_4	2.307 ± 0.15
C_5	$2.17 \pm 1.201 \times 10^{-3}$
C_6	437 ± 21
C_7	493
RSS	0.175
MRD	0.341
SEE	0.205
Residual	Systematic

CONCLUSIONS

Moisture adsorption 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 adsorption curves of *Lavandula officinalis* L. flowers. Chung - Pfost equation was the best fit with lowest error.

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