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Equilibrium moisture content isotherm characteristics of rapeseed

Le Anh Duc[1], Keum Dong Hyuk[2]
Nong Lam University, Ho Chi Minh City, Viet Nam
Retired scientist, South Korea
E-mail: leanhduc@hcmuaf.edu.vn

Abstract—The ERH and EMC of rapeseed were determined using static method with a constant environment chamber for various combinations of air temperature and relative humidity. The moisture desorption isotherm data are used to determine EMC equation. Four EMC/ERH equations are recommended as the best predictions of equilibrium moisture content for grains and oilseeds over wide ranges of temperatures and relative humidity was used: the Chung-Pfost, modified Halsey, modified Henderson, and modified Oswin, and their estimated parameter were evaluated for goodness of fit. The Modified Halsey equation is identified as the best adequate equation for prediting desorption EMC isotherm of rapeseed. The RMSE for ERH and EMC is 1.909% and 0.281%. The R^2 for ERH and EMC is 0.9936 and 0.9925, respectively. The modified Oswin equation is fairly good fits, and the Chung-Pfost and modified Henderson equation could not available for prediction EMC of rapeseed.

***Keywords*—rapeseed, equilibrium moisture content, isotherm, temperature, saturated salt**

INTRODUCTION

Rapeseed is used to product bio-diesel. Rapeseed needs to be dried to minimize damage for subsequent operations. In order to optimize the drying and storage processes of rapeseed, it is necessary to know the EMC.

The relationship between equilibrium moisture content (EMC) and equilibrium relative humidity (ERH) of grain is an important in the field of drying and storage. The desorption isotherm determines the lowest attainable moisture content of grain at a particular drying temperature and relative humidity. The EMC and the ERH are of primary important factors in order to fully describe the drying process, the effect of water activity on safe storage, and the intrinsic drying kinetics [2].

There are more than 200 equations have been developed theoretically, semi-theoretically or empirically to model the relationship between EMC or ERH and temperature of different biological materials that each model had some success simulating the EMC data for a particular food for a given range of relative humidity and temperature [2]. However, Chen and Morey (1989) concluded that no unique EMC/ERH equation has the ability to describe accurately the EMC/ERH relations for various types of biological materials in a broad range of relative humidity’s and temperatures. Therefore, it is necessary to select the most appropriate EMC/ERH models for a specific crop.

A considerable amount of work has been done on equilibrium isotherm of different agricultural products. A literature review revealed that most of the previously studies have been conducted on products such as corn, rice, soybean, peanuts and sunflower seed. However, studies on rapeseed are scarce.

MATERIALS AND METHODS

Using static method (sometimes called the EMC method) involves the use of saturated salt solutions to control the humidity in a chamber containing the material sample. The sample is allowed to equilibrate under conditions of controlled humidity and temperature.

Sample preparation: rapeseed samples were cleaned and stored at 4°C [3] in a laboratory refrigerator before experiments. The samples after removal from the refrigerator were sealed in airtight bags made of sheet polyethylene for 24 h [8] to allow for moisture equilibration to ambient room conditions. The initial moisture content of sample is 33.1% (d.b.). The moisture content of the samples was determined using the drying oven method: 10 g in a drying oven at 130°C for 4 h [1].

Glass desiccators were used as controlled-humidity chambers. Desiccators with wide-mouth about 2.5 litre with cap on the top was provided to create airtight environment. Lower compartment of the desiccators is separated by perforated china plate, held the different chemical salt solutions prepared with distilled water [7].

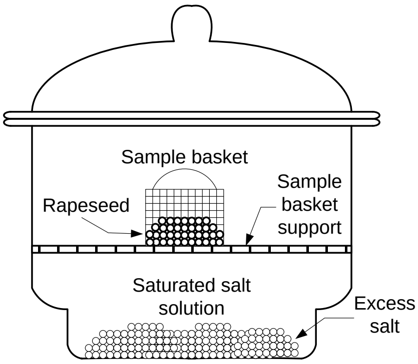

Fig. 1. Schematic diagram of glass desiccators with sample rapeseed.

The sample baskets with a 10 g sample of rapeseed were put into the desiccators and then samples were sealed in desiccators with the saturated salt solution. The desiccators were placed in an isothermal environment by using a temperature-controlled chamber (Figure 2). In this study, we used an incubator model HK-B1025, 0 ~ 120^{o}C, ± 0.1^{o}C.

Fig. 2. Glass desiccators in temperature-controlled chamber.

In the experiment process, the samples were removed for weighting at intervals of three days using electric balance (R420P, Sartorius, Germany, accuracy ± 0.001 g). The samples were considered to have reached equilibrium when the change in samples mass between several successive measurements was less than 0.005 g.

The eight salts used to produce constant humidity environments about from 11.3 to 83.6% in the desiccators were: lithium chloride (LiCl), potassium acetate (CH3COOK), magnesium chloride (MgCl2), potassium carbonate (K2CO3), magnesium nitrate (Mg(NO3)2), potassium iodide (KI), sodium chloride (NaCl), and Potassium chloride (KCl) sodium nitrate (NaNO3). Different combinations of three temperature levels were 40, 50 and 60^{o}C and eight relative humidity levels in the ranging from 11.3 to 83.6% were created a total of 24 experiments. Three replicates for each experiment were performed. The relative humidity of saturated salt solutions at different temperature used in the desiccators was determined by Greenspan's publish (1977).

The Chung-Pfost equation, modified Halsey equation, modified Henderson equation and modified Oswin equation are recommended as the best predictions of equilibrium moisture content for agricultural grains and oilseeds over wide ranges of temperatures and relative humidity [1], therefore four equations were applied to predict equilibrium moisture content isotherm characteristics of rapeseed.

The best-fit equation by using the coefficient of determination (R^2) and the root mean square error (RMSE). The higher R^2 value and the lower RMSE value were used as the criteria for goodness of fit.

RESULT AND DISCUSSION

After 16 days, the change of weight of all sample are less than 0.005 g, the experiments were stopped. The desorption equilibrium moisture content of rapeseed is presented in Table 1. The mean of the desorption equilibrium moisture content (EMC) of rapeseed ranged from 3.79 - 14.53%, 3.36 - 12.98% and 3.24 - 10.91% (db.) for the temperatures of 30, 40 and 50^{o}C, respectively in the relative humidity (ERH) ranged of 11.1 - 83.6%.

The four proposed equations were analyzed by a non-linear regression analysis, using the Statistical Analysis System (SAS ver.9.1) program. The values of the parameters were back substituted into equations, so as to predict EMC/ERH. The observed and predicted values were compared and statistically analyzed for determining the best-fit equation by using the coefficient of determination (R^2) and the root mean square error (RMSE). The higher R^2 value and the lower RMSE value were used as the criteria for goodness of fit. The results of analysis for four equations were presented in Table 2.

The experimental EMC data were fitted with the models. Figures from 3 to 5 showed the comparison of the predicted values versus experimental data for the different temperature conditions. Predicted curves were plotted using four proposed equations with the regression coefficients determined in Table 2. The curves showed the correlation between predicted and measured values. These predicted curves showed that the Modified Halsey equation is the best agreement between predicted and measured values.

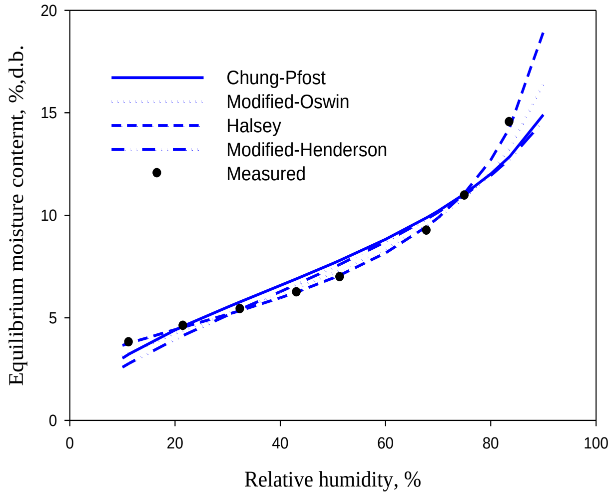

Fig. 3. Predicted and measured moisture desorption isotherms (EMC/ERH) of rapeseed at temperature of 30°C

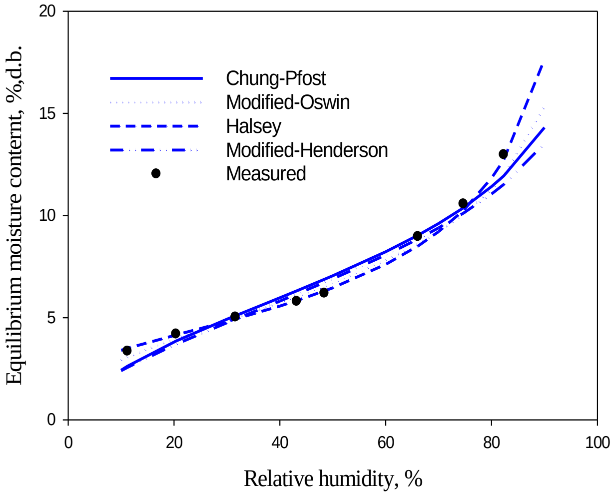

Fig. 4. Predicted and measured moisture desorption isotherms (EMC/ERH) of rapeseed at temperature of 40°C.

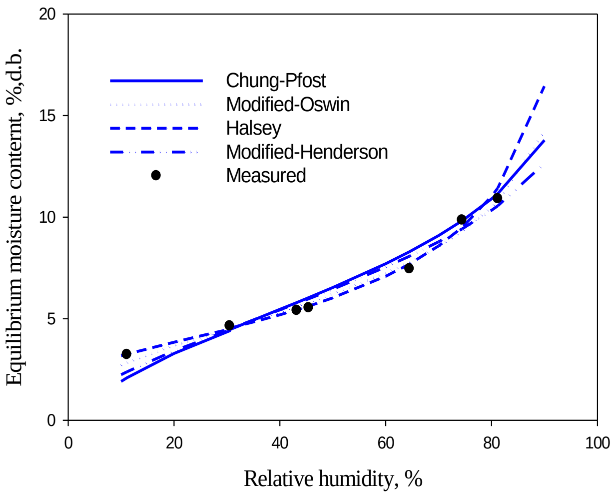

Fig. 5. Predicted and measured moisture desorption isotherms (EMC/ERH) of rapeseed at temperature of 50°C.

The Modified Halsey equation is identified as the best adequate equation for describing desorption EMC of rapeseed in the range of the relative humidity from 11 to 83%. The modified Oswin equation is fairly good fits, and the Chung-Pfost and modified Henderson equation could not available for prediction EMC of rapeseed.

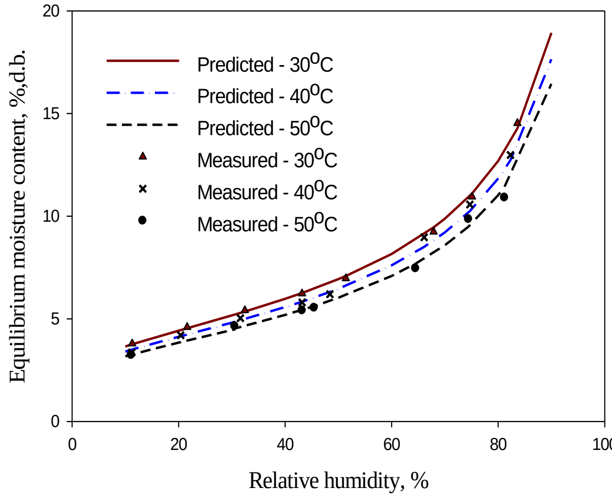

Fig. 6. Comparison of measured and predicted desorption EMC of rapeseed at three temperature levels of 30, 40 and 50°C by Modified Halsey equation.

The results in Table 2 showed that the Modified Halsey equation has RMSE values smaller than other equations, 1.909% and 0.281% for RH and EMC, respectively. The R^2 values are higher than other equations, 0.9936 and 0.9925 for RH and EMC, respectively. These results demonstrated that Modified Halsey equation is the best appropriate to predict desorption equilibrium moisture content of rapeseed.

$$RH = \exp[-\exp(-4.9758 - 0.0132 \cdot T) M^{-1.8755}]$$

$$M = [\exp(-4.9758 - 0.0132 \cdot T)]^{1/1.8755} (-\ln RH)^{-1/1.8755}$$

A comparison between the fitted EMC equation (Modified Halsey equation) and the measured values of EMC are shown in Figure 6. It showed that the Modified Halsey equation is identified as the best adequate equation for predicting desorption EMC isotherm of rapeseed.

IV. CONCLUSIONS

The equilibrium moisture content and equilibrium relative humidity of rapeseed were determined using static method with a constant environment chamber for various combinations of air temperature and relative humidity vary from 30 to 50°C and 11 to 83%, respectively.

Four EMC/ERH equations are recommended as the best predictions of equilibrium moisture content isotherm for grains and oilseeds over wide ranges of temperatures and relative humidity was used: the Chung-Pfost, modified

Halsey, modified Henderson, and modified Oswin, and their estimated parameter were evaluated for goodness of fit.

The fit equation by using the coefficient of determination (R^2) and the root mean square error (RMSE). The Modified Halsey equation is identified as the best adequate equation for prediting desorption EMC isotherm of rapeseed. The RMSE for ERH and EMC is 1.909% and 0.281%. The R^2 for ERH and EMC is 0.9936 and 0.9925, respectively.

The modified Oswin equation is fairly good fits, and the Chung-Pfost and modified Henderson equation could not available for prediction EMC of rapeseed.

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TABLE 1. Experimental desorption equilibrium moisture content data of rapeseed.

Temperature, °C	30°C							
ERH, %	11.28	21.61	32.44	43.17	51.40	67.89	75.09	83.62
EMC, % (d.b.)	3.79	4.59	5.41	6.23	6.97	9.24	10.95	14.53
Temperature, °C	40°C							
ERH, %	11.21	20.40	31.60	43.19	48.42	66.09	74.68	82.32
EMC, % (d.b.)	3.36	4.20	5.03	5.80	6.20	8.97	10.57	12.98
Temperature, °C	50°C							
ERH, %	11.10	-	30.54	43.20	45.44	64.49	74.43	81.20
EMC, % (d.b.)	3.24	-	4.65	5.41	5.54	7.46	9.86	10.91

TABLE 2. Estimated regression coefficients for Chung-Pfost, Modified Halsey, Modified Henderson, Modified Oswin equation.

Equation	Regression coefficients	RMSE		R^2	
		RH (%)	EMC (%)	RH (%)	EMC (%)
Chung-Pfost $RH = \exp\left[-\frac{A}{T+C}\exp(-BM)\right]$ $M = E - F.\ln[-(T+C).\ln(RH)]$	A = 391.7 B = 27.885 C = 44.1262 E = 0.2196 F = 0.0385	4.479	0.653	0.9667	0.9559
Modified Halsey $RH = \exp[-\exp(A+BT)M^{-C}]$ $M = [\exp(A+BT)]^{1/C}(-\ln RH)^{-1/C}$	A = −4.9758 B = −0.0132 C = 1.8755	1.909	0.281	0.9936	0.9925
Modified Henderson $RH = 1-\exp[-K(T+C)(100M)^N]$ $M = 0.01\left[\frac{\ln(1-RH)}{-K(T+C)}\right]^{1/N}$	K = 0.000282 C = 38.3729 N = 1.7844	4.661	0.682	0.9619	0.9564
Modified Oswin $RH = \frac{1}{(A+BT/M)^{1/N}+1}$ $M = (A+BT)\left(\frac{RH}{1-RH}\right)^N$	A = 0.0861 B = −0.00048 N = 0.3775	2.986	0.496	0.9846	0.9816

where: M: equilibrium moisture content (decimal, d.b.); RH: relative humidity (decimal, d.b.); T: temperature (°C); A, B, C, E, F, K, N: regression coefficients was determined from experimental data.