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【Original Paper】

Equilibrium Moisture Content of Coffee Bean

Pham Tri Thong[a], Tetushi Azuma[b], Takashi Nanmori[b], Takeshi Yasuda[b]

[a)]Faculty of Food Science and Technology, The University of Agriculture and Forestry, HoChiMinh City, Vietnam
[b)]Department of Biological and Environmental Science, Faculty of Agriculture, Kobe University, Kobe 657-8501, Japan

Abstract

Equilibrium moisture contents of coffee bean in sorption process were measured at three temperature regimes: 30, 40 and 50 °C in the equilibrium relative humidity ranging from 11% to 84% by a static method. Data obtained were subjected to the four reported sorption isotherms: the Henderson, the Chung and Pfost, the modified Halsey, and the modified GAB models by using non-linear regression procedures to estimate their equation parameters. Comparisons for the models are based on residual plots and some statistical criteria: coefficient of determination (R^2), mean relative percent error (P), root mean square error of moisture content (RMS) resulting from 0.95 to 0.99, 4.51 to 17.61, and 0.36 to 1.39; respectively. It was found that the modified Halsey and the modified GAB models adequately represented the experimental data for coffee bean.

Introduction

In the field of Food Science and Technology, the concept of Equilibrium Moisture Content (EMC) is very important and necessary in studying preservation and processing of biological materials. In order to predict safe storage conditions and drying behavior of agricultural products at different temperatures and relative humidities of surrounding air, the values of EMC of farm products are required.

The coffee bean, like other agricultural crops, is a hygroscopic material. The moisture content of the coffee bean reaches a value controlled by the relative humidity and temperature of its ambient air. The coffee bean gains or losses water from or to environment at a constant temperature since there is a difference value between water vapor pressure in a coffee bean and that of its surrounding air. When the equilibration of the two pressures is established, then the coffee bean can not gain or loss water any more. At this time, the moisture content of the coffee bean is termed the EMC and the relative humidity of surrounding air is termed the Equilibrium Relative Humidity (ERH).

The relationship between EMC and ERH of some agricultural products, expressed in several mathematical models based on theoretical, semi-theoretical and empirical study, has been investigated and published by a number of investigators in literature. Among them the two and three-parameter isotherm equations handling the dependency of EMC on both relative humidity and temperature were developed and modified by some of the following researchers: Henderson (1952), Chung and Pfost (1967), Halsey (1948) (Iglesias and Chirife modified, 1976); GAB (1946) (Jayas and Mazza modified, 1993). The EMC-ERH data for the coffee bean, however, are rarely published and have not been researched as much as for other farm products. Thus, there is a real need to carry out such important study on the coffee bean.

The objectives of this study were, (1) to experimentally obtain equilibrium moisture content data for *Robusta* coffee bean, at various temperature regimes (30, 40 and 50°C) under relative humidities in the range of 11-84%, and (2) to estimate the coefficients of the mathematical equations available for describing EMC-ERH relationships of the coffee bean.

Materials and Methods

Experimental products

Coffee beans (*Coffea canephora var. Robusta*), class I (superior) according to Vietnamese coffee official standard, were purchased at a coffee export station in BaoLoc town, LamDong province on October 2000. A preliminary moisture content determined of coffee beans was about 12-13% on wet weight basis (wb.) using a capacity type moisture meter (KETT, Japan).

After selecting sound beans, free of defect and materials other than grain, the experimental products were placed in airtight bags. Then all sealed bags were stored in a refrigerator until transported to the Lab of Tropical Plant Science, Kobe University, Japan on November 2000 for the following

experiments.

Preparation of samples

Approximately 5 g of *Robusta* coffee bean with same size and color were loosely placed in each of several small beakers. A set of three beakers for three replicates were suspended in a closed bottle containing saturated salt solution.

Preparation of Aqueous Solutions

The static method, with standard saturated salt solutions, was used in all isotherm experiments for generating constant relative humidities in closed containers or desiccators. The relative humidities, of five saturated salt solutions, at different temperatures are shown in Table 1. The steps of preparation were followed the ASTM Standard Practice E 104-85 (USA, 1996). Placing a quantity of the selected salts in the bottom of desiccators and then adding distilled water (Millipore, Milli-Q.Labo, Japan) in conjunction with stirring well the system on a magnetic stirrer (KPI, Model M_16, Japan) until the salt can absorb no more water as evidence by free liquid. To ensure that salt solutions remained saturated throughout the course of the experiment, excess salt was added to the saturated solutions.

Experiment with constant drying temperature

The desiccators were placed in a temperature-controlled oven (Sanyo) at drying temperatures of 30, 40 and 50 °C within a range of ± 1 °C. The experiments were run at each temperature and relative humidity setting. The samples were weighed daily using an analytical balance (AND FX-320) with an accuracy of 1 mg. Equilibrium conditions were considered to be reached when three consecutive measurements gave identical readings. The samples usually attained the EMC in about 3 weeks. The dry matter contents were measured by drying at 105 °C until there was no change in weight. The EMC values of samples were expressed in either percent or decimal on dry weight basis (db.).

Table 1. Equilibrium relative humidity in the range of 11 to 84% for various saturated salt solutions at three different temperatures

Saturated salt solutions	Temperature (°C)		
	30	40	50
LiCl	11.3	11.2	11.1
$MgCl_2$	32.4	31.6	30.5
$Mg(NO_3)_2$	51.4	48.4	45.4
NaCl	75.1	74.7	74.4
KCl	83.6	82.3	81.2

Source: International Union Pure and Applied Chemistry, CRC 2000.

Data Analysis

The coefficients for each listed EMC-ERH equation (Table 2) were determined using regression procedure non-linear of SPSS software version 7.5 to the experimental EMC-ERH data of coffee bean. Parameters were estimated for the models by taking the left member (M_p) of the equations to be the dependent variable; whereas, the others (aw and T or T_k) on the right one were assigned as independent variables. An equal number of data points was used to fit all equations so that the equations can be compared using coefficient of determination (R^2), mean relative percent error (P), root mean square error of moisture content (RMS), and residual plots. Higher value of R^2, smaller values of P and RMS and increased randomness of the residual plots indicate a better model.

Mean relative percent error (P) is defined as:

$$P(\%)=\frac{100}{N}\sum\frac{|PEMC-MEMC|}{MEMC}$$

and root mean square error of moisture content (RMS) is defined as:

$$RMS=\sqrt{\frac{\sum(PEMC-MEMC)^2}{N}}$$

where, PEMC: the predicted EMC value, MEMC: the measured EMC value, N: the number of data points.

The differences between the predicted EMC by a given equation and measured EMC values were plotted against measured EMC to give residual plots. The residual plots were assessed for pattern or randomness.

Results and Discussion

EMC-ERH data

Table 3 shows the mean practical values of three replicates of the EMC of coffee bean exposed to various ERH at three different temperatures in the study. It was observed that higher ERH values gave higher EMC values. This is because the increased relative humidity results in an increased amount of free molecules of water in environment. This excess moisture creates a high moisture vapor pressure, thus the vapor moves into the coffee bean.

Table 2. Equilibrium Moisture Content – Equilibrium Relative Humidity Models

Henderson, 1952	M_p	=	$[- \ln(1 - aw) / AT_k]^{(1/B)}$
Chung and Pfost, 1967	M_p	=	$(- 1 / B) \ln[- T_k \ln(aw) / A]$
Modified Halsey, 1948 (Iglesias and Chirife, 1976)	M_p	=	$[- \exp(A + BT) / \ln(aw)]^{(1/C)}$
Modified GAB, 1946 (Jayas and Mazza, 1993)	M_p	=	$[A (C / T) Baw] / \{(1 - Baw) [(1 - Baw) + (C / T) Baw]\}$

A, B and C: Constants
aw: Equilibrium Relative Humidity, decimal
M_d: Equilibrium Moisture Content, decimal dry basis
M_p: Equilibrium Moisture Content, % dry basis
T: Centigrade Temperature, °C
T_k: Absolute Temperature, °K

As a result, the moisture content of bean definitely increases. The mean of measured EMC values, standard deviation (SD) and coefficient of variation (CV) of Robusta coffee beans equilibrated at 11 to 84% relative humidity and at 30, 40 and 50°C are also given in Table 3. The coefficient of variation (CV) in EMC measurements was less than 2% for 12 of the 14 measured data points, and it was approximately 3% for the remaining two data points.

Effect of temperature

It was also indicated that higher temperatures resulted in lower moisture contents at a constant relative humidity. In other words, the amount of water in coffee bean decreases with increasing temperature at a constant relative humidity.

Table 3. Observed mean equilibrium moisture contents of coffee bean exposed to various equilibrium relative humidities at three different temperatures

Temperature (°C)	ERH (%)	EMC (% db.)[a]		
		Mean	SD[b]	CV[c]
30	11.3	4.79	0.06	1.30
30	32.4	6.95	0.12	1.76
30	51.4	9.13	0.10	1.10
30	75.1	15.78	0.08	0.49
30	83.6	21.48	0.09	0.40
40	11.2	3.88	0.10	2.47
40	31.6	5.98	0.08	1.36
40	48.4	7.83	0.22	2.77
40	82.3	20.27	0.11	0.53
50	11.1	3.33	0.03	0.92
50	30.5	5.38	0.04	0.69
50	45.4	7.20	0.04	0.50
50	74.4	14.82	0.05	0.31
50	81.2	18.54	0.18	0.99

[a] The initial moisture content of coffee bean was 15.19 ± 0.18 %db
[b] SD = standard deviation based on three replicates
[c] CV = (standard deviation / mean) x 100.

Evaluation of EMC-ERH models

The coefficients of Henderson, Chung & Pfost, modified Halsey, and modified GAB isotherm model are tabulated in Table 4. The quantitative standards (P, RMS and R^2) for these equations are also presented in Table 4. The residual plots for the models are shown in Figure 1.

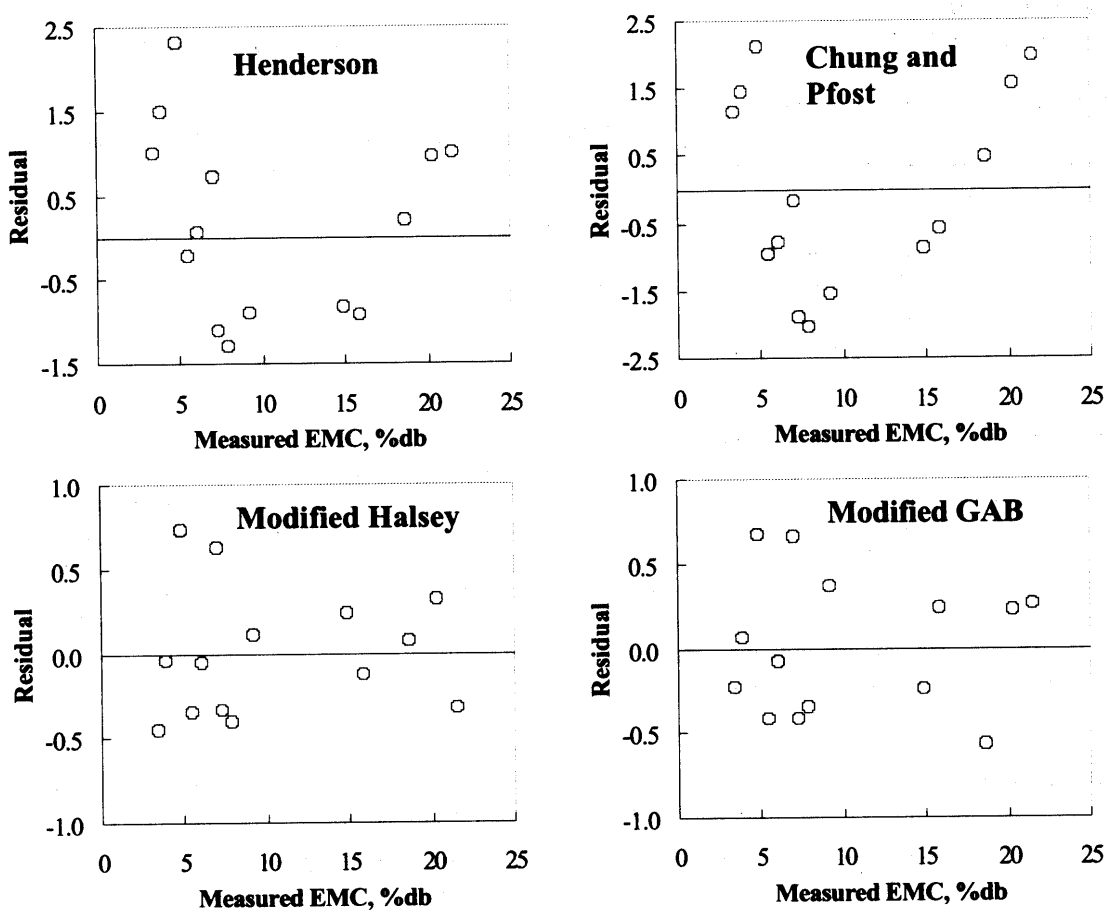


Figure 1. Residual plots for coffee bean evaluated by the Henderson, Chung and Pfost, modified Halsey, and modified GAB model.

Table 4. Coefficients of the selected models for coffee beans equilibrated at 11 to 84% relative humidity and at 30, 40 and 50 °C

	Model			
Coefficient	Henderson	Chung and Pfost	Modified Halsey	Modified GAB
A	0.00012	982.882	3.00861	4.73027
B	1.28285	0.14859	- 0.00485	0.93206
C	-	-	1.48682	896.412
R^2	0.969	0.949	0.997	0.996
P	13.99	17.61	4.51	4.55
RMS	1.08	1.39	0.36	0.39
Residual Plot	Patterned	Patterned	Random	Random

Relatively high R-squared values, ranging from 0.95 to 0.99, were found for all models (Table 4). Among them the highest R-squared value was obtained by the modified Halsey model. The modified Halsey and GAB equations gave the lowest values for P and RMS of EMC and also resulted in random residual plot (Figure 1). This indicates that they are the best two equations to describe EMC-ERH data of coffee bean. The Henderson and Chung and Pfost equations gave the third and fourth lowest P and RMS values but they were not statistically accepted since theirs residual plot indicated a probable pattern.

All the values of A, B, and C constants are given in Table 4, which are helpful in predicting the EMC for coffee bean under certain conditions of the relative humidity and temperature of the surrounding air.

The measured and predicted EMC values at different ERH and temperatures are shown in Figure 2. All ideal lines, slope m = 1, demonstrate that there is an absolute fit between the practical and theoretical values. It can be seen from Figure 2 that both the modified Halsey and GAB equations describe the experimental data better than the Henderson and Chung and Pfost equations. It can be, therefore, concluded that neither the Henderson nor the Chung and Pfost model is suitable for fitting the experimental data of coffee bean in this study.

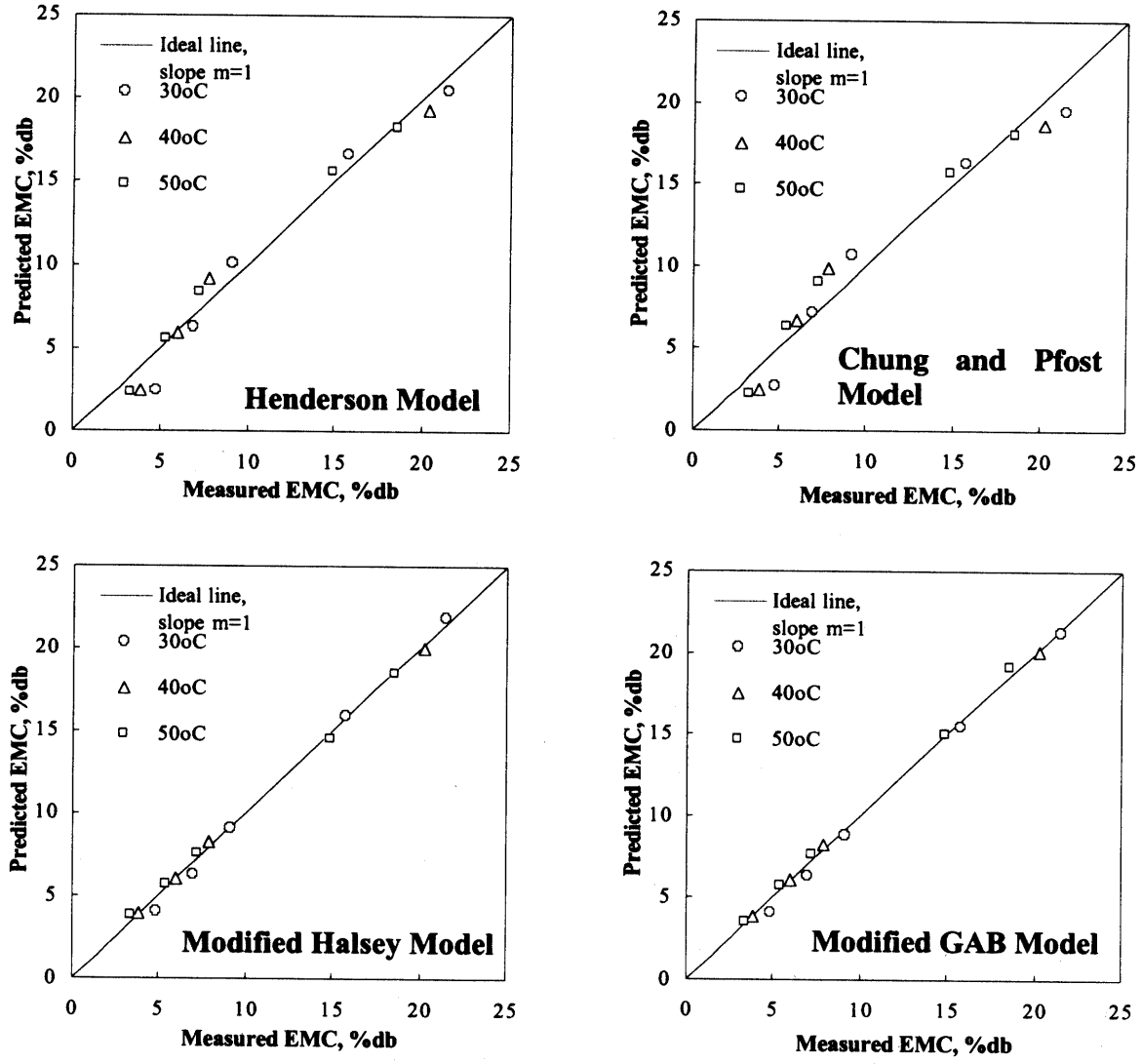


Figure 2. Relationship between the predicted and measured equilibrium moisture contents of coffee bean by fitting selected models at various temperatures.

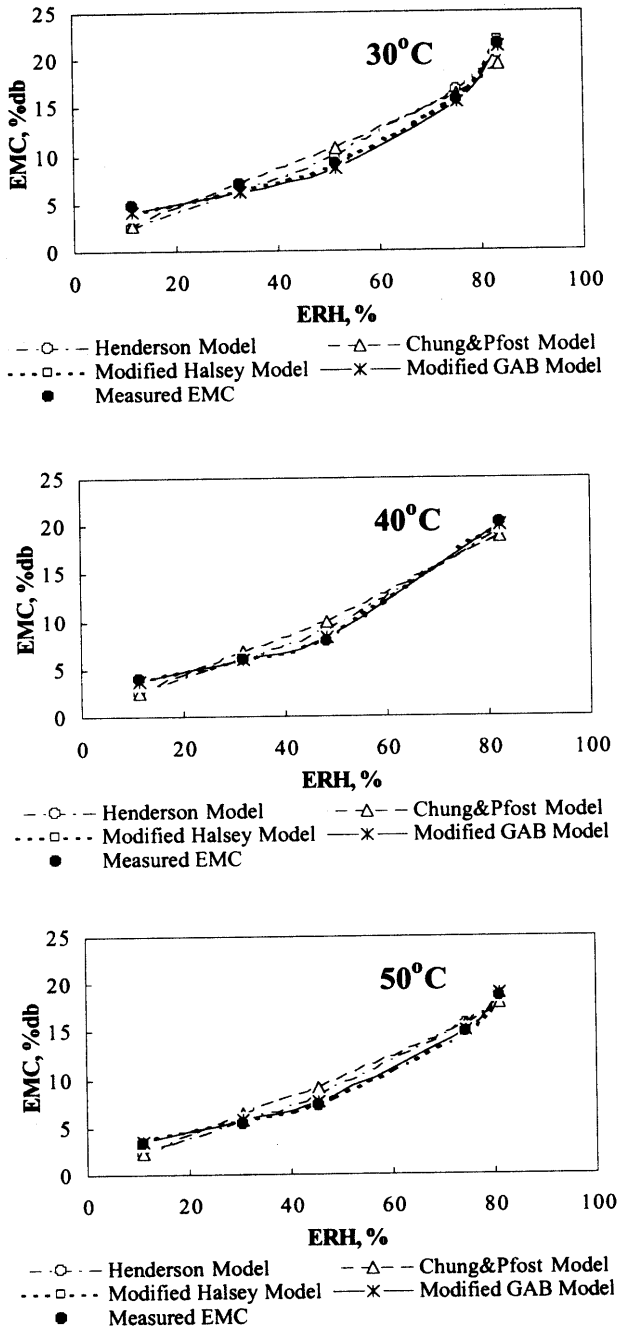


Figure 3. Measured and predicted EMC versus ERH for coffee bean at various temperatures.

The relationships between measured and predicted EMC values versus ERH at various temperatures are graphically presented in Figure 3. The curves obtained are known as the moisture sorption isotherms. The S-shaped curves in Figure 3 confirmed that the moisture sorption isotherms of coffee bean, like most foods, were classified as type II isotherms.

Conclusions

The following two conclusions can be drawn from this study:

1. The EMC of coffee bean decreases with an increase in temperature at constant relative humidity.
2. Based on the statistical parameters, the modified Halsey model is the best and the modified GAB is the

second best among the four models for the description of EMC data of coffee bean under the test conditions in this study.

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