DRYING CHARACTERISTICS OF PANGOLA GRASS

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ABSTRACT

To fit the desorption isotherm and adsorption isotherm for Pangola grass, the modified Henderson model, Chung-Pfost model, modified Halsey model, and modified Oswin model were used to fit the experimental EMC/ERH data. A step-by-step ERH measuring technique was used in this study. The ERH data were collected at three temperature levels of 5 °C, 25 °C and 50 °C for Pangola grass whole plant, stem, and foliage. The modified Halsey model has the best fit for both desorption isotherm and adsorption isotherm of Pangola grass whole plant as compared with other models.

Keywords: Hay, Equilibrium moisture content, Drying

INTRODUCTION

In Taiwan , the cultivated forage fields comprised 10,000 hectares, producing 150,000 tons of dry hay. The Pangola grass (Digitaria decumbens Stent) planting areas is about 7,000 hectares with an average dry hay production of 20 tons per hectare. The alfalfa hay is imported at an amount of 50,000 tons annually. The peak forage harvesting seasons is from May to October, a period of rainy and typhoon season.

The field drying hay is baled at approximately 20-25% moisture content, wet basis. This is because of weather and traditional hay making practice in Taiwan. Due to the influence of the weather, the grass can be cut two to three times per year and the risk of drying loss in the field is high. Climatic factors and the crop itself both influence the natural drying process. The principle of drying is that water evaporates from the surface of the drying material and is transferred to the surrounding air. Since the air is usually unsaturated, moisture in the material will continue to evaporate until the material is in equilibrium with the atmosphere. After field drying, the foraged is collected, packed, and stored.

To ensure the quality and increase the production of domestic forage, the Council of Agriculture (Ministry of Agriculture) initiated a hay processing project for establishing a Pangola grass drying machinery system in Taiwan. Only in so doing loss by bad weather can be avoided and the profits of the dairy farmers will be secured.

The moisture of an agricultural product when it is in equilibrium with the surrounding atmosphere is called the equilibrium moisture content (EMC). The relative humidity of the surrounding atmosphere is defined as the equilibrium relative humidity (ERH) at the particular temperature. The information of Pangola grass equilibrium moisture content is important for its role in drying and storing of the hay. Several modes (equilibrium moisture curves) have been developed to express the relationship between the moisture content of a particular material and its equilibrium relative humidity at the particular temperature (Oswin, 1946;Henderson, 1952; Chung and Pfost, 1967; Thompson et. al., 1968; Iglesias and Chirite, 1976; Pfost et. al., 1976; Halsey, 1984). The equilibrium moisture contents for alfalfa hay, Bromegrass, clover, oat straw, prairie hay, red clover and rye straw are available (Hall, 1980).

The objective of this study was to establish a relationship between Pangola grass forage EMC/ERH (equilibrium moisture content / equilibrium relative humidity) and temperature for the application in Pangola grass drying and storage.

MATERIALS AND METHODS

In the EMC/ERH study, the whole plant, stem, and foliage of Pangola grass (variety A254) were placed in an environment chamber (Lab-Lineambe-Hi-Lochamber) and exposed to temperatures of 5 °C, 25 °C, and 50 °C to study the desorption and adsorption EMC/ERH property by using the step-by-step ERH measuring technique, a method developed by Chen and Morey (1989).

Different samples of moisture content ranging from 5% d.b. to 60% d.b. were placed inside airtight containers and stored in an environmental chamber at 5 °C for more than two weeks. After two weeks, the temperature and relative humidity sensors of Rotronic I-100 transmitter were inserted into the sealed containers. When the temperature and relative humidity within the containers reached the equilibrium state (reading error within 0.1%), the equilibrium relative humidity and temperature inside the containers were recorded by data logger. The chamber temperature was then adjusted to the next higher temperature level of 25 °C and repeated the same sequence as conducted at 5 °C chamber temperature. The ERH data were collected at three temperature levels (5 °C, 25 °C and 50 °C).

After finishing the ERH measurement at 5 °C, 25 °C and 50 °C, the samples were then dried in an oven to calculate its moisture content according to ASAE Standard S358.1 (103 °C for 24 hours). The types of samples used in the ERH measurement were whole plant, foliage and stem of the Pangola grass.

RESULTS AND DISCUSSION

EQUILIBRIUM MOISTURE CONTENT MODELS

To fit the moisture content M, temperature T and relative humidity RH in a suitable model, four models were selected. The modified Henderson model (Thompson et. al., 1968): $RH=1-Exp[-A(T+C)M^B]$, Chung - Pfost model (Pfost et. al., 1976): $RH=Exp\{[-A/(T+C)] [EXP(-B\ M)]\}$, modified Halsey model (Iglesias and Chirite, 1976): $RH=Exp[-Exp(A+BT)M^{-C}]$, and modified Oswin model (Chen, 1988): $RH= 1/\{[(A+B\ T) / M]^C+1\}$ were used to fit the experimental EMC/ERH data. The constants of A, B, C for each model and the coefficient of determination R^2, standard error of the estimated value S.E., mean relative percentage deviation P, root mean square percentage error RMS and type of residual plot for each of the four models were listed in tables 1, 2, and 3 for desorption isotherms and in tables 4, 5, and 6 for adsorption isotherms.

Whole plant

From table 1, the modified Halsey model has proved to be the best fit model for desorption isotherm of whole plant of Pangola grass as compared with other models by examining the uniformly scattered residual and such characteristics as largest R^2 (0.995) and smallest S.E. (1.874), P (3.390), and RMS (5.150). From table 4, the modified Halsey model has also proved to be the best fit model for adsorption isotherm of whole plant of Pangola grass as compared with other models by examining the uniformly scattered residual and such characteristics as largest R^2 (0.991) and smallest S.E.(2.336), P (3.133), and RMS(4.302).

Figure 1 illustrates the S-shaped equilibrium moisture content curves (moisture equilibrium isotherms) for whole plant Pangola grass at three measured temperatures of 5 °C, 25 °C, and 50 °C in the drying process. The desorption and adsorption moisture contents and the hysteresis effect derived from modified Halsey model for whole plant Pangola grass is as shown in table 7. The maximum hysteresis effect (0.66-0.69% d.b.) occurs at the relative humidity of 50%. The hysteresis effect gradually increases with the increasing relative humidity until the relative humidity reaches 50%, then the hysteresis effect gradually reduces at higher relative humidity over 50%.

For drying practice, the desorption equilibrium moisture content at 50 °C, 60 °C, 70 °C, 80 °C, and 90 °C are listed in table 8. For storage practice, the adsorption equilibrium moisture content at 5 °C, 10 °C, 15 °C, 20 °C, 25 °C, 30 °C, 35 °C, and 40 °C are also listed in table 9. The monthly average temperature and humidity in Taiwan are 6.2 °C - 36.5 °C and 20% - 82% respectively.

Stem

As shown in table 2, both modified Oswin model and Chung-Pfost model can fit the stem desorption isotherm well after examining the uniformly scattered residual and higher R^2 and lower SE, P, and RMS. As shown in table 5, the modified Henderson model, modified Halsey model and Chung-Pfost model have uniformly scattered residual but the modified Halsey model has the highest R^2 (0.984) and lowest SE(2.439), P(2.555), and RMS(2.966). Therefore the modified Halsey model is recommended for stem adsorption isotherm.

Foliage

The four models have uniformly scattered residual and have acceptable values of R^2, SE, P, and RMS. The modified Oswin model is better than other models in fitting the foliage desorption isotherm in the viewpoint of highest R^2 (0.990) and lowest SE(3.211), P(5.481) and second lowest RMS(9.177).

As shown in table 6, the modified Henderson model, modified Halsey model and Chung-Pfost model have uniformly scattered residual but the modified Halsey model has the highest R^2 (0.975) and lowest SE(2.928), P(3.347), and RMS(4.163). Therefore the modified Halsey model is recommended for foliage adsorption isotherm.

CONCLUSIONS

The modified Halsey model has the best fit for both desorption isotherm and adsorption isotherm of Pangola grass whole plant as compared with modified Henderson model, Chung-Pfost model and modified Oswin model by examining the uniformity of scattered residual of regression, coefficient of determination R^2, standard error of the estimated value S.E., mean relative percentage deviation P, and root mean square percentage error RMS.

Both modified Oswin model and Chung-Pfost model can fit the Pangola grass stem desorption isotherm well. The modified Halsey model is recommended for Pangola grass stem adsorption isotherm.

The modified Oswin model is good for fitting the Pangola grass foliage desorption isotherm but the modified Halsey model is recommended for foliage adsorption isotherm.

REFERENCES

1. Chen, C. 1988. A study of equilibrium relative humidity for yellow-dent corn kernels. Ph. D. Dissertation. University of Minnesota, St. Paul, MN.
2. Chen, C. and R. V. Morey. 1989. equilibrium relative humidity (ERH) relationships for yellow-dent corn. Transactions of the ASAE 32(3):999-1006.
3. Chung, D. S. and H. B. Pfost. 1967. Adsorption and desorption of water vapor by cereal grains and their product. Part II : Development of the general isotherm equation. Transactions of the ASAE 10(4):552-555.
4. Hall, C. W. 1980. Drying and storage of agricultural crops. Westport, Connecticut.
5. Halsey, G. 1984. Physical adsorption on non-uniform surface. J. Chem. Phys. 16:931-937.
6. Henderson, S. M. 1952. A basic concept of equilibrium moisture. Agricultural Engineering 2:29-32.
7. Iglesias, H. A. and J. Chirife. 1976. Prediction of effect of temperature on water sorption isotherms of food materials. J. of Food Tech. 11:109-116.
8. Oswin, C. R. 1946. The kinetics of package life III. isotherm. J. Chem. Industry 65:419-421. London.
9. Pfost, H. B., S. G. Mourer, D. S. Chung, and A. Milliken. 1976. Summarizing and reporting equilibrium moisture data for grains. ASAE paper No.76-3524. American Society of Agricultural Engineers, St. Joseph, Michigan, U.S.A.
10. Thompson, T. L., R. M Paul and G. M. Forst. 1968. Mathematicalsimulation of corn drying - a new model. Transactions of the ASAE 24(3):582-586.

Table 1. Estimated parameters and criteria for the desorption ERH models of Pangola grass whole plant

	Modified-Henderson	Chung-Pfost	Modified-Halsey	Modified-Oswin
A	7.24351×10^{-5}	633.3481	4.67978	13.972
B	1.50601	0.13071	-5.8299×10^{-3}	-3.3956×10^{-2}
C	181.0139	144.9614	1.95593	2.309
R2	0.962	0.965	0.955	0.980
S.E.	4.931	4.717	1.874	3.569
P	11.879	10.125	3.390	7.334
RMS	27.181	20.233	5.150	16.582
Residual	1	1	2	1

Note: 1. Systematic pattern 2. Uniformly scattered points

Table 2. Estimated parameters and criteria for the desorption ERH models of Pangola grass stem

	Modified-Henderson	Chung-Pfost	Modified-Halsey	Modified-Oswin
A	5.25167×10^{-6}	1954.96	4.50713	16.10306
B	2.46543	0.1782	-3.57422×10^{-3}	-3.4932×10^{-2}
C	122.6858	159.2354	1.82084	3.83825
R2	0.948	0.966	0.919	0.974
S.E.	8.003	6.266	9.610	5.408
P	22.267	14.717	38.039	13.750
RMS	38.876	23.031	71.886	23.680
Residual	1	2	1	2

Note: 1. Systematic pattern 2. Uniformly scattered points

Table 3. Estimated parameters and criteria for the desorption ERH models of Pangola grass foliage

	Modified-Henderson	Chung-Pfost	Modified-Halsey	Modified-Oswin
A	1.5347×10^{-5}	963.1698	4.56475	13.14536
B	2.12187	0.18132	-6.1046×10^{-3}	-3.4758×10^{-2}
C	181.1813	120.7846	1.9305	3.16435
R2	0.980	0.987	0.978	0.990
S.E.	4.461	3.555	4.741	3.211
P	7.673	5.481	7.450	5.481
RMS	12.082	7.953	12.881	9.177
Residual	2	2	2	2

Note: 1. Systematic pattern 2. Uniformly scattered points

Table 4. Estimated parameters and criteria for the adsorption ERH models of Pangola grass whole plant

	Modified-Henderson	Chung-Pfost	Modified-Halsey	Modified-Oswin
A	5.2882×10^{-5}	746.168	4.2939	12.97463
B	1.7028	0.15075	-5.72246×10^{-3}	-3.52892×10^{-2}
C	157.7639	143.25	1.845	2.49427
R2	0.948	0.958	0.991	0.981
S.E.	5.725	5.173	2.3364	3.4856
P	10.414	8.346	3.133	6.5885
RMS	17.787	12.034	4.302	10.963
Residual	1	1	2	1

Note: 1. Systematic pattern 2. Uniformly scattered points

Table 5. Estimated parameters and criteria for the adsorption ERH models of Pangola grass stem

	Modified-Henderson	Chung-Pfost	Modified-Halsey	Modified-Oswin
A	9.17554×10^{-5}	595.271	5.02720	11.93053
B	1.40639	0.11566	-5.9341×10^{-3}	-3.32404×10^{-2}
C	179.978	159.2544	2.03166	1.89137
R2	0.952	0.955	0.984	0.911
S.E.	4.236	4.120	2.439	5.76498
P	4.905	4.293	2.555	6.552
RMS	5.666	4.839	2.966	11.359
Residual	2	2	2	1

Note: 1. Systematic pattern 2. Uniformly scattered points

Table 6. Estimated parameters and criteria for the adsorption ERH models of Pangola grass foliage

	Modified-Henderson	Chung-Pfost	Modified-Halsey	Modified-Oswin
A	1.6893×10^{-5}	476.4844	4.44336	11.041
B	1.29044	0.12014	-6.92035×10^{-3}	-3.09714×10^{-2}
C	156.4264	147.3789	1.8947	1.98116
R2	0.933	0.936	0.975	0.935
S.E.	4.772	4.672	2.928	4.705
P	5.348	4.975	3.347	5.064
RMS	6.428	5.735	4.163	8.926
Residual	2	2	2	1

Note: 1. Systematic pattern 2. Uniformly scattered points

Table 7. Desorption and adsorption equilibrium moisture content (% d.b.) for Pangola grass whole plant (modified Halsey model)

Temp. (°C)	Treatment	RH(%)								
		10	20	30	40	50	60	70	80	85
5	desorption	7.04	8.45	9.81	11.27	13.00	15.20	18.26	23.21	27.30
	adsorption	6.44	7..80	9.13	10.58	12.31	14.52	17.64	22.76	27.02
	hysterisis	0.60	0.65	0.68	0.69	0.69	0.68	0.62	0.45	0.28
25	desorption	6.62	7.96	9.23	10.61	12.24	14.31	17.19	21.85	25.70
	adsorption	6.04	7.33	8.58	9.94	11.57	13.65	16.58	21.39	25.39
	hysterisis	0.58	0.63	0.65	0.67	0.67	0.66	0.61	0.46	0.31
50	desorption	6.15	7.39	8.57	9.86	11.73	13.29	15.97	20.3	23.87
	adsorption	5.59	6.78	7.94	9.20	10.71	12.63	15.35	19.79	23.50
	hysterisis	0.56	0.61	0.63	0.66	0.66	0.66	0.62	0.51	0.37

Table 8. Desorption equilibrium moisture content (% d.b.) of Pangola grass whole plant (modified Halsey model)

RH (%)	Temperature(°C)				
	50	60	70	80	90
10	6.16	5.97	5.80	5.61	5.46
15	6.79	6.60	6.40	6.20	6.03
20	7.40	7.17	6.96	6.74	6.56
25	8.00	7.74	7.52	7.27	7.08
30	8.56	8.32	8.08	7.83	7.61
35	9.20	8.93	8.66	8.38	8.16
40	9.86	9.57	9.29	8.99	8.75
45	10.58	10.26	9.96	9.64	9.39
50	11.37	11.03	10.71	10.37	10.09
55	12.26	11.90	11.55	11.18	10.88
60	13.29	12.90	12.52	12.12	11.80

Table 9. Adsorption equilibrium moisture content (% w.b.) of Pangola grass whole plant (modified Halsey model)

RH (%)	Temperature (℃) 5	10	15	20	25	30	35	40
10	6.03	5.94	5.86	5.78	5.70	5.61	5.53	5.45
20	7.24	7.13	7.03	6.92	6.83	6.73	6.64	6.53
30	8.37	8.25	8.13	8.01	7.90	7.79	7.67	7.57
40	9.57	9.44	9.31	9.17	9.04	8.92	8.79	8.67
50	10.96	10.81	10.66	10.51	10.37	10.23	10.09	9.94
60	12.68	12.51	12.34	12.17	12.01	11.85	11.68	11.53
70	15.00	14.81	14.61	14.41	14.22	14.04	13.85	13.67
80	18.54	18.30	18.07	17.84	17.62	17.39	17.18	16.95
90	25.48	25.18	24.88	24.59	24.30	24.01	23.74	23.45

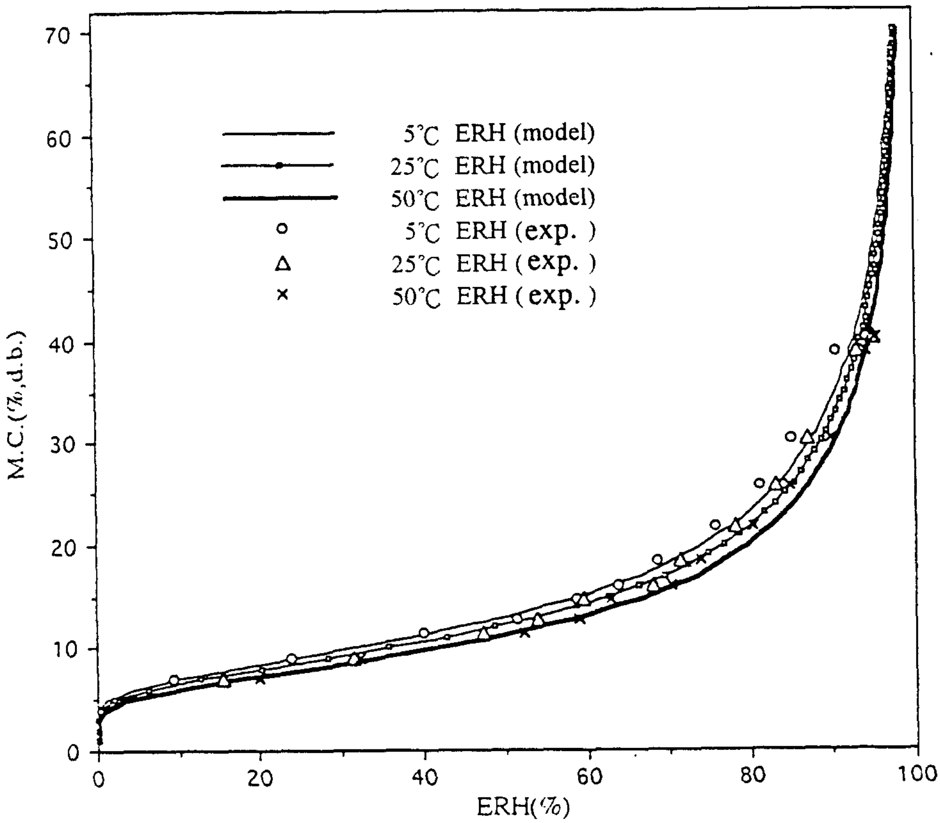

Figure 1. Equilibrium moisture content curves for Pangola grass whole plant at three temperatures (modified Halsey model)