Biosystems and Agricultural Engineering Faculty Publications

Biosystems and Agricultural Engineering

1985

Equilibrium Moisture Properties of Corn Cobs

G. M. White
University of Kentucky

Thomas C. Bridges
University of Kentucky, tom.bridges2@uky.edu

Samuel G. McNeill
University of Kentucky, sam.mcneill@uky.edu

Douglas G. Overhults
University of Kentucky, doug.overhults@uky.edu

Right click to open a feedback form in a new tab to let us know how this document benefits you.

Repository Citation

Equilibrium Moisture Properties of Corn Cobs

Equilibrium Moisture Properties of Corn Cobs

G. M. White, T. C. Bridges, S. G. McNeill, D. G. Overhults

| MEMBER | MEMBER | ASSOC. MEMBER | ASSOC. MEMBER |
| ASAE | ASAE | ASAE | ASAE |

ABSTRACT

EQUILIBRIUM moisture content-equilibrium relative humidity data for broken corn cobs have been determined for both desorption and adsorption conditions for three temperature levels and five moisture levels. The Modified Henderson and Chung equilibrium moisture equations have been fitted to these data by using non-linear regression procedures to estimate equation parameters. Both equations adequately represented the experimental data. A test of varietal differences indicated no significant difference in cob desorption ERH values for three selected corn varieties.

INTRODUCTION

Corn cobs have been shown to be a viable, usable and readily available source of biomass that can be burned to provide high quality thermal energy for drying crops and other farm energy applications (Payne et al., 1981; Morey et al., 1984). Corn is typically harvested at 24 to 28% moisture (wet basis). Cobs collected during harvest at these grain moisture levels can be expected to have moisture contents ranging from 40 to 50%. These cobs need to be dried below 40% moisture (20 to 30% appears to be optimum) before they can be burned effectively (Payne, 1980) and to even lower moisture contents if they are to be safely stored for later use.

There is an obvious need to know the equilibrium moisture properties of cobs in studying their drying characteristics. This information can help in developing relationships to predict the drying rate of cobs under various drying conditions. It can also be used to predict what moisture levels would be necessary for long-term safe cob storage. A search of the literature revealed no information of this type available for corn cobs.

The research reported in this paper was designed to obtain equilibrium moisture properties for corn cobs over the range of moisture contents and temperatures which might normally be encountered in drying and storing them for use as a biomass fuel. Experimental procedures were designed to determine these properties for both adsorption and desorption conditions. Separate

tests were also included to examine possible differences in the equilibrium moisture properties of cobs among different corn varieties.

EXPERIMENTAL APPARATUS AND PROCEDURES

Experimental Apparatus

Equilibrium relative humidities were determined using the closed-loop dew point system employed by Flood and White (1984). This system uses the same technique employed by Henderson (1970) and by Pixton and Warburton (1971). In this method a relatively small quantity of air is circulated in a closed system until it comes into moisture and temperature equilibrium with a relatively large sample of whatever hygroscopic material is being considered. Accurate measurements of the sample temperatuare and the dew point temperature of the circulating air establishes the equilibrium relatively humidity (ERH) of the material for its existing moisture content and moisture history (desorption and adsorption conditions). Owing to the relatively small volume of air being circulated, there is no significant change in sample moisture content during the equilibration process.

The apparatus employed in this investigation was essentially the same as that employed by Flood and White (1984) with the exception of the sample containers and the plywood box in which they were located. These were increased in size to accommodate cobs rather than grain. The sample containers were increased to 1225 mm in diameter and 285 mm in height. Each container could accomodate a 0.45 kg sample of broken cobs. Eight thermocouples were located along the centerline of each sample container—one in the bottom plenum, one in the top plenum, one just below the surface near where the air exited the sample and the others uniformly spaced throughout the sample depth. Dew point measurements were made using a General Eastern Model 1200-APS Dewpoint Hygrometer. Accuracy of the dew point measuring system was ± 0.15°C. Accuracy of the calibrated temperature measuring system was ± 0.1°C.

Description of Test Materials

The cobs used for most experiments in this study were from yellow dent corn of unknown genotype. When obtained, these cobs were 12 to 15 percent moisture content and broken-up to a considerable extent from the harvesting operation; however, to facilitate packing in the sample container of the test apparatus, all cob pieces were further reduced, if necessary, to approximately 20 to 40 mm in length. The shape and size distribution of the cobs used is outlined in Table 1. Values in this table represent the average size distribution obtained from the examination of five random cob samples. Variations in

TABLE 1. TYPICAL SIZE DISTRIBUTION OF BROKEN CORN COBS USED IN EXPERIMENTAL MEASUREMENTS (PERCENTAGE BY WEIGHT IN VARIOUS CATEGORIES)

Cross-section	Length of cob pieces			
of cob pieces	0 - 2 cm	2 - 4 cm	4 - 6 cm	Total
1/4 - round	21.2	20.7	5.4	47.2
1/2 - round	6.8	14.2	1.7	22.7
- round	7.0	20.4	2.7	30.1
Total	34.9	55.3	9.8	100.0

the cross-section of the cob pieces were related primarily to the condition of the cobs when received.

Another phase of this research was concerned with possible differences in the ERH properties of cobs from different corn varieties. Cobs for these measurements were obtained using a combine cob collector at harvest. Cobs from three different yellow dent corn varieties (Agrigold 4690, Northrup King Px95 and Ring Around R7MR) were collected. These cobs were less broken-up than those obtained earlier and were generally more circular in cross-section. Cob lengths were again reduced as necessary prior to their use in ERH tests. As harvested, the moisture content of these cobs ranged from 35 to 50%. All samples were frozen as harvested until they could be conditioned and tested for their ERH properties.

Preparation of Test Samples

Adsorption Measurements: In preparation for adsorption equilibrium moisture tests, approximately 10 kg of broken corn cobs were spread out in wire mesh baskets and allowed to come to approximate equilibrium with air at 43°C and 15% rh. This required 4 days and resulted in a cob moisture content of 2.9% (wet basis). This and all other moisture contents in this study were determined by drying triplicate samples (12 to 16 g each) of broken cobs in a 103°C convection oven for 24 h. Unless stated otherwise, all moisture contents are presented on a wet basis.

The low moisture cobs prepared in the above manner were divided into 6 equal sub-samples and exposed to 18°C air at progressively higher relative humidities until designated sub-samples reached approximately 6, 9, 12, 15, 20 and 23% moisture content, respectively. Once the desired moisture contents had been attained, the various sub-samples were thoroughly mixed and stored in moisture-proof containers at 5°C for at least 5 days before being used in any ERH test.

Desorption Measurements: For desorption experiments the moisture content of approximately 10 kg of broken cobs was increased to approximately 30% moisture content by spraying the cobs with water. This was done in several stages over a 2 day period. After each spraying, the cobs were thoroughly mixed and stored in moisture-proof containers at 10°C. After reaching the desired final moisture content (as indicated by cob weight) the cobs were mixed and stored at 5°C for 4 to 5 days before oven moisture samples were taken to accurately establish cob moisture content prior to drying.

The high-moisture cobs prepared by the above procedure were then divided into five equal sub-samples and exposed to drying temperatures ranging from 20 to 35°C until individual sub-samples had attained moisture contents of approximately 8, 13, 18, 23 and 27%

respectively. These samples were then individually mixed and stored in sealed containers at 5°C for at least 5 days before being used for any ERH measurements.

Only desorption ERH data was considered in testing for possible varietal differences. The cobs for these tests were harvested at greater than 35% moisture; therefore, it was not necessary to moisten the cobs before drying. Moisture contents for all three varieties were lowered in turn (using drying air temperatures of 20 to 35°C) to approximately 22, 15 and 9% for making desorption ERH measurements. After each adjustment in moisture, the sample lots were stored and tested in the same manner as other desorption samples.

Experimental Procedures

Prior to their use in ERH determinations, test samples were stored for 5 h or more (in a sealed container) in the same environmental chamber in which the test apparatus was located. This allowed the samples to come to approximate thermal equilibrium at the same temperature at which they were to be tested. The samples would then be placed in one of the sample containers of the ERH apparatus and air circulation at the rate of 700 mL/min started. The air pump was generally operated on a schedule of 5 min on and 15 min off except for the last hour before a reading was to be taken. It was then operated continuously.

Cob temperature and dew point temperature readings were taken after the cobs had reached thermal equilibrium and no change in the air dew point reading had been observed for a period of at least one hour. Five or more hours were generally required for the cobs to come to thermal equilibrium even though they had been preconditioned to near thermal equilibrium prior to being placed in the test apparatus.

After the cob and dew point temperatures had been recorded, triplicate moisture content samples were taken from the upper cob layers to establish the sample moisture content.

Dual sample containers in the test apparatus made it possible for ERH measurements to be made on two different test samples at the same time. This effectively cut in half the time required to complete the scheduled sequence of experimental measurements. Each sample had its own air pump, air circulation system and associated thermocouples for temperature measurements. The dew point sensor, however, was shared by the two systems with appropriate valves to allow it to be switched between systems as desired without any significant mixing of the two air volumes.

Experimental Test Conditions

Both adsorption and desorption cob samples were tested at 10, 30 and 50°C. Moisture contents ranged from 5.7 to 23.1% for the adsorption samples. For the desorption samples they ranged from 6.3 to 27.5%. Three replications of ERH measurements were made at each test condition. Tests were not randomized over the different temperatures because of concern regarding mold growth at the high temperatures and moisture contents. Instead, all tests at 10°C were conducted before those at 30°C and all tests at 30°C before those at 50°C were performed.

Variety Tests: A limited number of tests were conducted to determine the effect of corn variety on cob

TABLE 2. EXPERIMENTAL EQUILIBRIUM MOISTURE CONTENT - EQUILIBRIUM RELATIVE HUMIDITY DATA FOR CORN COBS.*

Parameter	Adsorption			Desorption		
T	10.1	29.9	49.9	10.1	30.0	50.0
M	6.3	6.0	5.8	7.4	7.4	6.5
RH	29.0	32.4	38.1	29.5	38.9	40.9
T	10.1	30.0	49.9	10.0	29.8	49.9
M	8.7	8.7	8.3	13.0	13.0	12.3
RH	37.7	52.6	57.5	63.5	69.6	77.5
T	10.0	29.9	50.0	9.9	29.9	49.9
M	11.8	11.6	11.2	17.8	17.5	16.1
RH	63.8	69.3	72.6	79.1	83.2	86.1
T	10.1	29.9	49.9	10.1	30.0	50.0
M	14.9	14.6	14.1	23.3	22.9	23.5
RH	73.5	78.3	83.1	89.3	90.6	92.7
T	10.1	30.0	50.1	10.1	30.1	50.0
M	20.1	19.9	18.5	27.3	27.6	26.4
RH	84.9	88.7	90.1	91.2	93.7	94.7
T	10.0	30.0	50.1			
M	22.7	22.8	22.2			
RH	88.8	91.6	92.0			

T = Temperature, °C
M = Equilibrium moisture content, % wet basis
RH = Equilibrium relative humidity, %

*Data are mean values from three replications

ERH properties. Desorption ERH tests were conducted at one temperature (10°C) and three moisture contents (9, 15 and 22%) for cobs collected from each of the three corn varieties. All tests were replicated three times.

RESULTS AND DISCUSSION

Mean values of measured experimental results are presented in Table 2. The Modified Henderson and Chung equations as presented in ASAE Data: ASAE D245.4 (1983) were used to model these data. These equations have been found by other investigators to adequately describe the equilibrium moisture properties of grains (Pfost et al., 1976) and other biological materials (Duggal and Muir, 1981; Pixton and Howe, 1983). Both equations are non-linear and involve the estimation of three parameters. Parameter estimation was accomplished using the SAS NLIN non-linear regression procedure (SAS, 1982).

Parameters were estimated for both equations for adsorption and desorption equilibrium moisture data from several standpoints. First, the equilibrium relative humidity (ERH) was assumed to be the dependent variable and the two equations arranged to predict ERH as indicated at the bottom of Table 3. Parameters were determined with EMC expressed on both a wet and dry basis when using all the data and when only using data for moisture contents less than or equal to 20% on a wet basis. The estimated parameters for each of the conditions analyzed along with the standard errors for relative humidity are presented in Table 3. Similar analyses with EMC as the dependent variable yielded the estimated parameters and standard errors for moisture content shown in Table 4. The different analyses provide flexibility in that the user can select the equation and associated coefficients which best suits his particular application.

TABLE 4. ESTIMATED PARAMETERS AND STANDARD ERROR FOR THE CHUNG AND MODIFIED HENDERSON EQUATIONS WHEN USED TO PREDICT EQUILIBRIUM MOISTURE CONTENT FOR CORN COBS IN 10 TO 50°C TEMPERATURE RANGE.

		Moisture content range, wet basis			
		Adsorption conditions		Desorption conditions	
Equation	Parameter	5.7 - 15.2	5.7 - 23.1	6.3 - 18.2	6.3 - 27.5
Chung	E	0.3000	0.3452	0.3090	0.3701
	F	0.05427	0.06594	0.05748	0.07244
	C	47.019	47.275	35.702	42.437
	SE	0.523	0.912	0.689	1.512
Modified	K	0.0002900	0.0004138	0.0002653	0.0004171
Henderson	N	1.549	1.279	1.544	1.246
	C	57.715	84.620	57.286	84.230
	SE	0.573	0.991	0.626	1.640

		Moisture content range, dry basis			
		Adsorption conditions		Desorption conditions	
Equation	Parameter	6.1 - 17.9	6.1 - 30.0	6.7 - 22.3	6.7 - 38.0
Chung	E	0.3612	0.4481	0.3819	0.5056
	F	0.06753	0.09004	0.07415	0.10552
	C	46.800	46.970	34.984	42.366
	SE	0.711	1.633	1.032	2.887
Modified	K	0.0003530	0.0006151	0.0003535	0.0005702
Henderson	N	1.397	1.077	1.354	1.051
	C	57.527	80.375	57.471	85.844
	SE	0.742	1.542	0.872	2.760

Equilibrium moisture equations:

Chung: $M = (E-F*LN(-(T+C)*LN(RH/100)))*100$
Modified Henderson: $M = (-LN(1-RH/100)/K*(T+C))**(1/N)$

M = Equilibrium moisture content, %
RH = Equilibrium relative humidity, %
T = Temperature, °C
SE = Standard error for moisture, %
E,F,C = Chung equation parameters
K,N,C = Modified Henderson equation parameters

| Equation | Parameter | Moisture content range, wet basis | | | |
| | | Adsorption conditions | | Desorption conditions | |
		5.7 - 15.2	5.7 - 23.1	6.3 - 18.2	6.3 - 27.5
Chung	A	262.52	234.61	252.73	228.71
	B	0.1836	0.1683	0.1761	0.1627
	C	50.766	51.822	44.734	46.077
	SE	2.707	2.843	2.641	2.906
Modified	K	0.0002908	0.0003543	0.0002658	0.0003230
Henderson	N	1.550	1.421	1.570	1.449
	C	57.734	65.173	52.496	59.421
	SE	2.728	2.894	2.506	3.048

| Equation | Parameter | Moisture content range, dry basis | | | |
| | | Adsorption conditions | | Desorption conditions | |
		6.1 - 17.9	6.1 - 30.0	6.7 - 22.3	6.7 - 38.0
Chung	A	224.24	194.72	209.30	185.84
	B	0.1490	0.1312	0.1384	0.1246
	C	51.165	52.909	45.380	46.805
	SE	2.874	3.506	3.030	3.727
Modified	K	0.0003540	0.0004587	0.0003403	0.0004373
Henderson	N	1.3980	1.2495	1.3961	1.2626
	C	57.533	64.553	52.146	57.926
	SE	2.768	3.169	2.637	3.427

Equilibrium relative humidity equations:

Chung: $RH = 100*EXP((-A/(T+C))*EXP(-B*M))$

Modified

Henderson: $RH = 100*(1-EXP(-K*(T+C)*(M**N)))$

M = Equilibrium moisture content, %

RH = Equilibrium relative humidity, %

T = Temperature, °C

SE = Standard error for relative humidity, %

A,B,C = Chung equation parameters

K,N,C = Modified Henderson equation parameters

An examination of Tables 3 and 4 indicates that there is little difference in the standard errors between the Chung and the Modified Henderson equations. When predicting ERH, the standard error for the Modified Henderson equation was slightly higher than that for the Chung equation in three instances and less in the five other cases. When predicting EMC, half of the standard errors were smaller for the Modified Henderson and half smaller for the Chung equation. As one would expect, standard errors for both equations were reduced when the considered moisture range was reduced by eliminating all data for moisture contents greater than 20%.

Adsorption ERH's were always greater than desorption ERH's at the same moisture content. This would be expected based on the theory of moisture hysteresis. Fig. 1 illustrates this difference where predicted wet basis adsorption and desorption EMC's at 30°C using the Modified Henderson equation and associated constants from Table 4 are plotted. There is not much difference in the 2 EMC's at low relative humidities; however, there is a gradual increase to 2 to 3 points of moisture difference at the higher humidities. This general trend or pattern between predicted adsorption and desorption of EMC's was consistent for both the Chung and Modified Henderson equations for all moisture and temperature conditions studied.

Plotted data points and predicted 30°C desorption isotherms for the Modified Henderson equation for both wet and dry basis EMC's are shown in Fig. 2. As can be seen, the accuracy of the moisture predictions are about the same for both curves. The scatter of the data about the two curves is typical of that experienced for all test conditions.
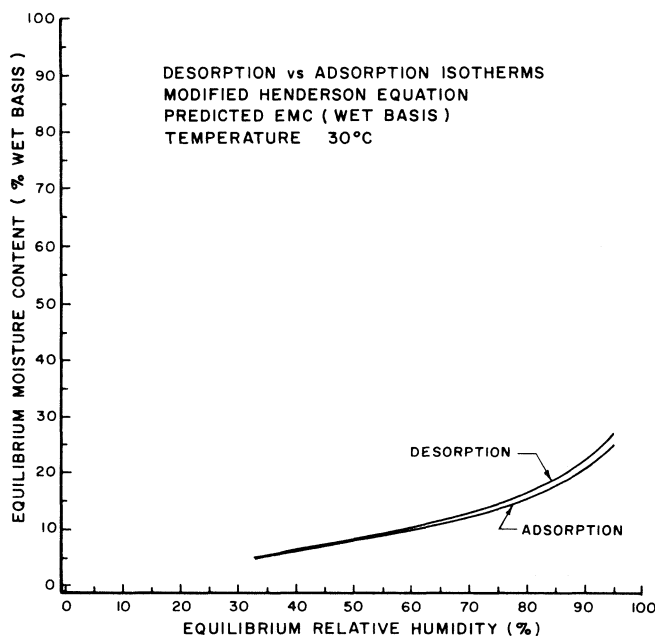

Fig. 1—Difference in wet basis desorption and adsorption isotherms at 30 °C when predicting EMC with modified Henderson equation.
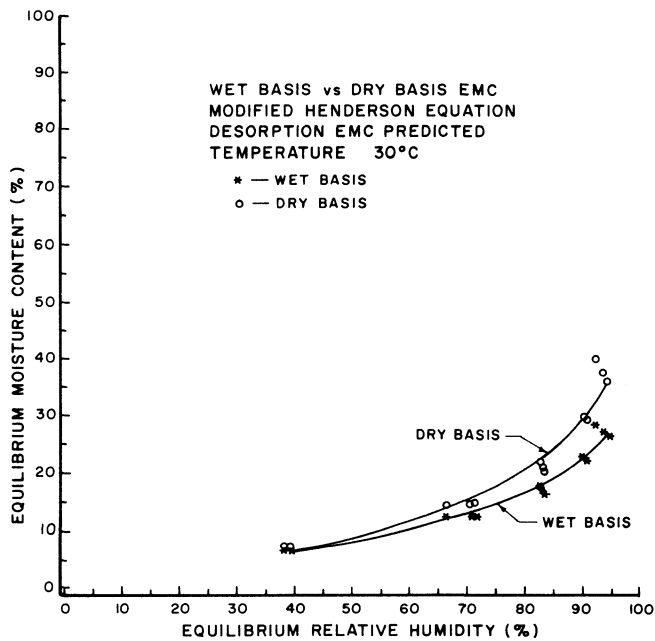
Fig. 2—Observed data and predicted 30 °C desorption isotherms using modified Henderson equation for both wet and dry basis EMC.

Fig. 4—Comparison of predicted 30 °C adsorption isotherms when using Chung equation to predict EMC vs. predicting ERH.

Differences in EMC predictions when using parameters developed for all moisture contents and those developed using only moisture contents less than 20% are illustrated in Fig. 3. The smooth curves are predicted wet basis desorption EMC's based on the Chung Equation at 30°C. Equation parameters are those shown in Table 4 for the two moisture ranges. The curve based on the lower moisture range fits the data better at the lower relative humidities.

The parameters obtained for the two equations with EMC as the dependent variable were not the same as the corresponding coefficients obtained when ERH was considered the dependent variable. Thus, the predicted relationship between EMC and ERH will be different

depending on which approach is used. Fig. 4 shows this difference for the Chung Equation at 30°C for adsorption conditions. The ERH predicted curve is based on the wet basis adsorption coefficients presented in Table 3 for all moisture contents. The EMC predicted curve utilizes parameters for the same conditions from Table 4. The ERH predicted curve fits the data better at the lower relative humidities, while the EMC predicted curve is better at the higher humidities. This tended to be true for most of the test conditions.

Fig. 5 is a plot of predicted wet basis desorption isotherms for 10, 30 and 50°C using the Modified Henderson equation and associated parameters from Table 4 for the entire range of moisture contents. Similar plots can be developed for both Chung and Modified
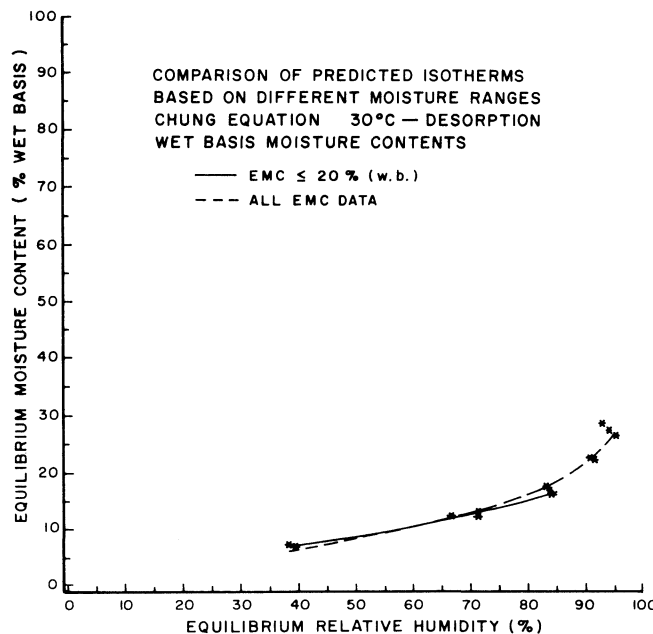

Fig. 3—Difference in desorption EMC predictions at 30 °C when Chung equation parameters based on data from all moisture contents vs. those based on data from moisture contents less than 20%.
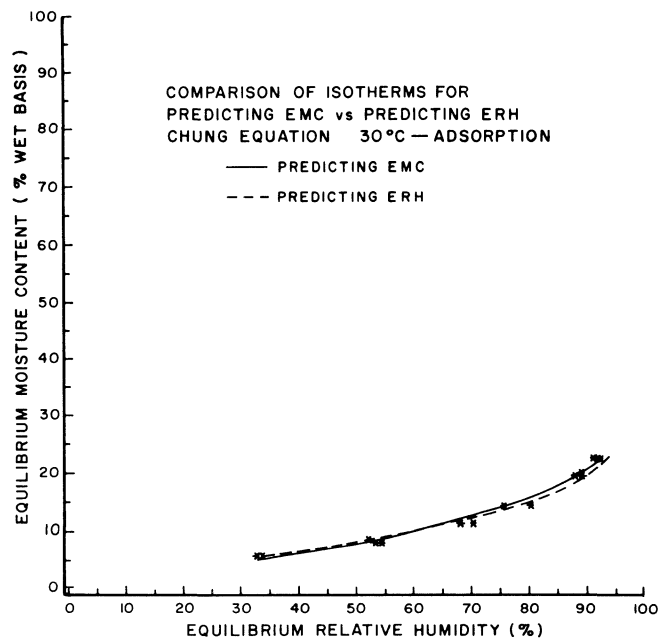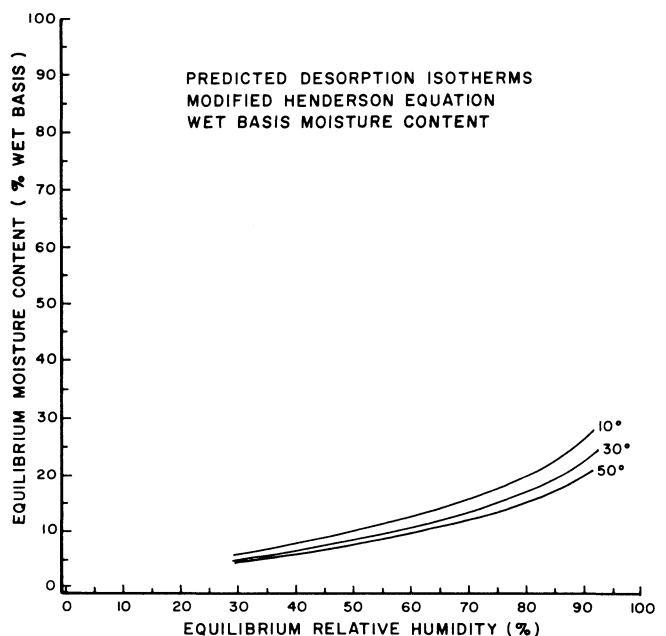

Fig. 5—Wet basis desorption isotherms from modified Henderson equation when predicting EMC.

Henderson equations for any of the conditions indicated in Tables 3 and 4. Such plots should be satisfactory for predicting EMC's over the ranges of moisture content and temperature used to develop the equation parameters.

As described previously, desorption ERH measurements were made on cobs from three yellow dent corn varieties at 10°C and at moisture contents of 9, 15 and 22%. An analysis of variance of these data revealed no significant difference in ERH between varieties at the 0.01 level. Although tested moisture contents were different, values from the variety tests were similar to those obtained for the desorption condition at 10°C in the primary experiments. Mean experimental ERH values were generally within one standard error of ERH's predicted when using the equations and parameters in Table 3. Based on this result, one can assume for design purposes that the adsorption and desorption data from this investigation and the resulting equations will satisfactorily describe the equilibrium moisture properties of most yellow dent corn varieties.

SUMMARY

Equilibrium moisture content—equilibrium relative humidity data for broken corn cobs have been determined for both desorption and adsorption conditions, for three temperature levels (10, 30 and 50°C) and for moisture levels ranging from 5.7 to 27.5%. The Modified Henderson and Chung equilibrium moisture equations (arranged to predict both EMC and ERH) have been fitted to these data by using nonlinear regression procedures to estimate equation parameters. Parameters have been estimated for desorption and adsorption conditions, wet basis and dry basis moisture contents, and for two moisture content ranges. The standard error for each prediction equation was also calculated.

There was little difference in standard errors between the Chung and the Modified Henderson equations. Both equations adequately represented the experimental data. The accuracy of predictions for either EMC or ERH can be improved by selecting the equation and associated coefficients which best fit a particular application while providing the lowest standard error.

A test of varietal differences indicated no significant difference in cob desorption ERH values for three yellow dent corn varieties. Based on this result it can be assumed that for design purposes the results from this study can be applied to the cobs from different yellow dent corn varieties.

References

1. ASAE Data. 1983. ASAE D245.4, Moisture Relationships of Grains. 1983 Agricultural Engineers Yearbook, ASAE, St. Joseph, MI 49085.

2. Duggal, A. K. and W. E. Muir. 1981. Adsorption equilibrium moisture content of wheat straw. Jour. Agric. Engr. Res. 26:315-320.

3. Flood, C. A., Jr., and G. M. White. 1984. Desorption equilibrium relationships for popcorn. TRANSACTIONS of the ASAE 27(2):561-565, 571.

4. Henderson, S. M. 1970. Equilibrium moisture content of small grain-hysteresis. TRANSACTIONS of the ASAE 13(6):762-764.

5. Morey, R. V., D. P. Thimsen, J. P. Lang and D. J. Hansen. 1984. A corncob-fueled drying system. TRANSACTIONS of the ASAE 27(2):556-560.

6. Payne, F. A. 1980. The conversion of corncobs into thermal energy for drying grain using a gasification and combustion process. Unpublished Ph.D. Dissertation, University of Kentucky, Department of Agricultural Engineering, Lexington.

7. Payne, F. A., I. J. Ross, J. N. Walker and R. S. Brashear. 1981. Gasification-combustion of corncobs for drying grain. Agricultural Energy, Volume 2, Biomass Energy, Crop Production. ASAE, St. Joseph, MI 49085.

8. Pfost, H. B., S. G. Maurer, D. S. Chung and G. A. Milliken. 1976. Summarizing and reporting equilibrium moisture data for grains. ASAE Paper No. 76-3520, ASAE, St. Joseph, MI 49085.

9. Pixton, S. W. and S. Warburton. 1971. Moisture content/relative humidity equilibrium of some cereal grain at different temperatures. Jour. Stored Prod. Res. 6:283-293.

10. Pixton, S. W. and R. W. Howe. 1983. The suitability of various linear transformations to represent the sigmoid relationship of humidity and moisture content. Jour. Stored Products Res. 19(1):1-18.

11. SAS Institute, Inc. 1982. SAS User's Guide: Statistics, 1982 Edition. SAS Institute, Inc., Cary, NC 27511.