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Evaluation of a Bulk Drying Model for Peanuts[1]

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ABSTRACT

Results of a peanut bulk drying model, PEADRY8, have been compared with experimental test results for Virginia-type peanuts. The model describes the peanut pod as two separate components with moisture movement in both liquid and vapor form. The Henderson equation was used to describe the equilibrium moisture contents of the kernel and the hull. The following conclusions were drawn: (1) predicted drying times averaged 11% longer than the observed values; (2) predicted kernel moisture contents at the top of the wagons averaged 5% less than the measured values; (3) predicted hull moisture contents at the top of the wagons averaged 17% higher than the observed values; (4) predicted hull final moisture contents at the top of the wagons average 21% higher than measured values and (5) predicted exhaust air temperatures averaged 1% higher than measured values.

An attempt was made to improve the fit of the observed and simulated results by changing the equation to describe the equilibrium moisture contents. The Chung-Pfost equation, compared to the Henderson equation, was more accurate in describing the hull moisture content and less accurate in describing the kernel moisture content history. Changing the reference air flow rate of the thin-layer drying relationship did not give a better fit between the observed and predicted data.

Several drying simulations were found to be very sensitive to small changes in either wet-bulb or dry-bulb temperature. Small errors in wet-bulb temperature measurement could account for the predicted drying times for six experiments which were excessively long relative to observed values.

Key Words: Peanut, kernel, hull, bulk drying, experimental and simulated results, equilibrium moisture content equations.

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[3]It should be emphasized that the peanut curing operation involves more than "drying" or moisture removal. However, the mathematical model and the experimental observations made in this study were concerned only with the moisture removal process. Thus the term "drying" is used throughout this manuscript rather than the term "curing" which implies other chemical changes which may also take place.

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Several thin-layer drying[3] models for peanuts have been published. Most of them have treated the peanut pod as a single homogeneous material (12, 9, 10). The thin-layer relationship developed by Troeger and Butler (12) was extended by the authors to a bulk-drying model called PNTDRY. Colson and Young (7) presented a thin-layer drying model which treats the peanut pod as two separate components. Their model, based on previous studies conducted by Chinnan and Young (4, 5), describes the moisture movement in both liquid and vapor form. The drying parameters were determined using thin-layer drying experiments for virginia-type peanuts reported by Beasley and Dickens (2). The thin-layer drying relationships developed by Colson and Young (7) were extended to the bulk-drying program called PEADRY8. Butts *et al.* (3) compared the two bulk-drying models for simulating bulk-drying tests for runner-type peanuts.

The objectives of this study were:

1. To compare the peanut drying simulations of the program PEADRY8 with experimental drying data for virginia-type peanuts taken during the 1988 and 1989 harvest seasons at Lewiston, NC;
2. To investigate the effect of various equilibrium moisture content equations (EMC) on the fit between simulated and experimental drying results;
3. To determine the effect of various reference air flow rates on the fit between simulated and experimental results; and
4. To investigate the effects of small errors in either wet-bulb or dry-bulb temperature measurement on the simulated drying process.

Materials and Methods

Experimental bulk-drying data on virginia-type peanuts were collected during 1988 and 1989 at the Peanut Belt Research Station at Lewiston, NC. Peanuts were dried in a total of 46 conventional (2.4m x 4.3m) peanut drying wagons during tests of a solar assisted partial air recirculation facility described by Young *et al.* (15). This experimental data was used to make comparisons between simulations made by PEADRY8 and actual observations.

During the drying process, samples were taken periodically from the top layer of peanuts. After shelling, the kernel and hull moisture contents were determined gravimetrically by drying them at 130 C for 6 h according to the ASAE Standard (1). Kernel moisture contents were also determined using a Dickey-John Model GAC II electronic moisture meter. Drying in the wagons was terminated when peanut kernels at the top of the wagon reached 11% w.b. according to the GAC II moisture meter. Initial kernel oven moisture contents ranged from 29.8% to 15.9% wet basis while final kernel oven moisture contents ranged from 19.84% to 8.73% wet basis. Initial and final hull oven moisture contents ranged from 28.8% to 15.8% and from 18.83% to 11.41% wet basis, respectively. Depth of peanut beds ranged from 1.07m to 1.68 m.

The PEADRY8 drying model numerically simulated the drying process in each of the 46 drying wagons using 15-minute time steps and ten drying layers. Simulation runs were terminated when the kernel moisture content at the top of the wagon was equal to the oven moisture sample taken from the top of the load at the termination of the drying test. Experimental initial kernel and hull oven moisture contents, air flow rates, kernel to pod mass ratios and measured dry-bulb and wet-bulb temperatures taken every 15 minutes at the drying fan inlets were used as input parameters for the simulation program. For those tests in which the simulated kernel moisture content at the top of the wagon had not reached the desired termination value at the time the actual drying test ended, the original temperature file was extended using the data for the last 24 h in order to simulate the required drying time. The experimental and simulation results were compared for each year and the results of the two years were combined and analyzed statistically.

In the PEADRY8 simulation program, the Henderson (8) EMC equation is used. In Young's investigations (13), the Chung-Pfost (6) and the Smith (11) equations were found more accurate in describing EMC of both peanut hulls and kernels than the Henderson equation. In this study, the effects of the different EMC equations on the bulk-drying simulation were investigated by modifying and running the PEADRY8 simulation program with each of the equations.

As discussed by Colson and Young (7), the PEADRY8 program assumes the hull drying parameters to vary with air flow rate according to the following relationship:

$$K = K_0 (V/V_0)^L \quad \text{when } V < V_0 \qquad (1)$$

$$K = K_0 \quad \text{when } V \geq V_0 \qquad (2)$$

where

K = drying parameter, h^{-1},

K_0 = drying parameter at reference air flow rate, h^{-1},

V = apparent air velocity through the peanuts,k m/s,

V_0 = reference apparent air velocity, m/s,

and L = constant.

In the absence of thin-layer drying data at different air flow rates, the following assumptions were made concerning the parameters and use of equation (1) and (2) in PEADRY8:

(1) It was assumed that the value of L was 0.7 as used by Young and Dickens (14). This implies that the resistance to moisture transfer between the peanut hull and the air is primarily at the surface and that the flow is turbulent such that the mass transfer coefficient varies with approximately the 0.7 power of the Reynolds number.

(2) The reference air velocity was assumed to be 0.375 m/s based on the studies of Beasley and Dickens (2) which indicated that air velocities above that level had negligible effect on the thin-layer drying rate of peanuts.

(3) The value of the drying parameters at the reference air velocity were assumed to be those determined by Colson and Young (7). Equation (1) was used to estimate the value of drying parameters at air velocities below reference level while at higher air velocities the drying parameters were assumed to remain constant at the reference values according to Equation (2).

Since no thin-layer data were available for testing these assumptions, investigations of other relationships between the air flow rate and the hull drying parameters were also considered. The model was run using a value of V_0 of 0.0285 m/s. This caused the drying parameters in the bulk-drying tests to remain constant at the values determined by Colson and Young (7) since all experimental air velocities were above the assumed reference value. The same results could have been achieved by setting the value of L to 0.0. This alternate assumption is equivalent to assuming that there was no effect of air velocity on the drying parameters.

The effect of small errors in the measurement of wet-bulb temperature such as might be experienced due to partial drying of the wetted wick was investigated by running the simulations with the wet-bulb temperature decreased by values of 0.5 and 1.0 C. Effects of small errors in both wet-bulb and dry-bulb temperatures such as might be experienced due to heating of the air by the fan were investigated by rerunning the simulations with the dry-bulb temperatures increased by 1.0 C and the wet-bulb temperatures increased according to psychrometric relationships for a heating process.

Results and Discussion

A. Analysis of the Drying Process

Figures 1, 3, and 5 show the simulated drying curves for the kernels and the hulls in the first (bottom) layer for wagons 11, 21, and 46, respectively. Figures 2, 4, and 6 show both the simulated and the experimental drying curves for the tenth (top) layer for the same wagons. Figures 1-6 also display the variation of the EMC of the kernels and the hulls calculated by the Henderson equation.

For wagon 11 of 1989 the experimental and predicted drying times were almost equal. There were small oscillations in the inlet air conditions and this caused small fluctuations in the EMC's of both the kernels and the hulls as can be seen in Fig. 1. The EMC's are calculated from the instantaneous values of temperature and relative humidity at the layer of interest. Despite the EMC fluctuations the drying of the kernel was continuous but there were oscillations in the drying of the hull in the first layer as shown in Fig. 1. Initially, the drying of the hull is very fast but it slows down when the moisture content approaches the EMC. Since the hull is very porous, it responds quickly to changes in the environment and in the latter stages of drying, oscillations are forced by fluctuations in the inlet air condition. Figure 2 illustrates the situation at the top of the wagon. We can see that drying was continuous so the oscillation in the inlet air condition was dampened so that its effect didn't appear at the top. As the figure shows, initially the predicted moisture content of the hull increased and the predicted hull moisture contents were greater than the observed values. The predicted kernel moisture contents were less than the observed values during the first stages of drying but in later stages the model accurately predicted the moisture content changes.

Figures 3 and 4 show the drying curves for wagon 21 of 1989. The predicted and experimental drying times were equal for this experiment. The oscillations of the inlet air conditions were great and this was reflected in the EMC's and in the drying curves. Before and after 70 h from the beginning of the process there were two sharp changes in the relative humidity of the inlet air which were great enough to

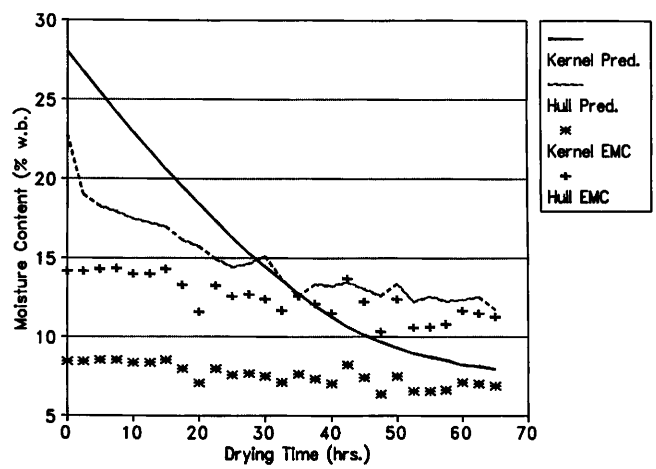

Fig. 1. Drying curves for the bottom layer of wagon number 11 in 1989 experiments.

affect the drying curve of the hull at the top layer. The hull moisture content reached a lower value at about 74 h but it began to increase again after these sharp changes. Figure 4 shows that the predicted kernel moisture contents were less than observed values and the predicted hull moisture contents were higher than observed values in the initial stages of the drying process.

Figures 5 and 6 illustrate the experimental and simulated results for wagon 46 of 1989. The drying time for this experiment was 38.5 h while the simulated drying time was 54.75 h. Extending the original temperature data file for the last 24 h was not satisfactory because it caused a sharp change in the inlet air conditions (both the dry-bulb and the wet-bulb temperatures decreased) and an increase in the hull moisture content. This simulation shows that the extension of the data files may be a source of significant errors.

The trend of predicted hull moisture contents higher than observed values and the predicted kernel moisture contents slightly less than observed values was the general case for all the wagon drying tests.

B. Statistical Analysis of the Results

Drying time: The predicted versus experimental drying times until the top of the wagons reached the cutoff moisture level are illustrated in Fig. 7. The simulated drying times were approximately 19% longer than the experimental ones, with differences ranging from 52% shorter to 407% longer. A review of the results showed that there were at least seven experiments for which some of the initial parameters or temperature data might be erroneous. There were six wagons for which predicted drying times were excessive and for which wet-bulb temperature data suggested insufficient wetting of the wick. There was one wagon for which predicted

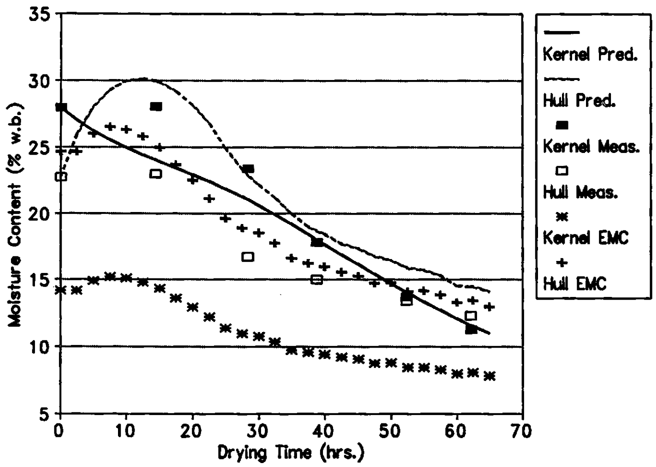

Fig. 2. Drying curves for the top layer of wagon number 11 from 1989 drying experiments.

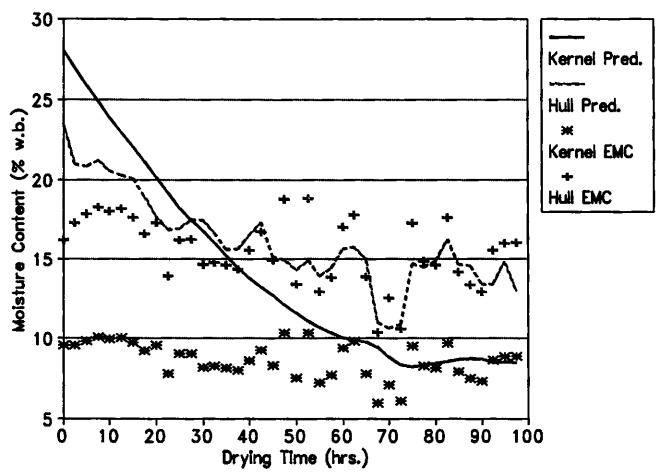

Fig. 3. Drying curves for the bottom layer of wagon number 21 of the 1989 drying experiments.

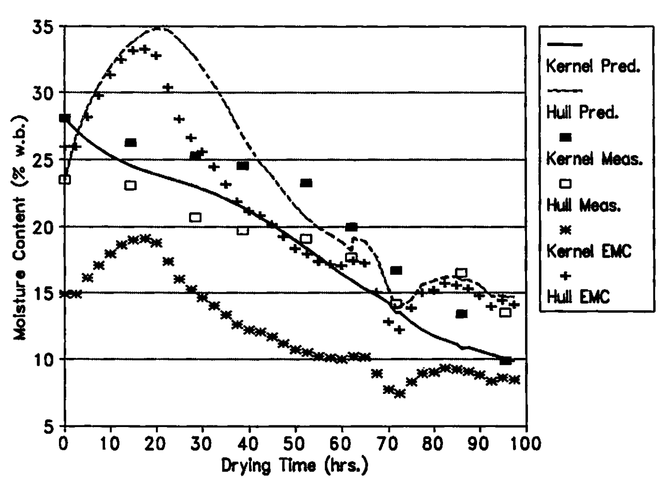

Fig. 4. Drying curves for the top layer of wagon number 21 of the 1989 drying experiments.

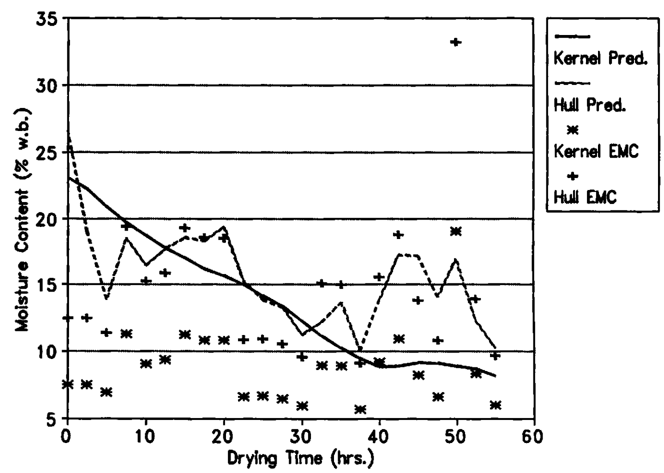

Fig. 5. Drying curves for the bottom layer of wagon number 46 of the 1989 drying experiments.

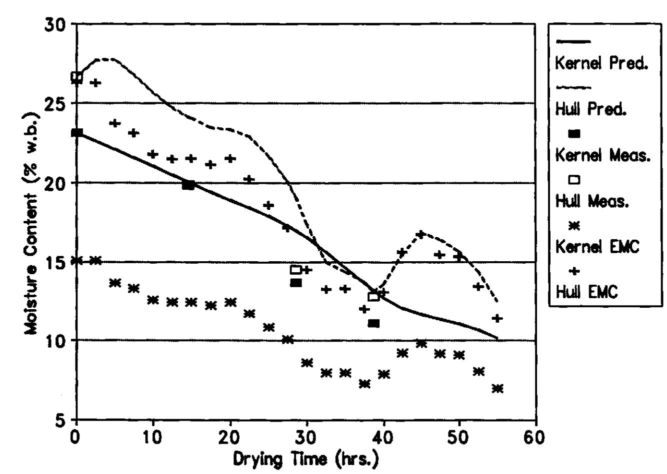

Fig. 6. Drying curves for the top layer of wagon number 46 of 1989 drying experiments.

drying time was very low and it is suspected that the initial moisture content of the load was not uniform. Omitting these wagons (#22, #23, #35, and #45 in 1988 and #26, #34, and #36 in 1989) from consideration, the linear regression analysis showed that the predicted drying times averaged 11% longer than experimental values, with differences ranging from 31% shorter to 45% longer with an R^2 value of 0.76 and a standard error of 10.7 h. If the lines were not forced through the origin the regression analysis resulted in an R^2 value of 0.76 and standard error of 10.8 h. Figure 7 shows the regression lines and labels the points which were omitted from the regressions for this and following parameters.

Exhaust air temperature: The predicted exhaust air temperatures are illustrated as a function of the experimental values in Fig. 8. The linear regression analysis with respect to the experimental exhaust air temperatures resulted in a slope of 1.01 and an R^2 value of 0.69. The simulated exhaust air temperatures averaged 1% higher than the experimental values, the standard error was 1.7 C, the difference between the predicted and measured values ranged from -5.2 C to +7.8 C. The regression analysis not forcing the line through the origin resulted in a standard error of 1.7 C, and R^2 value of 0.69, and a slope of 0.93. The regression lines are shown in Fig. 8. The agreement between simulated and experimental exhaust temperatures indicates that the mass and energy balance of the bulk-drying model is accurate.

Kernel moisture content at top of wagon: The simulated kernel moisture contents are shown in Fig. 9 as function of the measured values. The simulated values averaged 5% less than the experimental values as indicated by the slope of the linear regression analysis which resulted in an R^2 value of 0.72. The standard error of the simulated kernel moisture content was 2.12% and the differences between the predicted and the measured values ranged from -9.73% to +4.30%. When the line was not forced through the origin, the linear regression analysis gave an intercept of 4.36%, a slope of 0.71, a standard error of 1.71%, and R^2 value of 0.82. The regression lines are illustrated in the figure.

Hull moisture content at top of wagon: The simulated hull moisture contents averaged 17% higher than the experimental values. The linear regression analysis resulted in a slope of 1.17 and an R^2 value of 0.57. The standard error was 3.33% and the differences between the predicted and measured moisture contents ranged from -5.75% to +13.14%. The predicted hull moisture contents versus the measured values and the regression lines are shown in Fig. 10. There are some hull moisture content values in Fig. 10 higher than the highest initial value of 28.8% since the moisture content during drying can increase due to condensation from the air and/or movement of moisture from the kernels to the hulls. The regression analysis not forcing the line through the origin resulted in an intercept of -4.11%, a slope of 0.95, and

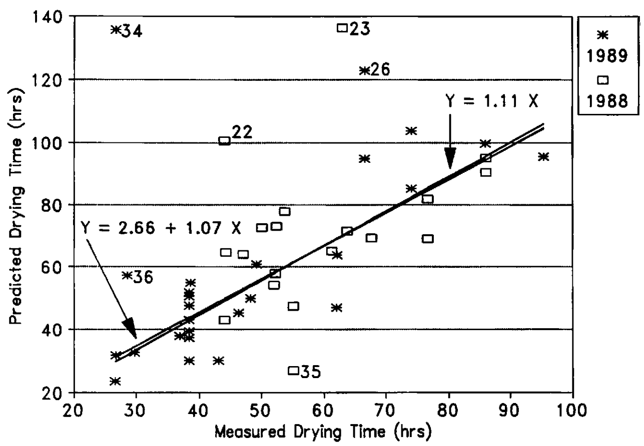

Fig. 7. Predicted versus experimental wagon drying times for 1988 and 1989.

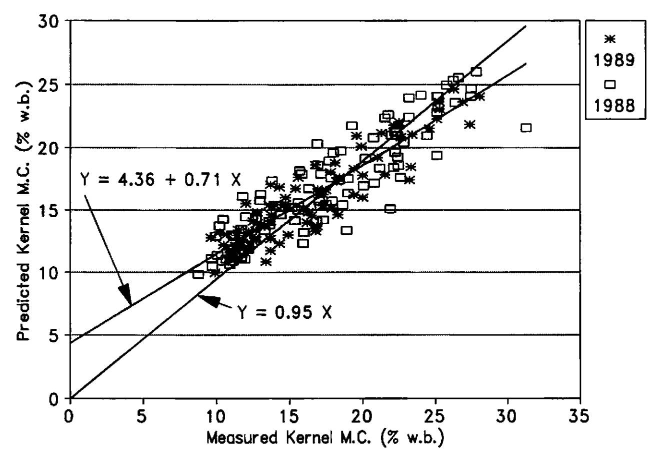

Fig. 9. Comparison of predicted and measured kernel moisture contents at the top of drying wagons during 1988 and 1989.

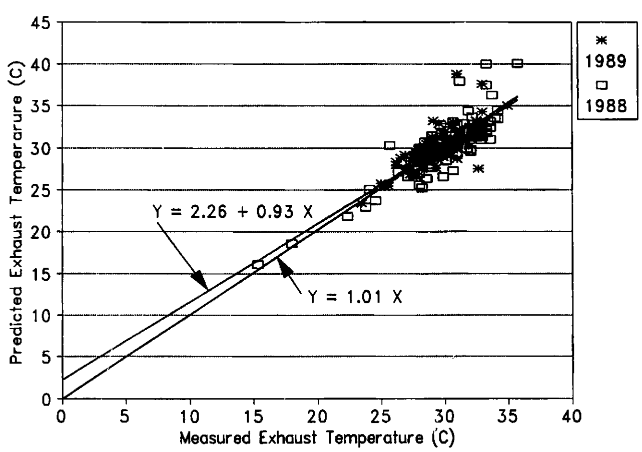

Fig. 8. Comparison of predicted and measured exhaust air temperatures for wagon drying studies of 1988 and 1989.

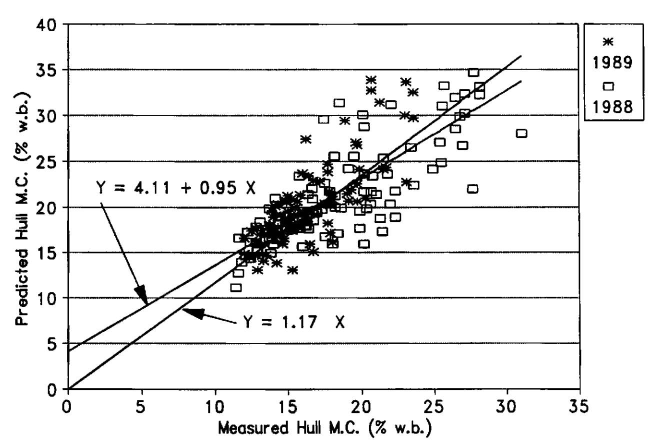

Fig. 10. Comparison of predicted and measured hull moisture contents at top of peanut drying wagons in 1988 and 1989.

an R^2 value of 0.60.

Hull final moisture content at top of wagon: The simulated hull final moisture contents are shown in Fig. 11 as a function of the measured values. The measured hull final moisture contents for tests giving shorter than measured simulated drying times were predicted at the simulated drying times from experimental values. The linear regression analysis forcing the line through the origin resulted in a slope of 1.21 and an R^2 value of 0.49. According to the regression analysis, the model predicted hull final moisture contents which averaged 21% higher than the observed values and the standard error in the prediction was 1.67%. The differences of the predicted and the measured values ranged from -0.54% to +6.01%. When the line was not forced through the origin the regression analysis resulted in an intercept of 0.28%, a slope of 1.19, an R^2 value of 0.49, and a standard error of 1.69%. The regression lines are also shown in Fig. 11.

The statistical analysis of the results showed that the standard errors of the prediction of the moisture contents were generally higher for the tests of 1988 than for 1989 but the slopes of the regression lines were very close for the two years. The standard errors for 1988 and 1989 were: 2.27% and 1.95% for kernel moisture content, 3.42% and 2.90% for hull moisture content, and 1.54% and 1.77% for hull final moisture content, respectively. There were only slight differences between years in the predictions of the drying times and exhaust air temperatures.

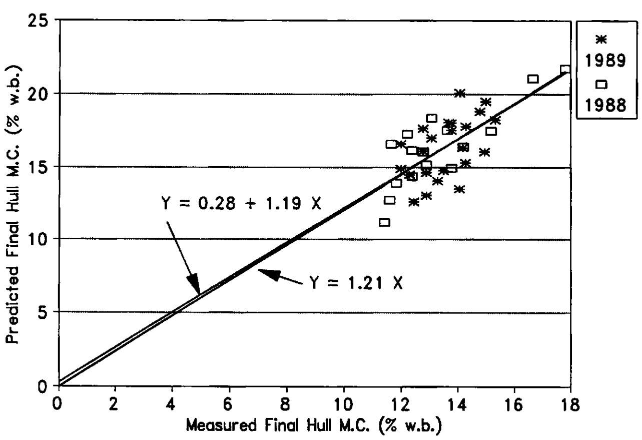

Fig. 11. Comparison of predicted and measured final hull moisture contents at top of peanut wagons during 1988 and 1989.

C. The Effect of the EMC Equations on the Results

Simulated kernel moisture contents were generally lower than the observed values and the simulated hull moisture contents were generally higher than observed values when using the Henderson EMC equation in PEADRY8. A comparison of the Chung-Pfost and the Smith EMC equations with the Henderson equation indicates that each of the various equations give higher hull EMC's at lower relative humidities and lower hull EMC's at higher relative humidities than does the Henderson equation. Smith's equation does not contain the temperature dependencies of the EMC, which indicates that the temperature dependencies are not large.

Since the drying parameters of the PEADRY8 model were evaluated by Colson and Young (7) using the Henderson equation, they were re-evaluated in this study when the EMC equation in PEADRY8 was changed. They were evaluated using the Chung-Pfost and the Smith desorption isotherm equations and the thin-layer drying tests conducted by Beasley and Dickens (2). The drying times, which were 120 h, were applied to terminate each drying process and the observed and the predicted moisture contents were compared. Table 1 gives the results of linear regression analysis between the predicted moisture contents using the three desorption equilibrium moisture relationships and the observed data.

Table 1. Comparison of three desorption equilibrium moisture equations in fitting thin-layer drying data of Beasley and Dickens (2).

Property	Desorption Isotherm Equation		
	Henderson	Chung-Pfost	Smith
Kernel moisture content			
standard error, %	1.48	1.54	1.59
R^2	0.98	0.98	0.98
slope	1.02	1.03	1.03
Hull moisture content			
standard error, %	1.56	1.45	1.29
R^2	0.98	0.98	0.98
slope	1.03	1.04	1.03

The results show that the Chung-Pfost and the Smith equations are more accurate in describing the hull moisture content and the Henderson equation describes more precisely the kernel moisture content. It may also be noted that the predicted moisture contents were slightly higher than observed values. Changing the drying coefficients used in the PEADRY8 program did not give general improvement in the evaluation of the kernel and the hull moisture content history. A complete investigation showed that the hull final experimental and predicted EMC's differed and this caused the lack of general improvement.

Table 2 shows the experimental final hull moisture contents for the Beasley-Dickens' experiments and the equilibrium values calculated by the different desorption isotherm equations. The dry-bulb temperatures in ^{0}C and the relative humidities in percents for the tests are shown. The differences between the hull final experimental and the calculated EMC's using the Henderson equation are usually lower when the relative humidity is low (test at 33.3 C and 57%

Table 2. Comparison of experimental final hull moisture contents (% w.b.) in drying data of Beasley and Dickens (2) with values predicted by three desorption equilibrium moisture content equations.

No.	Temp. C	RH %	Experimental	Calculated		
				Henderson	Chung-Pfost	Smith
1	22.2	50	10.5	10.34	12.10	11.43
2	22.2	78	15.75	17.45	16.91	16.59
3	27.2	78	16.0	17.27	16.83	16.59
4	30	50	8.75	10.14	11.97	11.43
5	33.3	57	12.0	11.54	12.95	12.43
6	33.3	67	11.25	14.14	14.74	14.31

relative humidity is a slight exception) while the differences using the Smith equation are lower at high relative humidities. The calculated EMC's are generally higher than the experimental ones. These can explain the lack of any general improvement due to changing the drying parameters using the Chung-Pfost or the Smith equation.

The PEADRY8 program was re-run for each wagon drying experiment using the Chung-Pfost desorption isotherm equation to describe the EMC and using the drying parameters developed by Colson and Young (7). The results were:

1. Predicted drying times (excluding the experiments mentioned earlier) were 13% longer than the observed values, with differences ranging from 28% shorter to 48% longer (Henderson's equation gave 11% which ranged from 31% shorter to 45% longer), the standard error was 10.2 hours and the R^2 was 0.78. The standard error and R^2 values indicate slightly more accurate predictions by the Chung-Pfost equation than by the Henderson equation but the slope of the line is a little higher.
2. Simulated kernel moisture contents were 3% less than observed values, the standard error of the estimation was 2.19%, and the R^2 value was 0.74. Thus, the standard error increased a little but the R^2 value increased also which shows that the estimation is better and the underprediction decreased. The differences between the predicted and the observed moisture contents varied between -8.98% and +5.01%.
3. Simulated hull moisture contents were 9% higher than the observed hull moisture contents, the standard error was 2.92%, and the R^2 value was 0.46. The differences between the estimated and the experimental moisture contents ranged from -7.87% to +10.19%. Values calculated using Henderson's equation were 3.33%, 0.57, -5.75% and +13.14%.
4. Simulated hull final moisture contents were 19% higher than experimental values, the standard error was 1.21%, the differences between experimental and estimated values varied from +0.20% to +4.94% and the R^2 value was 0.43.

Based on either slope of regression lines or standard errors, the Chung-Pfost equation more accurately describes the hull drying process than does the Henderson equation. However, results are mixed for kernel moisture contents and predicted drying times. Table 3 gives a comparison of the results. The results show that the PEADRY8 model using both of the desorption isotherm equations underestimate the kernel moisture content and overestimate the hull moisture content.

The PEADRY8 program was also run using the Smith isotherm equation to calculate the EMC's. This equation gave better results than the Henderson equation except for the kernel moisture content but worse than the Chung-Pfost equation except for the hull final moisture contents.

D. The Effect of Varying Reference Air Flow Rate

For these experiments which were conducted at air flow rates of approximately 11.11 $m^3/min\ m^3$ and a depth of approximately 1.34 m (ranging from 9.43 $m^3/min\ m^3$ to 16.11 $m^3/min\ m^3$ and from 1.07 m to 1.68 m), the apparent velocity was approximately 0.248 m/s. This means that effective hull drying parameters were reduced by the ratio $(0.248/0.375)^{0.7}=0.75$ in the bulk model when the original estimates of reference air velocity and the exponent L were used. At the reduced reference air velocity of 0.0285 m/s, the effective drying parameters were the same as those evaluated for the thin-layer experiments. The prediction of the drying time using the reduced reference air velocity was a little better than that obtained using the original value of reference air velocity but the results for all other comparisons were worse.

The investigation showed that the fit between predicted and observed data could not be improved by changing the reference air velocity. The drying process for the whole pod is controlled primarily by the moisture transfer from the kernel to the hull and thus effects on drying of the whole pod due to changing air velocity would be expected to be small. However, the initial drying rate of the hull would be expected to vary to some degree with air velocity. Additional data for thin-layer drying at different air velocities is needed in order to more thoroughly evaluate the bulk-drying model.

Table 3. Results of linear regression between PEADRY8 simulated results for wagon drying tests when using the Henderson and the Chung-Pfost equilibrium moisture content equations.

Property	Desorption Equilibrium Moisture Equation: Henderson	Chung-Pfost
Kernel moisture content		
standard error, %	2.12	2.19
error range, % w.b.	-9.73 to +4.30	-8.98 to +5.01
error range, % of measured	-31 to +37	-30 to +43
R^2	0.72	0.74
slope	0.95	0.97
Hull moisture content		
standard error, %	3.33	2.92
error range, % w.b.	-5.75 to +13.14	-7.87 to +10.19
error range, % of measured	-21 to +70	-31 to +55
R^2	0.57	0.46
slope	1.17	1.09
Hull final moisture content		
standard error, %	1.67	1.21
error range, % w.b.	-0.54 to +6.01	+0.20 to +4.94
error range, % of measured	-4 to +43	+1 to +42
R^2	0.49	0.43
slope	1.21	1.19
Exhaust air temperature		
standard error, C	1.7	1.8
error range, C	-5.2 to +7.8	-5.7 to +8.1
R^2	0.69	0.64
slope	1.01	1.01
Drying time		
standard error, h	10.7	10.2
error range, % of measured	-31 to +45	-28 to +48
R^2	0.76	0.78
slope	1.11	1.13

E. The Effect of Errors in Wet-Bulb and Dry-Bulb Temperature

Several simulations were found to be very sensitive to a slight reduction in the wet-bulb temperature and the predicted drying times decreased greatly. For example, for test 46 of 1989 when the experimental wet-bulb temperature was decreased by 0.5 C or 1 C the predicted drying time was 51.75 h or 48.00 h, respectively, and the original predicted drying time was 54.75 h. The disagreement between the predicted and the measured drying times was the largest for test 34 of 1989, the experimental drying time was 26.75 h and the predicted drying time was 135.75 h. Decreasing the wet-bulb temperature 0.5 C or 1 C, the drying time decreased to 89.75 h or 71.75 h, respectively. Similar results were found for test 26 of 1989. The experimental and the predicted drying times were 66.67 and 122.75 h. Decreasing the wet-bulb temperature by 0.5 or 1.0 C, decreased the predicted drying times to 89.75 and 74.75 h respectively. When the same method was applied for test 11 of 1989 the drying time hardly decreased.

Increasing the plenum dry-bulb temperature by 1 C decreased the predicted drying times for the tests. Some example results are: #11 from 63.75 h to 58.25 h; #16 from 94.75 h to 82.75 h; #26 from 122.75 h to 79.25 h; #34 from 135.75 h to 77.75 h; #46 from 54.75 h to 50.75 h. The data show that neglecting the temperature rise in the fan could cause a significant difference in the predicted drying time depending on the temperature range and the efficiency of the fan.

The results indicated that small errors in either wet-bulb or dry-bulb temperature measurement can significantly affect the fit between observed and simulated data depending on the temperature range encountered in the test. In the present investigation, errors in wet-bulb temperature measurements were thought to be responsible for the predicted drying times being greater than the observed times for several wagons in which predicted drying times were much greater than observed values.

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