Drying Soybeans with Heated Air

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RELATIVELY little information is available on the drying characteristics of soybeans. Lee (1959) investigated the thin-layer drying of rewetted soybeans and correlated his data with a diffusion drying model. More recently, Alam and Shove (1971) simulated deep bed drying of soybeans with natural air. The object of this study is to determine thin-layer drying characteristics of soybeans as affected by harvest moisture content and drying air conditions. Initial moisture contents were in the 20 to 33 percent (wet basis) range with drying air temperatures ranging from 100 to 220 F.

EXPERIMENTAL PROCEDURE

Soybeans of the Cutler variety were hand harvested and shelled at naturally occurring moisture contents of 20, 23 and 33 percent (wet basis). The shelled beans were then put in plastic bags, flushed with nitrogen, and stored at −20 F for approximately 6 weeks. Beans were removed from the freezer the day before each drying test and allowed to thaw overnight at room temperature. The thawed beans were mixed thoroughly and their moisture content determined by the Brown-Duvel method.

The experimental dryers used in this study contained 2 drying trays having an area of approximately 1 sq ft each. A test sample containing 300 ± 0.1 g of wet beans was dried in each tray. This size sample formed a layer one bean thick when spread evenly over the tray. Weight losses during each test were determined by removing the trays from the dryers at regular intervals for weighing. With each weighing, the position of the trays in each dryer was rotated and weighings were alternated between the two trays. All samples were dried to a weight corresponding to a moisture content of 10 percent (wet basis) based on the initial moisture content determination. Each test was replicated three times.

Drying air temperatures used in this study were 100, 130, 160, 190 and 220 F, and these were controlled to within ± 0.5 F. A constant dewpoint temperature of 46 ± 1 F was maintained for all tests. Air flow velocities varied from 45 to 60 fpm and were assumed to have little or no effect on drying rates.

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ANALYSIS OF RESULTS

Data from the experiments were first analyzed using the logarithmic drying model employed by other investigators (Barre, et al, 1971; Henderson and Pabis, 1961; and Ross and White, 1972) to describe the thin-layer drying characteristics of shelled corn. Drying rate constants and dynamic equilibrium moisture contents such as those used by Ross and White (1972) were estimated from the data by using a computerized least squares technique. However, this type of drying model did not adequately describe the observed thin-layer drying process for soybeans. Predicted equilibrium moisture contents were above the level to which the beans were actually dried, and deviations between predicted and observed levels of moisture were often in the range of ± 2 to 4 percent.

Preliminary studies with several other drying equations indicated that a model similar to that used by Page (1949) and later by Sabbah (1968) would adequately describe the experimental data. This model was of the form,

$$MR = \frac{M - M_E}{M_o - M_E} = \exp\left[-(kt)^n\right] \qquad [1]$$

where:

MR = moisture ratio,
M = moisture content (dry basis) at any time (t),
M_o = initial moisture content (dry basis),
M_E = equilibrium moisture content, (dry basis),
k = rate of drying constant (hr^{-1}),
t = time in hours, and
n = constant

When the dynamic equilibrium moisture content, M_{DE}, was substituted for M_E and the three parameters, M_{DE}, k, and n were estimated using the least squares method, resulting predictions were in close agreement with observed data. However, further study indicated equally good fits of the data could be obtained from widely different combinations of the three parameters. Therefore, consistent or reliable estimates for the drying parameters could not be established. It was noted, however, that values of M_{DE} obtained by the foregoing least squares process were only slightly higher than values of the static equilibrium moisture which might be expected for the test conditions. It was reasoned that perhaps an adequate description of the data might be obtained if static equilibrium moisture contents were used in equation [1].

Several investigators (Alam and Shove, 1971; Larmour et al, 1944; Lee, 1959; and Ramstad and Geddes, 1942) have presented data on static equilibrium moisture contents of soybeans, but little of this data falls within the range of temperatures and relative humidities used in this study. Henderson's (1952) equilibrium moisture equation has been applied to a wide range of materials and air conditions. In the absence of appropriate experimental data, Henderson's equation was used to estimate M_E for use in fitting the drying data of these tests.

Since it was no longer necessary to estimate M_E from the data, the model (equation [1]) was transformed to a linear equation of the form

$$\ln(-\ln MR) = n \ln k + n \ln t \qquad [2]$$

Values of n and k for each test were then determined by linear regression. The regression coefficient, r^2, for fitting the foregoing model to the data was greater than 0.98 for all tests.

No theoretical relationship between the exponent, n, and the various test conditions was known. Plots were made with several different variables and the most consistent relationship was found to be between n and the drying air temperature. The change in n over the range of initial moisture contents was very small as compared with its change over the range of experimental temperatures. A multiple regression analysis was used to evaluate the relative effect of initial moisture and temperature on the value of n. Results of this regression showed that the initial moisture term was not significantly different from zero at the 99 percent level of confidence, thus confirming the hypothesis that initial moisture was not important. The initial moisture term was eliminated from the multiple regression model, and the regression was rerun with temperature as the only independent variable. Results of this regression are presented in Fig. 1. The regression coefficient of 0.90 indicates

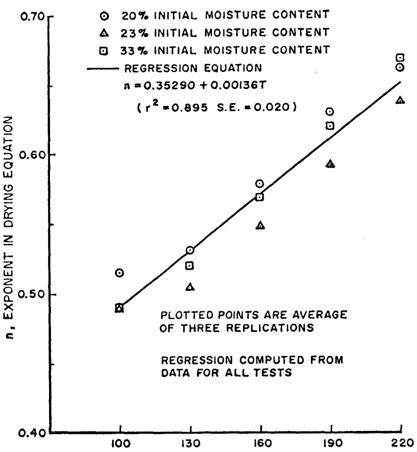

FIG. 1. Variation of the exponent, n, with drying air temperature.

a large amount of the variation in n is explained by the regression equation but other unknown factors may also have some influence on this exponent.

Page (1949) reported that the time exponent in his model was a function of relative humidity. When a relative humidity term was added to the regression model used for this data, only a very slight improvement in the regression was noted. Relative humidities used in these tests ranged only from approximately 1 to 16 percent. A much wider range would be needed before any possible relative humidity effect could be properly evaluated.

Using equation [2] and values of n as calculated from the regression equation in Fig. 1, new k values were computed for each test and used to analyze the influence of experimental conditions on the rate of drying constant.

Henderson and Pabis (1961) discussed the use of an Arrhenius type equation to relate k to the absolute temperature of the drying air. The equation is of the form,

$$\ln k = a + b/T_a \quad \ldots\ldots\ldots \quad [3]$$

where:

k = rate of drying constant,
a, b = constants, and
T_a = absolute temperature of drying air (deg R).

Ross and White (1972) successfully used this equation to relate the thin layer rate of drying constant of shelled corn to drying air temperature. A regression analysis was used to determine if the k values of this study could be related to temperature by a similar equation. Results of the regressions are shown in Fig. 2. Regression coefficients greater than 0.99 were obtained for all three initial moisture contents, again indicating a very good fit of the equation to the rate of drying constants as determined from the data. Regression lines for the 20 and 23 percent initial moisture contents could have been combined into 1 equation with satisfactory results. However, no attempt was made to do so because the results indicate that k does vary with initial moisture content but the effect was not obvious in this case due to the relatively small difference between the two lowest initial moisture contents.

Fig. 3 is a plot of observed moisture content data and typical prediction curves for two different drying temperatures. The parameters k and n were determined from their respective regression equations and the prediction curve calculated using equation [1]. These prediction curves are in very close agreement with the observed data.

Severe physical damage in the form of cracking of the beans was observed during the drying tests. Cracking usually consisted of a splitting of the seed coat and formation of v-shaped fissures which encircled about three-fourths of the bean. In some of the high temperature and high moisture tests, several beans also had indentations after drying. Indentations and cracks rarely occurred in the same bean. Cracks were all well developed within 5 min after drying had begun. One possible explanation for the physical damage is that rapid drying near the surface caused the outer portion of the beans to shrink before the inner portion had begun to dry, thereby causing large physical stresses within the bean.

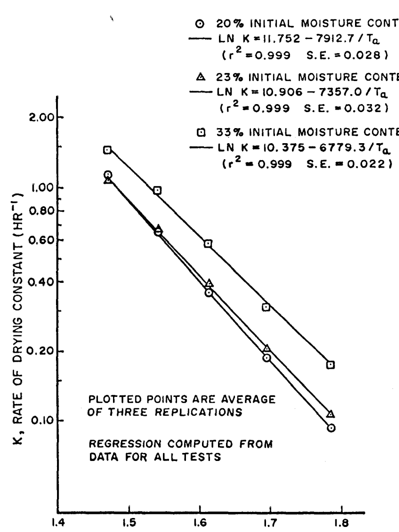

FIG. 2. Rate of drying constant as a function of the reciprocal of drying air temperature.

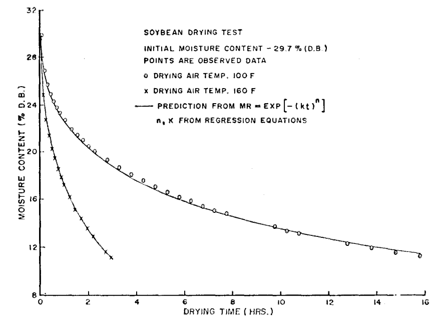

FIG. 3. Predicted drying curve for soybeans.

Summary and Conclusions

Soybeans hand harvested at initial moisture contents of 20, 23 and 33 percent were dried in thin layers with air temperatures of 100, 130, 160, 190 and 220 F. The equation

$$MR = \exp\left[-(kt)^n\right]$$

gave a very good description of the observed data. Equilibrium moisture contents were calculated using Henderson's equation. Regression equations were developed which related the parameters n and k to temperature of the drying air. The equations were of the form

$$n = \beta_0 + \beta_1 T$$

and

$$\ln k = a + b/T_a,$$

where β_0, β_1, a, and b are constants determined by regression analyses.

Severe physical damage to the beans was noted during drying. Damage was more pronounced at higher temperatures and moisture contents. From these observations, it would appear that physical damage due to drying may limit the ranges of temperature and/or relative humidity which can be used for drying soybeans.

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