Modeling Quality in Bulk Peanut Curing

J. M. Troeger[1]

ABSTRACT

A bulk peanut curing model was modified to indicate conditions which affect peanut quality. The model simulates changes in moisture content as affected by the temperature and humidity of the drying air. Equations were developed for simulating hourly changes in the ambient temperature. Conditions promoting mold growth and mycotoxin production were indicated when relative humidities in the dryer exceeded an upper limit. Poor milling quality was indicated by relative humidities below a lower limit based on extension recommendations. Cumulative time for each of these conditions was determined with various levels of ambient temperature, initial moisture and dryer control settings. A control scheme is given for setting the plenum thermostat. The results show that better control of the dryer operating conditions will maintain the quality factors at a satisfactory level.

Key Words: drying, curing, peanuts, milling quality, simulation, model, mold growth.

Quality of peanuts can be described in different ways. Milling quality refers to the ability of the kernel to resist splitting and skinning during processing (4). Poor milling quality may indicate harsh drying conditions that generally produce poor flavor. Mold growth and aflatoxin may also seriously affect peanut quality. Quality losses can occur from the late stages of production through windrow curing, combining, handling, bulk curing and storage. Once quality is lost, it generally cannot be recovered so care must be taken to maintain quality through each process.

Milling quality is lowered significantly when peanuts are dried too rapidly or are overdried. Beasley and Dickens (2) determined the percent of split and baldface kernels when peanuts were dried with temperatures from 24 to 43 C and RH from 40 to 82%. Fewest split kernels occurred with dryer conditions of 27 to 32 C and RH about 80%. Lower RH produced progressively more split kernels at all temperature levels. Attempts to add moisture to overdried peanuts to restore milling quality have had mixed results (2,3).

1Agricultural Engineer, USDA-ARS, POB 748, Georgia Coastal Plain Experiment Station, Tifton, GA 31793.

Drying peanuts too slowly may result in mold growth and subsequent aflatoxin production. The molds *Aspergillus flavus* and *A. parasiticus*, which produce aflatoxin, grow at relative humidities above 80 to 85%. Optimum temperature for *A. flavus* growth is 36-38 C but it can grow at temperatures from 6 to 46 C (5). Aflatoxin will most likely develop at a temperature of 30 C when the RH exceeds 80-85% but can occur in the 15 to 40 C temperature range. Aflatoxin development has been found within 48 hours. Development of aflatoxin can be highly variable depending on the condition and drying history of the peanuts.

Bulk curing of peanuts can be simulated by representing the peanut mass as a series of single layers (7), each of which loses moisture in response to the conditions of the air entering that layer. The bulk curing model requires parameters describing ambient, operational and initial conditions. The model calculates the time - MC relationship of the peanuts for each layer and the time - temperature - humidity relationships of the air passing through the peanuts.

The objective of this study was to develop a method for estimating the effects of curing conditions in the simulation model on milling quality and on aflatoxin production. The effects of various control schemes on quality, as well as on drying time and energy use, could then be determined by simulation.

Materials and Methods

Simulating hourly ambient temperatures. Hourly ambient temperature is one of the parameters used in the curing simulation model. Since the hourly temperature pattern varies from day to day, a method was needed to simulate a standard hourly temperature pattern for a given maximum and minimum ambient temperature. A model was developed to simulate the hourly ambient temperature for given daily maximum and minimum temperatures.

A relative ambient temperature was defined to vary between one (at maximum) and zero (at minimum).

$$t_{rel} = (t - t_{min}) / (t_{max} - t_{min}) \qquad (1)$$

where:

t_{rel} = relative ambient temperature

t = hourly ambient temperature, C

t_{min} = minimum daily ambient temperature, C

t_{max} = maximum daily ambient temperature, C

It was hypothesized that the hourly variation in relative ambient temperature could be approximated as the sum of two or more sine functions with different periods. Hourly ambient temperature records for September through November, 1978 through 1987 at Tifton, GA were used in developing the model.

The data were divided into groups according to range of daily temperature at 2 C intervals since a sunny day (wide temperature range) would be more likely to show a distinct, repeatable pattern than a cloudy day (narrow temperature range). The relative temperatures within each range were averaged by hour. Regression methods were used to determine the combinations of periods and offsets that would best fit the data. Periods other than 12 and 24 hours did not significantly improve the fit of the data. The relative temperature was modeled by summing two sine functions with periods of 12 and 24 hours with offsets of 0 and 14 hours respectively.

$$H_{12} = \pi\,(H/6) \qquad (2b)$$

$$H_{24} = \pi\,((H + 14)/12) \qquad (2a)$$

$$t_{rel} = 0.399 + 0.158 \sin(H_{12}) + 0.452 \sin(H_{24}) \qquad (3)$$

$$t_d = t_{rel}\,(t_{d.max} - t_{d.min}) + t_{d.min} \qquad (4)$$

where:

H_{12}, H_{24} = period functions
H = hour of day
t_{rel} = relative temperature
t_d = dry bulk temperature, C
$t_{d.max}$, $t_{d.min}$ = maximum and minimum dry bulk temperature, C

The offsets and coefficients determine the time of day that the maximum and minimum temperatures occur. The time of occurrence of maximum or minimum temperature is affected by time of sunrise and sunset. There are changes in the shape of the curve depending on time of year and latitude. For the purposes of this study, the daily variation in the shape of the ambient hourly temperature curve was not considered because it did not significantly affect the results.

The same experimental data were used to develop a relationship between the dry-bulb and wet-bulb temperatures. Regression analyses of these data resulted in the following equations:

$$T_{w.max} = 0.99939\,T_{d.max} - 0.58473\,(T_{d.max} - T_{d.min}) \qquad (5)$$
$r^2 = .9999$

$$T_{w.min} = 0.99714\,T_{d.min} \qquad (6)$$
$r^2 = .9999$

where:

$T_{d.max}$, $T_{d.min}$ = maximum and minimum dry bulb temperatures, K
$T_{w.max}$, $T_{w.min}$ = maximum and minimum wet bulb temperatures, K

The same relative temperature model described the hourly wet bulb temperatures:

$$t_w = t_{rel}\,(t_{w.max} - t_{w.min}) + t_{w.min} \qquad (7)$$

where:

t_{rel} = relative temperature
$t_{w.max}$, $t_{w.min}$ = maximum and minimum wet bulb tempertures, C

Applicability of these equations to other locations will require experimental data from those areas.

Fig. 1 shows the actual and simulated ambient dry bulb and wet bulb temperatures for a typical 5-day period. When the maximum and minimum temperatures vary between successive days, the calculated ambient temperatures are discontinuous at midnight. To provide a smooth transition between days, the maximum daily temperature used in Eqs. 4 and 5 was interpolated linearly between 3:00 pm and 3:00 pm on successive days. Likewise the minimum daily temperature in Eqs. 4, 5 and 6 was linearly interpolated from 6:00 am to 6:00 am of successive days. These times approximate the time of day of occurrence of the maximum and minimum daily temperatures. Fig. 2 illustrates the method of interpolation.

Modeling milling quality. An indicator of milling quality for a curing treatment could be represented by the time that the temperature and RH of the plenum air fall outside acceptable limits. Extension services in the various peanut producing areas have issued recommendations for proper curing conditions for peanuts based on available research data relating curing conditions to milling quality.

Recommendations for heated air curing of peanuts by the Georgia Extension Service (6) are shown in Fig. 3. In the "A" region, drying is slow and not economical with possible mold development. Operating the dryer in the "B1" region is acceptable only when peanut MC is above 20%. Mold may develop if operation is continued under these conditions for more than 48 hours. Operation in region "B2" results in moderate drying with final MC at 7.5 to 10%. There is little danger of overdrying when operating in this region. Continuous operation in region "B3" produces a moderate drying rate but peanuts may over-dry because of the low equilibrium moisture level. The MC must be closely monitored to avoid overdrying. Continuous operation in the "C" area with rapid drying will result in lower milling quality. Milling quality and flavor deteriorate significantly when curing air temperature exceeds 35 C for an extended time period. As the air moves from the plenum to the exhaust, it will generally gain moisture (higher RH) and lose heat (lower temperature). Conditions at other points

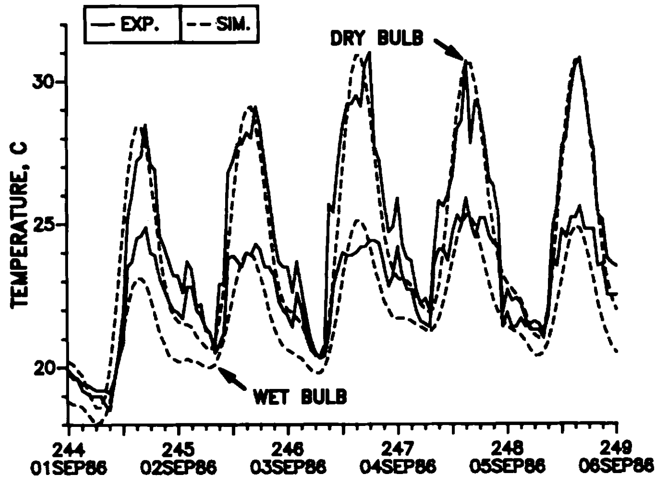

Fig. 1. Experimental and simulated ambient temperatures.

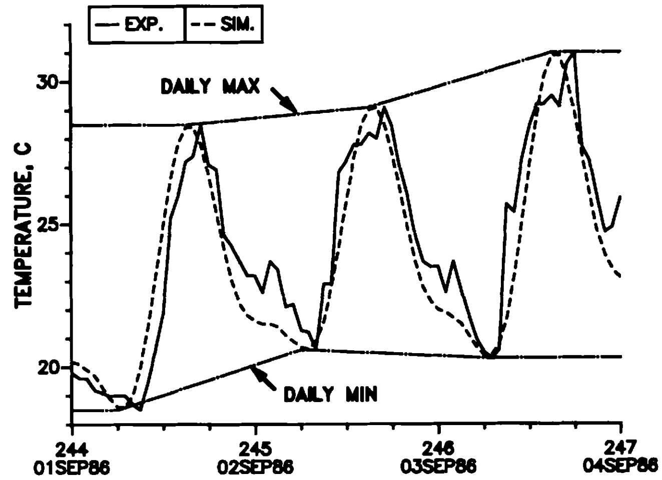

Fig. 2. Max and min temperatures used to calculate simulated hourly ambient dry bulb temperatures.

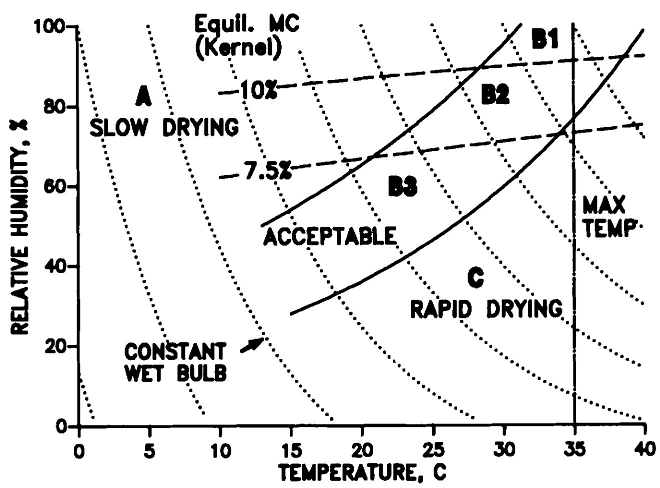

Fig. 3. Recommended peanut curing conditions, Georgia Extension Service.

in the bin will fall on a constant wet bulb line. Depending on airflow, MC and depth, conditions could reach saturation (100% RH) at other points in the bin.

Regression procedures were used to develop equations for the upper and lower limits for the Georgia recommendations.

Upper limit:

$$RH_{LU} = \exp(3.4188 + 0.037870\, t_d) \qquad r^2 = .992 \qquad (8)$$

Lower limit:

$$RH_{LL} = \exp(2.5726 + 0.050443\, t_d) \qquad r^2 = .995 \qquad (9)$$

where

t_d = dry bulb temperature, C

RH_{LU} = upper RH limit, %

RH_{LL} = lower RH limit, %

and RH_{LU}, RH_{LL} do not exceed 100%.

Alternatively, equations 8 and 9 may be expressed in terms of the dew point temperature. This form is more useful for determining the proper plenum temperature for a given set of ambient conditions:

Upper limit:

$$RH_{LU} = \exp(3.8404 + 0.024873\, t_{dp}) \qquad r^2 = .999 \qquad (10)$$

Lower limit:

$$RH_{LL} = \exp(3.4425 + 0.030047\, t_{dp}) \qquad r^2 = .999 \qquad (11)$$

where

t_{dp} = dew point temperature, C.

Using the hourly ambient temperature simulation equations developed previously (Eq. 1-7), Eq. 9 for the lower acceptable RH limit and equations for the psychrometric relationships (1), the time that ambient conditions fall in the rapid drying region were determined for a range of maximum and minimum temperatures (Fig. 4.). This shows that for certain ambient conditions, the phenum conditions will fall outside acceptable limits for good milling quality for part of the day. Alleviation of this condition would require adding moisture to the air entering the dryer to raise the RH. Current commercial dryers only allow addition of heat to lower the RH.

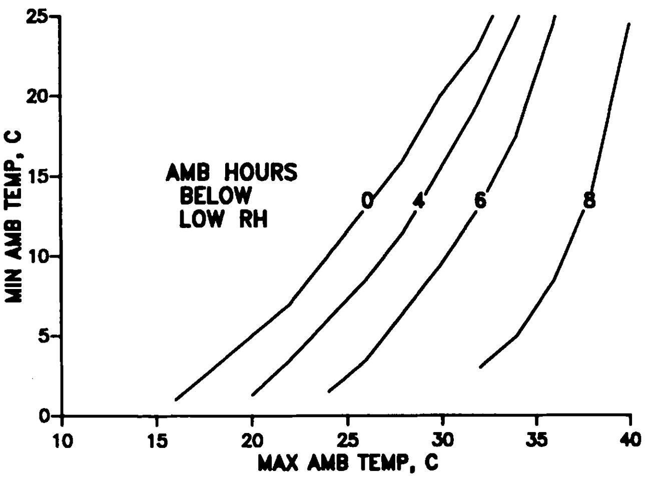

Fig. 4. Time that ambient RH is less than the recommended limit.

Development of plenum control temperature. A series of simulations were run using a range of maximum plenum temperatures and plenum temperature rises with a range of ambient maximum and minimum temperatures. Time above the upper RH limit (Eq. 8) and time below the lower RH limit (Eq. 9) were determined. These results showed that a maximum plenum temperature can be determined based solely on the minimum ambient temperature (Fig. 5.). This maximum plenum temperature will minimize the time that the plenum temperature is outside the acceptable RH range. The temperature rise in the plenum must be above some minimum level (Fig. 5). The plenum temperature will be maintained within the desired range by the thermostat in the plenum.

Regression equations for the plenum temperature limits are:

Upper limit:

$$TPMX_U = 16.6238 + 0.66643\, t_{d\,min} - 0.0030952\, t_{d\,min}^2 \qquad (12)$$

$r^2 = .998$

Lower limit:

$$TPMX_L = 10.1524 + 0.77286\, t_{d\,min} - 0.0035238\, t_{d\,min}^2 \qquad (13)$$

$r^2 = .999$

where

$t_{d\,min}$ = minimum ambient dry bulb temperature, C

$TPMX_U$ = upper limit for plenum temperature, C

$TPMX_L$ = lower limit for plenum temperature, C

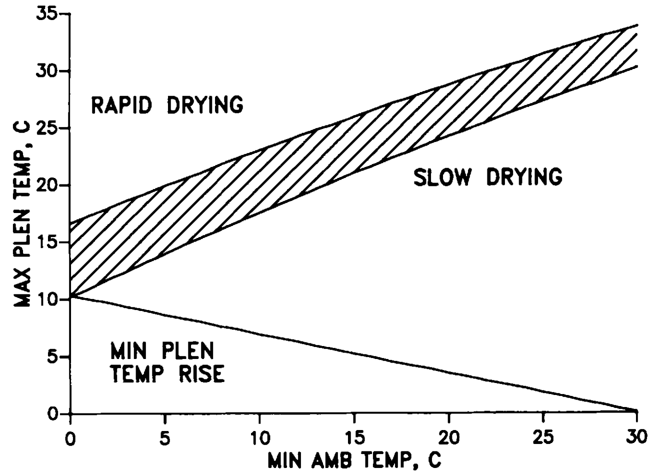

Fig. 5. Maximum plenum temperature and plenum temperature rise based on minimum ambient temperature.

Modeling aflatoxin quality. The model bulk peanut curing described by Troeger and Butler (7) was used to determine exhaust conditions that may support mold growth and aflatoxin production. The peanut curing simulation model was run with the following values for the input variables:

Maximum ambient temperature: 15 to 35 C

Ambient temperature range (difference between ambient max and min); 5 to 20 C

Airflow rate:	10 and 20 $m^3/(m^3\ min)$
Initial MC:	20 to 35 % wet basis
Plenum temperature rise:	15 C

Maximum plenum temperature: (calculated - Eq. 12)

Output variables for this study included: total curing time, time RH of the exhaust layer was above 85% (with temperature between 15 and 40 C) and time RH of the plenum layer was below the lower RH limit (RH_{LL} - Eq. 9).

Simulated curing began at 6:00 pm and continued until the average MC of the peanuts dropped below 10%. Dryer area was 10.4 m^2 and depth was 1.37 m which are common in drying wagons used in the Southeast. Sixteen layers were simulated using a time-step of 0.125 h.

Results and Discussion

Milling quality. Results of the simulation on milling quality offer the dryer operator a relatively simple method for controlling the conditions of the curing air with commercially available equipment currently in use. With knowledge of the expected minimum temperature for the next morning (readily available in weather forecasts), the operator consults Fig. 5 or uses Eqs. 12 and 13 to determine the proper setting for the thermostat in the plenum. The thermostat setting needs to be altered only once per day. This assures that the plenum air is within acceptable limits to the extent that relative humidity can be altered by adding heat. Occurrences of low humidity ambient air in the afternoon may still result in plenum air conditions outside the acceptable range.

Performance of this model for setting the plenum thermostat was checked using actual hourly ambient dry bulb and wet bulb data. The plenum thermostat was set at 6:00 pm based on the minimum temperature for the succeeding day and the upper temperature limit (Eq. 12). Results for representative data are shown in Figs. 6 and 7. In practice, the dryer operator would use the predicted minimum temperature from the local weather forecast.

Aflatoxin quality. The RH at the exhaust layer is dependent on the peanut MC, depth and airflow as well as the ambient conditions and dryer control settings. Higher

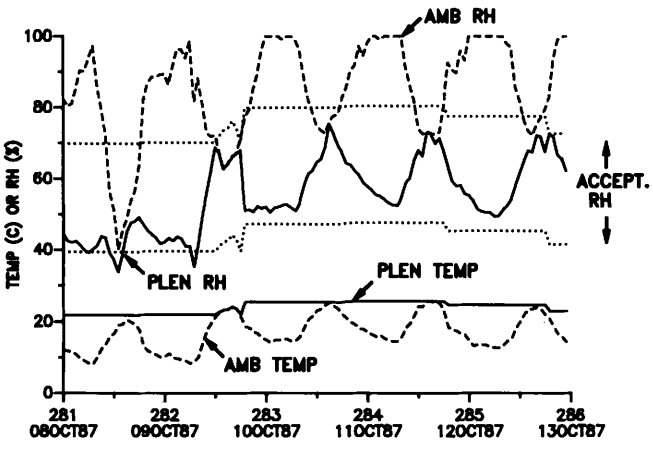

Fig. 6. Plenum temperature control based on actual ambient conditions (low ambient temperatures).

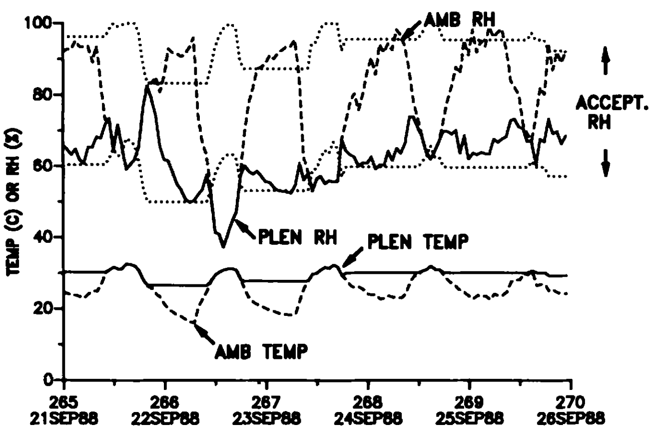

Fig. 7. Plenum temperature control based on actual ambient conditions (high ambient temperatures).

airflow will decrease the time for high RH at the top of the bin (Fig.8). Higher MC will also increase the time that peanuts in the exhaust layer are subject to conditions favorable to aflatoxin production. Fig. 8 also illustrates that high RH conditions are more likely to occur at higher ambient temperature conditions.

The range of ambient temperature also has a significant effect on occurrence of high RH conditions (Fig. 9). A narrow temperature range would occur under cloudy conditions and higher afternoon RH while a wider range would occur with full sun and lower afternoon RH.

Quality curing conditions. High RH conditions at the top of the bin are best avoided by allowing the peanuts to partially dry in the windrow if weather conditions are favorable. If peanuts must be harvested at a high MC, then a higher airflow rate or a shallower depth will reduce the time for conditions favorable for mold growth and aflatoxin production in the top layer.

Proper curing alone will not assure high quality peanuts. Curing can maintain the quality but if the quality of peanuts entering the dryer has deteriorated, the quality of the peanuts leaving the dryer will be no better.

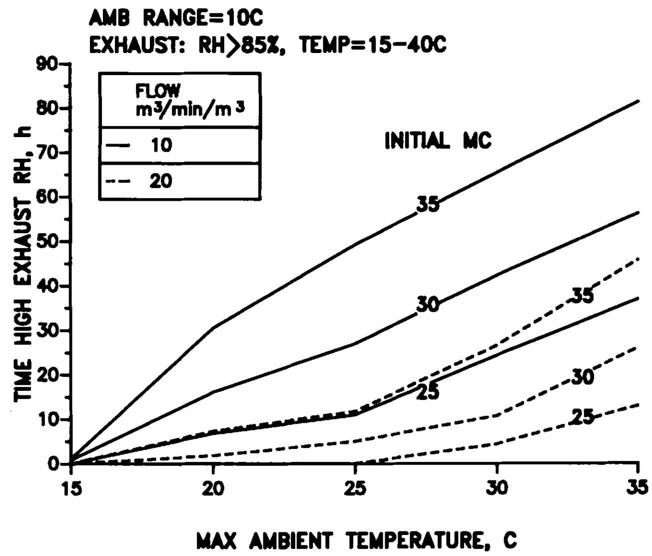

Fig. 8. Time that exhaust RH exceeds 85% with airflow and initial moisture.

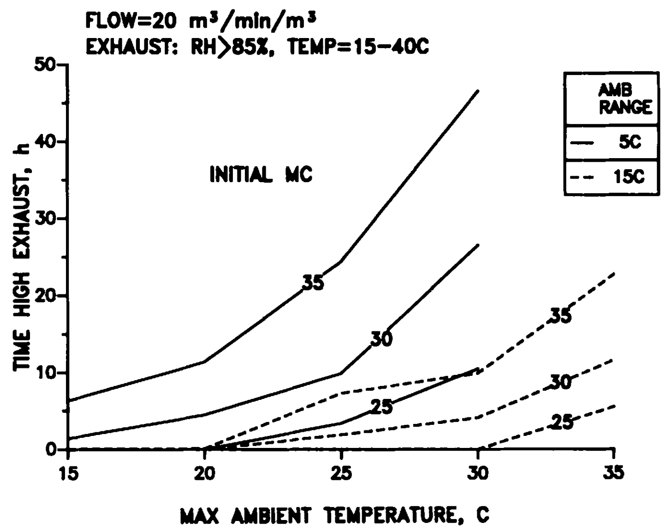

Fig. 9. Time that exhaust RH exceeds 85% with initial moisture and ambient temperature range.

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