Chapter 12

HARVESTING, CURING AND ENERGY UTILIZATION

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Peanut harvesting and curing operations are highly mechanized in all producing areas of the United States. Mechanization has resulted in shorter harvest periods with lower labor requirements. It has also increased the producer's capital requirements, increased his technical knowledge requirements, and contributed to processing and marketing problems. Good peanut production practices can often be negated by improper harvesting and curing practices. The harvesting and curing operations may affect the quality of farmers stock peanuts with respect to milling or shelling characteristics, mold development, quality of oil, germination of seed, and flavor.

Harvesting includes all operations involving the removal of peanuts from the ground and separating them from the soil and vine. These operations may include field preparation, vine clipping, digging, shaking, windrowing, and combining.

Curing refers to the process during which the moisture content of peanuts is reduced to a safe level for maintenance of quality. While moisture removal is the most apparent result of the curing process, other chemical and physiological processes continue which may have significant effects on the flavor and quality of the peanuts. These considerations lead to rather severe restrictions on the range of curing conditions which can be recommended.

Mills and Samples (1973) reviewed the historical development of peanut harvesting practices while Dickens and Pattee (1973) discussed the peanut curing process and postharvest physiology. Allen and Person (1975) and Sorenson and Person (1975) have discussed the peanut harvesting and drying procedures prevalent in Texas. It is the purpose of this chapter to discuss current recommendations for harvesting and curing, present an introduction to simulation procedures which may be used to optimize production practices, present basic property information for peanuts which relates to the curing process, and briefly discuss the energy requirements for the harvesting and curing processes.

DIGGING

Timing of Digging Operation

As an indeterminate crop, peanuts continue to produce pods as long as the vines remain healthy. Figure 1 presents non-dimensionalized curves for the total production (harvested yield, below-ground losses and aboveground losses)

of pods and the harvested yield as a function of growth period (days from planting). These curves are based on average results from harvesting studies at Lewiston, NC, over a 5-year period from 1974-1978 using Florigiant and NC5 varieties. Other varieties have similar pod production patterns. Note that the total pod production continually increased with growth period but that harvested yield reached a peak and then declined due to increased field losses at the longer growth period. The % of the total yield which was lost in the digging and combining operations was relatively constant up to about 145 days. Beyond that time the % of losses increased rapidly such that after 175 days over 40% of the total yield was lost. The time at which additional losses more than offset additional production will vary from year to year because of differences in growing conditions and will vary between varieties due to maturation differences. Figure 1 illustrates that peak yields can only be obtained within a relatively short period.

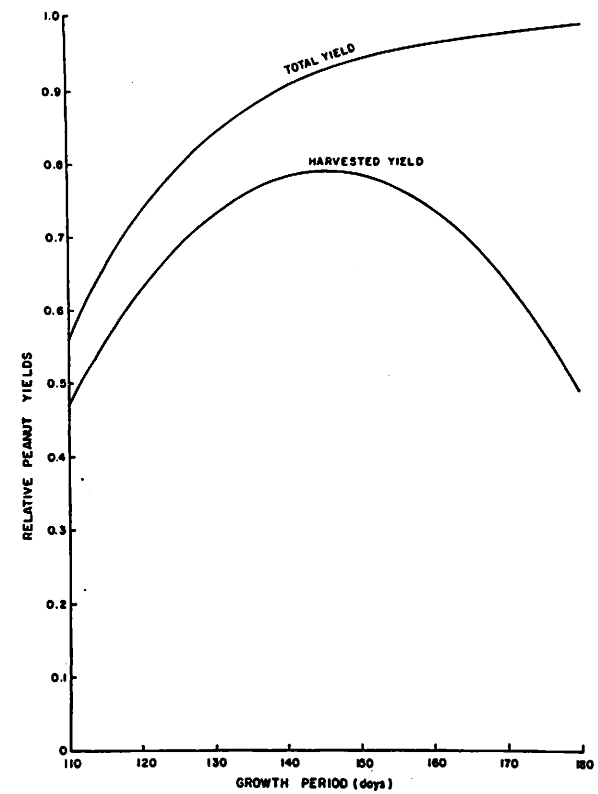

Fig. 1. Relative peanut yields versus growth period (days from planting to digging).

A separate chapter is devoted to methods for estimating peanut maturity with a goal of determining the optimum digging time (see Chapter 16). However, physiological maturity alone does not determine the optimum time for digging but must be used in conjunction with soil type, soil moisture content, weather conditions during field curing, general vine condition, frost probabiling all the pertinent factors is not presently available.

A system used rather successfully by many producers is based on the change in color of the inside of the hull. As pods mature the inside of the hull darkens. A "rule of thumb" used to predict optimum digging time has been to dig when 75% of the pods are dark. This indicates that a high percentage of the pods are mature and field losses are likely to increase faster than new pod development if digging is delayed. Other maturity indices may also be used to predict the best digging date.

Optimum soil moisture for digging would be comparable to that desired for good cultivation. High moisture soil is difficult to separate from the pods and roots, whereas soil with optimum moisture will crumble readily. If the soil is too dry and hard, penetration by the digger blades is difficult and blades tend to rise into the pod zone resulting in severe pod losses.

Predigging Operations

Two predigging operations practiced by many growers are vine clipping and coultering. Some peanut varieties under good growing conditions produce dense, heavy foliage. Vine clipping may be necessary to reduce the amount of foliage entering the combine to aid in separation efficiency. Vines should be clipped immediately before digging with a cutter set to remove the top one-third of erect type or the top one-half of the prostrate type varieties. Excessive vine clipping should be avoided because digger-shakers do not handle short plants efficiently. Excessive clipping may also cause pod shedding if the digging operation has to be delayed.

Branches of prostrate growing varieties often lap in the middle and present a problem in separating plants according to a row regime at harvest. For these varieties, coultering often precedes the digging operation. All blades used for coultering or vine clipping must be sharp and must cut cleanly without dragging to prevent pod loss.

Mechanics of Digging Operation

Peanut diggers are presently of 2 different types based on the type of windrow which is produced. The first and older type lifts the peanuts from the soil, shakes dirt from the plants, and deposits the plants in a random orientation within a windrow. Most new diggers are of the second type, which differs in that the plant orientation is controlled such that peanut pods are primarily at the top of the windrow and exposed to the sun. Figure 2 illustrates the windrow obtained from the use of an inverter type digger.

Digging can cause a high percentage of the total losses incurred during harvest. Digging losses are influenced by several conditions, including plant diseases, weeds, soil moisture and the maturity of pods at digging.

Proper maintenance and operation of digging equipment is important. Conditions that may cause excessive losses are improper pitch of blades, use of dull blades and incorrect digger-shaker or ground speed.

Excessive ground speed tends to strip pods from the plants; however, soil will not flow properly if the speed is too slow. Excessive speed of the digger-shaker combination will tend to lift the vines too rapidly and leave an excessive

Fig. 2. Peanut digger-shaker-windrower producing an inverted windrow.

number of pods in the ground.

There appears to be no published data on the energy requirement for the digging operation. Tractor size is influenced more by the lifting capacity of the tractor than by the power required for operation of the digger. Estimates of the energy requirement are in the range of 35 to 45 kWh/ha with a tractor power requirement of 35 to 40 kW.

CURING

An understanding of moisture content determination and equilibrium moisture content are helpful in understanding peanut curing. A brief discussion of each parameter follows.

Moisture Content Definitions

The moisture content of a product may be expressed in either of 2 ways: (1) wet-basis (w.b.) or (2) dry-basis (d.b.) moisture content. They are defined by the following mathematical relations:

$$m = \frac{W_{H_2O}}{W_{H_2O} + W_{d\,m}} \qquad (1)$$

$$M = \frac{W_{H_2O}}{W_{d\,m}} \quad (2)$$

where

m = wet basis moisture content, decimal;
M = dry basis moisture content, decimal;
W_{H_2O} = mass of water in a sample of the material;
$W_{d\,m}$ = mass of dry matter in the sample.

The wet-basis moisture content is used in the marketing system and is a direct indication of the fraction of the total mass of material which is water. However, the amount of water to be removed in a drying operation is not directly proportional to the change in wet-basis moisture content to be experienced. The dry-basis moisture content is often more convenient for the calculation of moisture to be removed in a drying process since in this case the water to be removed is proportional to the change in moisture content.

If moisture content expressed in one manner is known, then the other can be calculated from the following relations:

$$m = \frac{M}{1+M} \quad (3)$$

or

$$M = \frac{m}{1-m} \quad (4)$$

The amount of water to be removed in a drying process may be determined from one of the following relationships:

$$\frac{E}{P} = \frac{m_1-m_2}{1-m_1} \quad (5)$$

or

$$\frac{E}{P} = \frac{M_1-M_2}{1+M_2} \quad (6)$$

where

E = mass of water to be removed in drying from m_1 to m_2 (M_1 to M_2);
P = mass of dried material at m_2 (M_2);
m_1 = initial wet-basis moisture content, decimal;
m_2 = final wet-basis moisture content, decimal;
M_1 = initial dry-basis moisture content, decimal;
M_2 = final dry-basis moisture content, decimal.

(a) Example 1:

If peanuts at 25% w.b. moisture content are to be dried to 10% w.b., then,

$$\frac{E}{P} = \frac{.25-.1}{1-.25} = \frac{.15}{.75} = 0.2.$$

This means that for each kg of peanuts at 10% w.b. the mass of water removed during the drying process would be 0.2 kg.

(b) Example 2.

If peanuts at 50% w.b. moisture content are to be dried to 10% w.b., then,

$$\frac{E}{P} = \frac{.5-.1}{1-.5} = \frac{.4}{.5} = 0.8.$$

Thus, 4 times as much water must be removed as in Example 1.

Equilibrium Moisture Content

The equilibrium moisture content of a product is the moisture content which the product would reach if left in a fixed environment for an infinite period of time. The equilibrium moisture content of a particular material is a function of the temperature and relative humidity of the environment to which it is exposed and of its previous moisture history. Figure 3 illustrates typical equilibrium moisture content isotherms showing the hysteresis which exists between sorption processes and desorption processes.

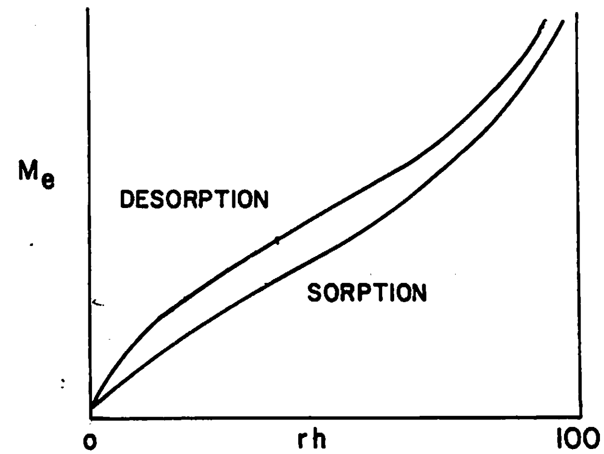

Fig. 3. Typical equilibrium moisture content isotherms for a biological material.

Experimental evaluations of the equilibrium moisture content of peanuts have been conducted by Karon and Hillery (1949), Beasley and Dickens (1963), Singh and Ojha (1974), Troeger and Butler (1970) and Young (1976). The experimental desorption and sorption isotherms determined by Young (1976) for peanut seed are given in Figures 4 and 5, respectively. Note that the effect of temperature on equilibrium moisture content is relatively small. The desorption isotherms for seed indicate a tendency for lower equilibrium moisture contents at higher temperature when the relative humidity is low and a reverse effect or no effect of temperature at relative humidities above 70%.

The equilibrium moisture content data was fitted by 5 different equations to determine appropriate constants and to compare the "goodness" of fit. Considering the simplicity of the equation as well as its ability to fit experimental equilibrium moisture isotherms, the Smith equation (Smith, 1947) was sug-

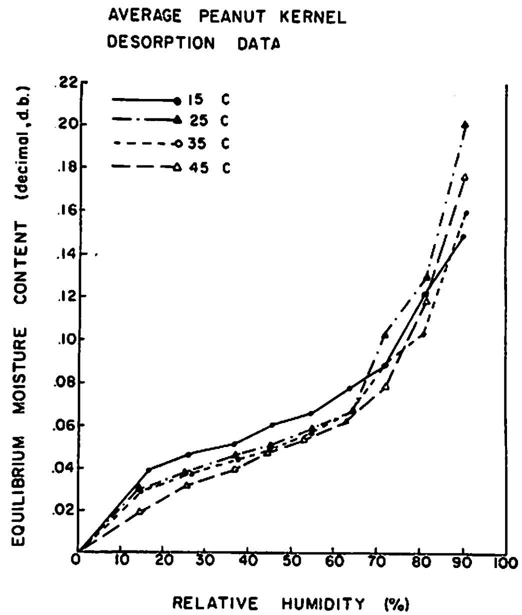

Fig. 4. Experimental desorption isotherms for peanut seed. Reprinted from Trans. of ASAE 19:146 (1976). Copyright 1976 by Amer. Soc. of Agric. Engrs.

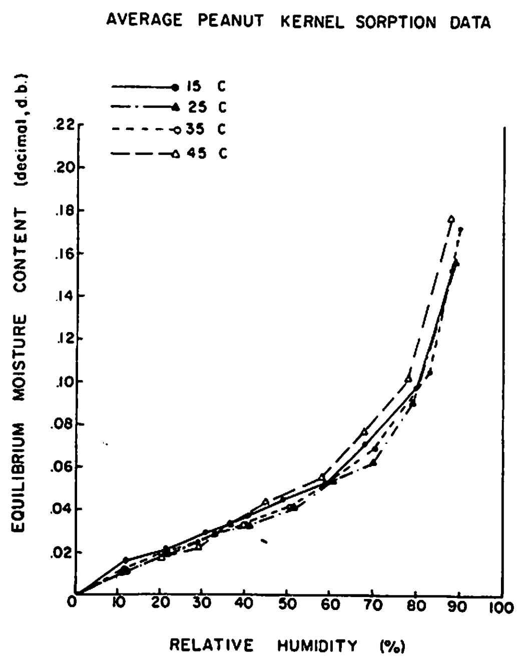

Fig. 5. Experimental sorption isotherms for peanut seed. Reprinted from Trans. of ASAE 19:146 (1976). Copyright 1976 by Amer. Soc. of Agric. Engrs.

gested by Young (1976) to be the most useful for predicting equilibrium moisture contents of peanut seed and hulls at relative humidities above 30%. The Smith equation is:

$$M = A - B\,ln\,(1-rh) \quad (7)$$

where

M = equilibrium moisture content, decimal, dry basis;
rh = relative humidity, decimal;
A and B are parameters which vary with materials, moisture history, and temperature.

Table 1 presents the values of A and B for seed and hulls for both desorption and sorption isotherms at a temperature of 15 C. The parameters vary with temperature in a manner proportional to the change in density of liquid water

Table 1. Parameter values for Smith's equilibrium moisture content equation for peanut seed and hulls at 15 C (Young, 1976).

	Desorption		Sorption	
Material	A	B	A	B
Seed	0.01448	0.06302	0.00098	0.06567
Hulls	0.07003	0.08514	0.02370	0.08199

with temperature. Thus,

$$A = A_o \frac{\rho}{\rho_o} \quad (8)$$

and

$$B = B_o \frac{\rho}{\rho_o} \quad (9)$$

where

A_o = value of A at a reference temperature;
B_o = value of B at a reference temperature;
ρ_o = density of water at reference temperature, kg/m^2;
ρ = density of water at temperature for which A or B is to be evaluated, kg/m^3.

The parameters of the well-known Henderson equation (Henderson, 1952) were also evaluated and are presented in Table 2. The equation suggested by Henderson is:

$$M = 0.01 \left[- \frac{\ln(1-rh)}{cT}\right]^{\frac{1}{n}} \quad (10)$$

where

M = equilibrium moisture content, decimal, dry basis;
rh = relative humidity, decimal;
T = absolute temperature, K;
c and n are parameters which vary with material and moisture history.

Table 2. Parameter values for Henderson's equilibrium moisture content equation for peanut seed and hulls (Young, 1976).

	Desorption		Sorption	
Material	c	n	c	n
Seed	12.78×10^{-5}	1.518	22.68×10^{-5}	1.339
Hulls	10.08×10^{-5}	1.288	14.04×10^{-5}	1.321

The Henderson equation did not give as good a fit of the experimental data as the Smith equation.

Table 3 presents tabular data for sorption and desorption equilibrium moisture contents of hulls and seed at 15 C as predicted by the Smith equation with the parameters of Table 1.

Table 3. Equilibrium moisture contents (dry basis) at 15 C predicted by Smith equation with parameters of Table 1.

	Desorption		Sorption	
rh	Seed	Hulls	Seed	Hulls
0.30	0.0370	0.1004	0.0244	0.0529
0.35	0.0416	0.1067	0.0293	0.0590
0.40	0.0467	0.1135	0.0345	0.0656
0.45	0.0522	0.1209	0.0402	0.0727
0.50	0.0582	0.1290	0.0465	0.0805
0.55	0.0648	0.1380	0.0534	0.0892
0.60	0.0722	0.1480	0.0612	0.0988
0.65	0.0806	0.1594	0.0699	0.1098
0.70	0.0904	0.1725	0.0800	0.1224
0.75	0.1018	0.1881	0.0920	0.1374
0.80	0.1159	0.2071	0.1067	0.1557
0.85	0.1340	0.2316	0.1256	0.1792
0.90	0.1596	0.2661	0.1522	0.2125
0.95	0.2033	0.3251	0.1977	0.2693

FIELD CURING

When dug, peanuts have high moisture contents which must be reduced for marketing and safe storage. This drying is usually done in 2 stages: (1) field drying completely or to 20 to 25% wet-basis moisture and (2) artificial drying in wagons or bins to 8 to 10% wet-basis moisture after combining. Since the initial moisture content of the peanuts may be in the range of 50 to 60% wet-basis, a large amount of water must be removed.

Under drought conditions the moisture content of peanuts at the time of digging may reduce to 25-30% w.b. This reduces the amount of water which must be removed after digging but often creates conditions within the soil which are favorable for the growth of *Aspergillus flavus* and the production of aflatoxin. Thus, very dry field conditions should be avoided if possible.

Rate of Drying in Windrow

The equilibrium moisture content is a very important consideration in drying of the peanuts. If the peanuts are exposed to an environment for which the equilibrium moisture content of the peanuts is less than the existing moisture content, then moisture will be transferred away from the peanuts to the environment. If the peanuts are exposed to an environment for which the equilibrium moisture content of the peanuts is greater than the existing moisture content, then moisture will be transferred to the peanuts from the environment. The magnitude of the difference between the existing peanut moisture content and the equilibrium moisture content affects the rate of moisture transfer. This may be expressed mathematically as:

$$\frac{dM}{dt} = -k(M-M_e), \qquad (11)$$

where

$\frac{dM}{dt}$ = rate of change of moisture content with respect to time, hr^{-1};

k = drying parameter which is a function of material and temperature, hr^{-1};

M = moisture content, decimal, dry basis;

M_e = equilibrium moisture content, decimal, dry basis.

Equation (11) may also be written in terms of a relative humidity difference, a vapor pressure difference, a temperature difference, or a humidity ratio difference. In each case the equilibrium moisture content relationship is needed to quantify the appropriate drying potential.

Vedak (1974) proposed a method for simulating the drying of peanuts in the windrow based on numerical solution of the expression:

$$\frac{dm}{dt} = -k(rh_e-rh), \qquad (12)$$

where

$\frac{dm}{dt}$ = rate of change of wet basis moisture content, hr^{-1};

rh_e = air relative humidity in equilibrium with existing moisture content, decimal;

rh = relative humidity of environment, decimal;

k = drying parameter which is a function of material, moisture content, and temperature, hr^{-1}.

The suggested procedure was further evaluated by Young (1977) for the drying of peanuts in inverted windrows. Figure 6 shows the simulated and experimental average drying curves for peanuts dug at Lewiston, NC, on 3 different dates in 1974.

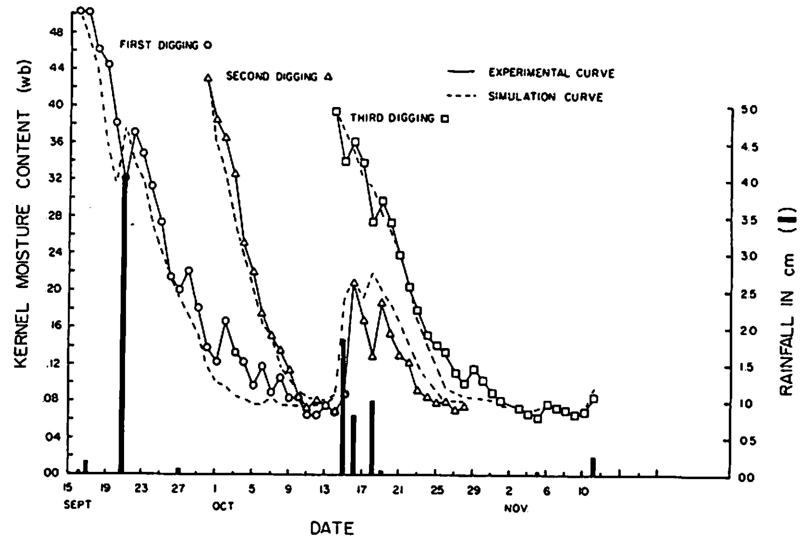

Fig. 6. Simulated and experimental drying curves for peanuts in inverted windrows at Lewiston, NC, in 1974. Reprinted from Trans. of ASAE 20:782 (1977). Copyright 1977 by Amer. Soc. of Agric. Engrs.

Steele and Wright (1977) have developed a similar windrow drying model based on the relationship:

$$\frac{dM}{dt} = -k_1 (T_a - T_o), \qquad (13)$$

where

$\frac{dM}{dt}$ = rate of change of dry basis moisture content, hr^{-1};

T_a = ambient air temperature, K;

T_o = temperature of air in equilibrium with peanuts at existing moisture content and air wet-bulb temperature, K;

k_1 = drying parameter which is a function of the material and its moisture content, $hr^{-1} K^{-1}$.

The model was tested and parameters evaluated for peanuts drying in inverted, random, and down windrows at the Tidewater Research and Continuing Education Center in Suffolk, VA.

Temperature Effects

The predominant effect of temperature on drying is due to the reduced relative humidities that accompany temperature increases. The reduced relative humidity results in a lower equilibrium moisture content for the peanuts and thus a greater drying potential. The temperature may also affect the drying by changing the value of the drying parameter, k, of equation (12). In the procedure of Vedak (1974), the drying parameter was considered to increase with an

$$k = k_o \left(\frac{Pst}{Pso} \right)^{0.7}, \qquad (14)$$

where

k = drying parameter at ambient temperature, hr^{-1};

k_o = drying parameter at some reference temperature, hr^{-1};

p_{st} = saturation water vapor pressure at the ambient temperature, kPa;

p_{so} = saturation water vapor pressure at the reference temperature, kPa.

Effect of Moisture Content on Drying Parameter

Experimental investigations of peanut drying have indicated that the drying parameter also varies with the moisture content of the peanuts. In the procedure of Vedak (1974), the drying parameter was modeled as a function of moisture content as follows:

$$k_o = a_1 + a_2 m + a_3 m^2, \qquad (15)$$

where

k_o = drying parameter at 21.1 C (70 F), hr^{-1};

m = wet-basis moisture content, decimal;

a_1, a_2, and a_3 = constants, hr^{-1}.

The constants were evaluated by Young (1977) as $a_1 = 0.000426$, $a_2 = 0.0343$, and $a_3 = 0.0057$.

In the model developed by Steele and Wright (1977), the drying parameter was assumed to vary with moisture content as follows:

$$k_1 = k_2 M^{k_3}, \qquad (16)$$

where

k_1 = drying parameter which is function of material and moisture content, $hr^{-1}K^{-1}$;

M = dry-basis moisture content, decimal;

k_2 and k_3 = dimensionless constants.

Values of k_2 and k_3 were evaluated for different digging dates, windrow types, and weather data sources.

Rainfall Effects

During periods of rainfall, the moisture transfer between the peanuts and the environment cannot be satisfactorily simulated by the above relationships, which consider water to be transferred in the vapor phase. The equation used by Young (1977) to account for moisture changes due to rainfall is:

$$\Delta M = \propto (1-m)R, \qquad (17)$$

where

ΔM = change in dry-basis moisture content during day, decimal;

$\propto$ = proportionality constant, cm^{-1};

m = wet-basis moisture content, decimal;

R = rainfall for the day, cm.

Steele and Wright used the following relationship to account for moisture changes during rains:

$$\Delta M = k_4 R^{0.5}, \quad (18)$$

where

ΔM = change in dry-basis moisture content during a 3 hr. period, decimal;

k_4 = proportionality constant, $cm^{-0.5}$;

R = rainfall during a 3 hr. interval, cm.

A restriction was placed on the peanut moisture when using this equation which prevented pod moisture contents from exceeding 120% dry basis. Steele and Wright (1977) used a multiplier to increase the drying parameter during drying periods following rainfall.

Losses in the Field

During windrow curing and subsequent combining, peanuts are subject to above ground field losses. The magnitude of these losses is expected to be a function of rainfall, peanut moisture content, age of peanuts at digging, period of time peanuts have been in windrow, digger adjustments and combine adjustments. A procedure for predicting the effect of each of these factors on above ground field losses has not been developed. However, studies at Lewiston, NC, with NC5, NC6, and Florigiant varieties have given some indication of the average effects of windrow drying period and age of peanuts at digging for peanuts in inverted windrows in North Carolina. Figure 7 is a plot of the % of the peanuts lost above ground as a function of days in the windrow for peanuts of 3 different ages. These curves are regression fits of experimental data from harvesting studies from 1974 through 1979. No difference between the 3 varieties was found to be statistically significant. Figure 7 should be considered preliminary at this time. However, it illustrates a trend for an initial reduction in % above ground losses with an increase in windrow drying time during the first few days of drying (possibly due to more efficient combining of the drier peanut vines) followed by significant increases in % above ground losses for longer windrow drying periods. There is also a trend toward increased above ground losses for more mature peanuts, as can be seen by comparing the curve for peanuts dug 160 days after planting and the curve for peanuts dug 120 days after planting. This is probably due to the weakened peg condition of the more mature peanuts which allows a higher percentage of shedding during mechanical operations

COMBINING

Timing of Combining Operation

The proper time to begin combining depends on weather conditions, combine capacity, total area of peanuts to be harvested, and availability of facilities for artificially completing the drying process. Under good field drying conditions the moisture content of the peanuts may drop to a marketable level of 10% (w.b.) or below, thus eliminating the need for energy consumption to complete the drying. However, while the moisture content is reduced in the windrow, the field losses increase with increased exposure in the windrow.

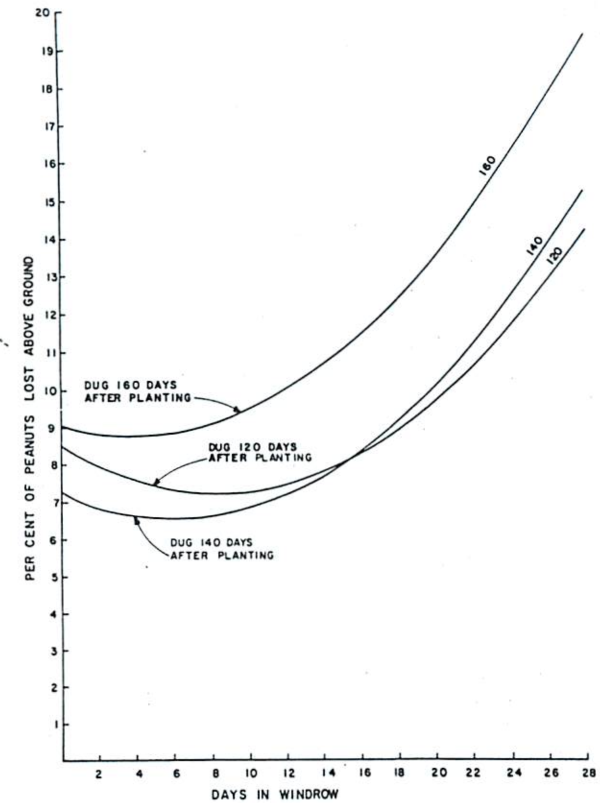

Fig. 7. Percent of peanuts lost above ground versus days in windrow.

Also, the percentages of loose shelled kernels (LSK), sound splits, and damaged seed tend to increase with time spent in the windrow. Thus, the energy conservation advantage of increased windrow drying periods may be offset by increased losses and a reduction in quality.

The optimum time for combining peanuts occurs when the rate of additional savings from windrow drying is just offset by the rate of additional costs from field losses and quality deterioration. Procedures for predicting this optimum time are not yet available since the effects of weather conditons on losses and peanut quality cannot be accurately predicted. Common practice is to start combining when the seed moisture content is 20-25% (w.b.). If peanuts initially at 50% (w.b.) are dried to 25% (w.b.) before combining, the amount of moisture which must be removed artificially is reduced by 75%. Since this amount of drying in the windrow can normally be accomplished within 4 to 6 days, field losses and quality deterioration are not likely to offset the energy savings to be experienced.

Mechanics of Combining

The combining operation can be broken down into 4 parts as follows: (1) the from the vines; (3) the foreign material is separated from the peanuts and scattered on the land with the vines; and (4) the peanuts are deposited in bulk tanks or bags. A cut-away view of a typical peanut combine is given in Figure 8.

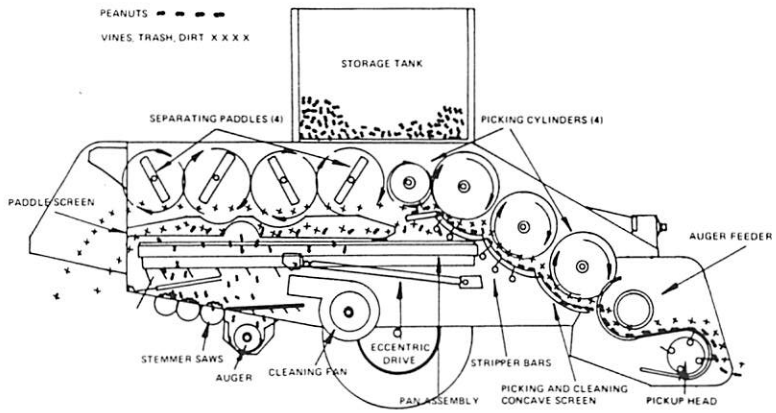

Fig. 8. Cut-away view of a typical peanut combine. (Courtesy of Lilliston Corp.)

In order to minimize losses in the pickup operation, it is important that the pickup speed be synchronized with the ground speed so that the windrow flows like a ribbon from the ground, over the pickup and into the combine. If the pickup speed is too fast relative to the ground speed, the windrow will tear apart and strip fruit from the vine before they enter the combine. If the pickup speed is too slow relative to the ground speed, it will overrun and drag the windrow. The pickup fingers should be adjusted so they lift the windrow without digging into the soil.

The adjustment of picking cylinder speed and clearance can have a major effect on picking efficiency and on the number of LSK which are produced. The operator's manual for the combine should be studied and the manufacturer's recommendations should be followed as closely as possible. Adjustments may be necessary during each day of operation since vine conditions change from morning to night.

The separation of peanuts from foreign matter takes place in the cleaning section of the combine. This function is greatly affected by the air flow provided for cleaning purposes. Adjustments of the air flow should be made based on manufacturer's recommendations and on field observations of the foreign material remaining in the harvested peanuts and of the number of pods being blown out the rear of the combine.

Once the peanuts have been separated from the vines and foreign material, they are conveyed to either bulk tanks or bags. Pneumatic conveying is often used for peanuts due to the mechanical damage which results from auger conveying systems. The amount of air provided to the conveying system can also be adjusted. This air flow should be sufficient to prohibit clogging of the conveyor ducts but should not be high enough to cause excessive impact damage to the peanuts when they contact bends in the ducts or when they exit into the final storage bin.

Combine bulk bins are constructed such that they will dump directly into drying wagons as shown in Figure 9. Nonuniform depths of peanuts in the wagons will lead to nonuniform drying and the possibility of spoilage in deep

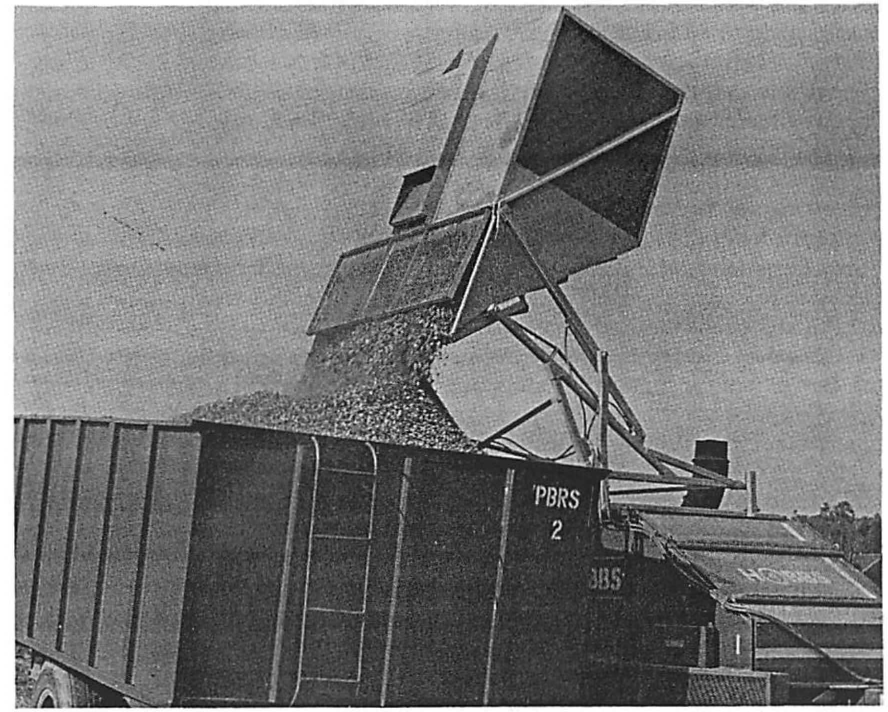

Fig. 9. Combine bulk bin dumping peanuts into drying wagon.

areas while shallow areas may actually overdry. Thus, if a wagon is only partially filled, the peanuts should be leveled before drying. Also, care should be taken to avoid overfilling the drying wagon by heaping peanuts in the center of the wagons.

Energy Consumption

The energy requirement for combining peanuts will vary widely depending upon the condition of the vines at the time of combining. Energy requirements may also vary considerably among various brands of combines though no published data have been found to quantify the mean requirements or the variability. Estimates of the energy requirement are in the range of 100 to 130 kWh/ha with a power requirement of 50 to 60 kW.

Alternative Harvesting Methods

Essentially all peanuts in the United States are harvested using the windrow harvesting method which has been previously described. However, 2 other methods should be mentioned here due either to their historical significance or to possibilities for the future. The first is the stackpole method of harvesting which was traditionally used prior to the development and acceptance of the mobile combine. In the stackpole procedure, peanut vines with pods still attached are manually stacked around poles in the field to dry to a marketable level. The stacks of peanuts are then picked using a stationary picker. Pickers traditionally used in the stackpole procedure utilized a carding picking principle rather than the cylinder principles used in modern combines. The carding-type picker operates by dragging the peanut vines over screens through which the peanuts fall and are thus pulled from the plant. Pickers using this principle of picking are no longer commercially available.

There are still a few peanut seed producers who use the stackpole method of harvesting. However, most of these now use the cylinder-type combine for peanut picking. The primary disadvantage of the stackpole harvesting method is the large labor requirement for placing peanuts in the stacks and for later transporting stacks to the picker. It is also generally believed that field losses for the stackpole method exceed those for the windrow harvesting method. The advantage usually given for the stackpole method is higher quality planting seed. Investigations by Young and Moore (1972) have indicated that germination of stackpole peanuts was comparable to that of windrow harvested peanuts at early digging dates but was significantly higher at later digging dates.

The second alternative to the windrow harvesting method is the once-over method. This procedure was first investigated by Mills (1961) and has more recently been further developed by Butler et al. (1970) and Wright (1973). In the once-over harvesting procedure, a special machine is used which can dig the peanut plants from the ground and pick the peanuts from the vines in one pass through the field. Wright and Steele (1979) have discussed improvement in picking efficiency and peanut quality which may be achieved using the once-over procedure and Coffelt et al. (1979) have discussed the use of the once-over procedure for seed peanuts. Advantages of the once-over procedure include less damage to peanuts and elimination of the weather risk for windrow drying. The primary disadvantage is the large amount of moisture which must then be removed in the artificial drying process. Concern about the availability of fuel for drying of freshly dug peanuts has thus far prevented the development of once-over harvesters on a commercial basis.

An advantage of the once-over harvesting procedure which has not yet been fully explored is the use of the peanut vines for hay. Peanut vines are known to make high quality hay if they can be harvested at their maximum nutritional level. However, a large portion of the value for hay is lost when vines remain in a windrow for several days. It is possible that part or all of the additional drying costs for the once-over harvesting method could be offset by the use of the higher quality peanut foliage as hay. However, certain pesticides currently used on peanuts have not been approved for peanut hay utilization.

ARTIFICIAL DRYING OR CURING

Once peanuts are picked from the vines and placed in wagons or bins, they must be dried promptly to a moisture level which is safe for storage. Failure to reduce the moisture content to a marketable level of less than 10% (w.b.) within a period of 2 or 3 days may result in quality losses from biological activity.

Though the terms "drying" and "curing" will be used interchangeably in this chapter, it should be emphasized that certain physical and biochemical changes in addition to moisture loss occur during preservation by drying. It is desirable to cure peanuts in a manner to preserve or enhance their quality. Peanut curing treatments are recommended that have been shown to produce seed which do not skin or split excessively during shelling and which have an acceptable flavor. This places some rather stringent requirements on temperature, relative humidities, and air flow rates for acceptable peanut curing.

Thin-Layer Drying Relationships

In order to understand the effect of various drying conditions on peanut quality and energy requirements, it is first necessary to know the effects of the conditions on the drying of fully exposed pods. The manner in which fully exposed pods dry may be described by thin-layer drying relationships similar to those discussed in the section on field curing. The temperature and relative humidity of the drying air establish the equilibrium moisture content of the peanuts. The difference between the equilibrium moisture content and the existing moisture content then establishes the potential for drying. The rate at which moisture is transferred between the peanuts and the environment may then be described by a relationship similar to equation (11) or by the diffusion equation. The drying parameter, k, is affected by temperature and air velocity.

Young and Whitaker (1971), Whitaker and Young (1972a,b), Chhinnan and Young (1977a,b) have evaluated several mathematical models for thin-layer drying of peanuts and have evaluated equation parameters giving the best fit of experimental data. Figure 10 illustrates the effect of drying air temperature on the rate of drying of individual (or thin-layers) of peanut pods. The plots of moisture ratio, $MR = \frac{M-M_e}{M_o-M_e}$, indicate that the drying parameter, k, increases with an increase in temperature. Young and Whitaker (1971) found that the drying parameter, k, for the diffusion equation assuming a spherical body varied according to the Arrhenius equation:

$$k = 33730\, e^{-(4003/T)} \quad (19)$$

where

k = peanut pod drying parameter for diffusion thin-layer drying using a spherical body, hr^{-1}; and

T = absolute temperature of drying air, K.

This temperature effect on the drying parameter is in addition to the effect that a change in temperature will have on the equilibrium moisture content. No significant effect of dew-point temperature on the drying parameter was found.

Temperature and Relative Humidity Effects

The rate of drying affects the milling quality of peanuts. Milling quality includes skin-slippage and splitting of seed during the shelling operation.

As discussed in the section on thin-layer drying relationships, increased temperatures result in increased drying rates both due to an increase in the drying parameter, k, and due to a reduction in the relative humidity of the drying air.

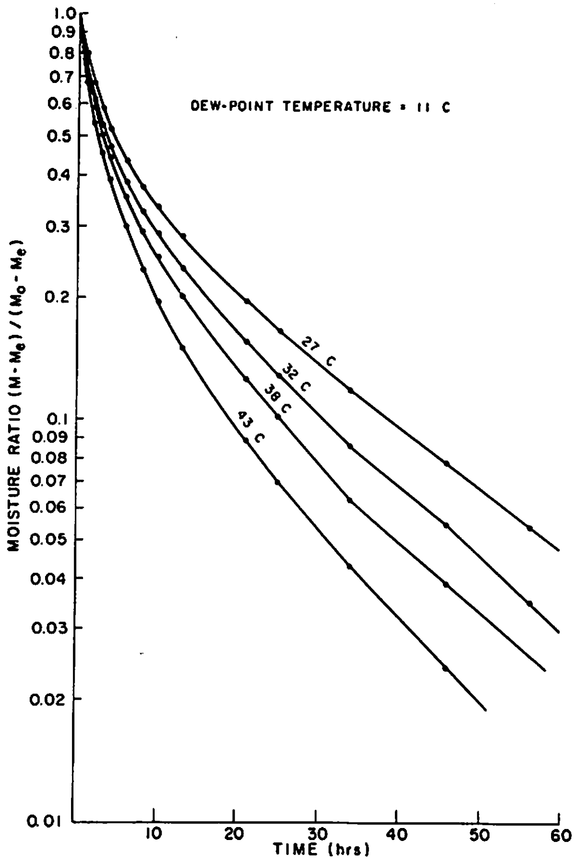

Fig. 10. Effect of peanut drying air temperature on the thin-layer drying of peanut pods. Reprinted from Trans. of ASAE 14:309 (1971). Copyright 1971 by Amer. Soc. of Agric. Engrs.

Reduced relative humidities of the drying air result in lower equilibrium moisture contents and thus higher drying potentials.

Dickens and Beasley (1963) and Beasley and Dickens (1963) have investigated the effects of drying temperatures and relative humidities on milling quality. Fast drying rates as well as overdrying of seed below 8 to 8.5% (w.b.) were found to reduce the milling quality. Results of these studies have led to the curing recommendations of the North Carolina Agricultural Extension Service (Glover, 1977) in which the drying conditions should be maintained within specific ranges of temperatures and relative humidities. Figure 11 presents a psychrometric chart on which the desirable ranges of temperatures and relative humidities for acceptable drying rates are given. When the ambient air relative humidity is high (such as at night or in damp weather), the temperature should be raised a few degrees to lower the relative humidity and increase the drying rate (drying conditions move horizontally to the right on the psychrometric chart as heat is added). When the relative humidity is low, no heat is needed.

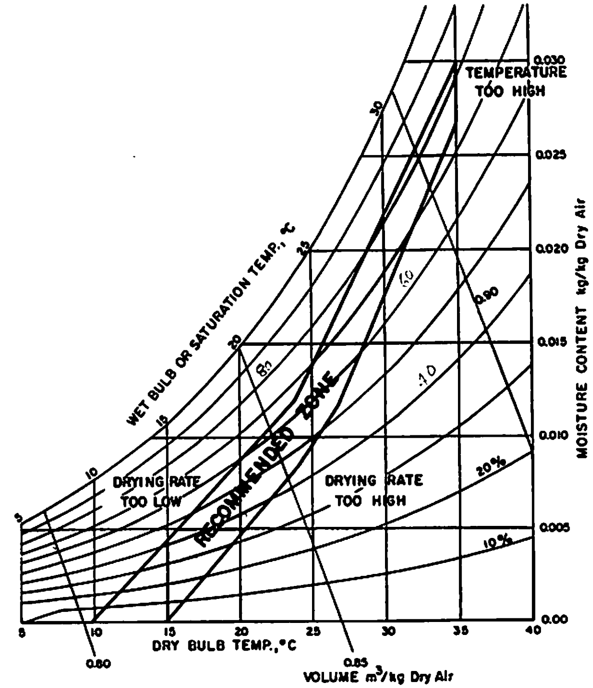

Fig. 11. Psychrometric chart showing recommended range of air condition for peanut curing.

Temperature of the drying air is also associated with the flavor of the cured peanuts. Studies by Beasley and Dickens (1963) have indicated that temperatures above 35 C result in off-flavor development in the peanuts. More off-flavor is produced in the immature seed, and off-flavor appears to be more pronounced in peanuts which are in the 20 to 30% (w.b.) moisture content range when exposed to the high temperature.

Controls for peanut dryers to maintain the condition of the air within the desired zone under all conditions are not available. Drying air conditions may be maintained fairly close to the desired zone, however, by using a humidistat and a thermostat exposed to ambient conditions and a high limit thermostat inside the drier plenum. The high limit thermostat is set at 35 C so that air will not be heated high enough to produce off-flavor. The thermostat and humidistat in the ambient environment are adjusted such that heat is added when the ambient temperature is less than approximately 25 C and the ambient relative humidity is above approximately 65%. The heater should be adjusted such that when heat is called for the temperature rise will be between 5 and 10 C. Exact recommendations for control settings vary between states but are similar to those given above.

Specific Heat

The specific heat of a substance is a measure of the energy required to raise the temperature of the substance. Specific heat values are needed to determine the amount of energy stored in a product at different temperature and moisture conditions. If the temperature of the product changes during the drying process, then the change in stored energy will affect the energy consumption of the process.

Wright and Porterfield (1970), Suter (1972), and Young and Whitaker (1973) have evaluated the specific heat of peanuts. A differential scanning calorimeter was used by Young and Whitaker (1973) in determining the specific heat of virginia type peanuts. The results were expressed as:

$$C_{pk} = (-0.125 + 0.00167\,T)(1-m) + C_{pw}m \qquad (20)$$

and

$$C_{ph} = 0.170\,(1-m) + C_{pw}m, \qquad (21)$$

where

C_{pk} = specific heat of peanut seed, cal/g K;
C_{ph} = specific heat of peanut hulls, cal/g K;
C_{pw} = specific heat of water, cal/g K;
T = absolute temperature, K; and
m = product moisture content, wet-basis decimal.

The specific heat values found by Wright and Porterfield (1970) for spanish peanuts are similar to those reported for the virginia type.

Bin or Wagon Drying

When peanuts are placed in a drying bin or wagon and the drying process is begun, air at the desired temperature and relative humidity is forced upward through the peanuts. Computer models of the bulk drying process have been described by Vedak and Young (1976), Chhinnan and Young (1978), and Troeger and Butler (1979). These simulations may be used to estimate the required drying time and energy consumption under varying conditions of air flow, temperature, and initial moisture content. A drying zone is initially created in the lower layers of the peanuts. As the drying process continues, this drying zone moves upward through the batch of peanuts, thus completing the drying process.

In Figure 12, peanuts above the drying zone are still at a relatively high moisture content while those below the drying zone have reached a moisture content close to the equilibrium moisture content for the drying air conditions. The drying process must be operated long enough for the drying zone to move upward through the entire batch of peanuts. If air temperature is too high and/or relative humidity is too low, the bottom layers of peanuts will be overdried and overall quality will be reduced. If air temperature is too low, relative humidity too high, and/or air flow rate is too low, then the drying rate of the batch of peanuts will be too low and spoilage will occur before the drying process is complete.

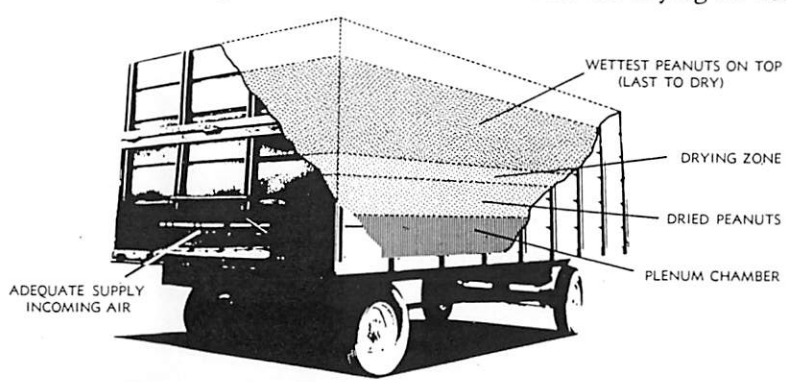

Fig. 12. Cut-away view of peanut drying wagon showing drying zone

The thickness of the drying zone is a function of the air flow rate. If the air flow rate is very high, the drying zone will become very thick and more uniform drying of the entire batch will occur. However, during the total drying period more air will exit from the top of the batch in an unsaturated condition thus reducing the energy efficiency of the process. If the air flow rate is very low, the drying zone will be narrow, wide gradients will exist in moisture content from top to bottom, and energy efficiency will be high. Thus, a compromise must be reached between providing air flow rates to yield high energy efficiencies on the one hand versus high drying rates and uniformity of drying on the other. Current recommendations vary considerably between peanut producing states. An air flow rate of 10 m^3/min m^3 (Glover, 1977) is recommended in North Carolina for drying 25% (w.b.) peanuts while recommendations in Alabama for peanuts at that moisture content are approximately 19 m^3/min m^3 (Mayfield and Donald, 1979). Blankenship and Pearson (1976) have conducted studies of the effect of air flow rates between 11 and 60 m^3/min m^3 on the drying rate and quality of green peanuts in 0.9 m deep beds. Drying rates increased with air flow rate with little effect on quality.

Resistance of Peanuts to Air Flow

In order to properly select fans for providing air flow through peanut drying facilities, it is necessary to have knowledge of the resistance to air flow provided by the peanuts. Shedd (1953), Coates and Beasley (1961), and Steele (1974) have investigated the pressure drop which occurs when air is forced through peanuts at various rates. Steele (1974) developed the following relationship for the apparent velocity of air through a bed of peanuts:

$$v = 0.0184\left(\frac{\Delta p}{RL}\right)^{0.618}, \qquad (22)$$

where

v = apparent air velocity through bed of peanuts, m^3/sm^2;
Δp = pressure drop through bed of peanuts, Pa;
L = thickness of peanut bed, m;
R = moisture content correction factor, dimensionless.

The moisture content correction factor, R, was determined to vary linearly with the dry-basis moisture as follows:

$$R = 0.962 + 0.00392\,M, \qquad (23)$$

where

M = peanut moisture content, % dry basis.

Figure 13 is a plot of the apparent air velocity through peanuts of various moisture contents versus the pressure drop per unit depth. Note that the effect of moisture content is small at lower moisture contents but increases significantly at high moisture levels.

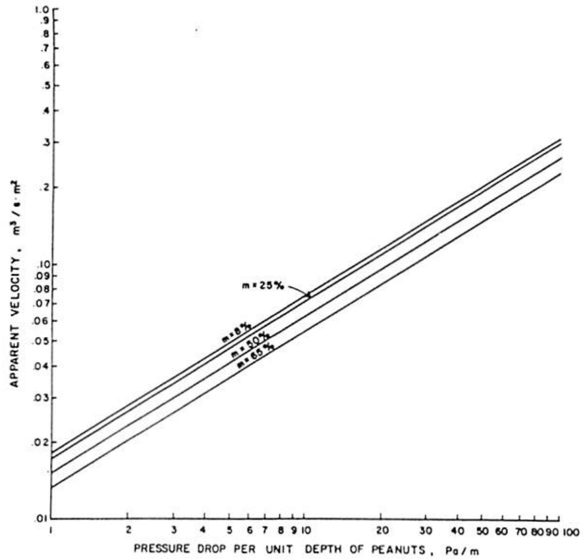

Fig. 13. Apparent air velocity through peanuts versus the pressure drop per unit depth for different moisture contents (% w.b.).

Fan Requirements

Fans used for drying peanuts must be able to provide the quantity of air needed while working against the static pressure required to force the air through the peanuts and the system ducts and plenum. The static pressure required to force the air through the peanuts can be determined from Figure 13 if the desired air flow rate is known. Pressure drops through the ducts will depend on (1) the size and length of ducts, (2) the size and shape of air gates, and (3) the number of turns the air has to make. To keep duct losses low it is recommended (Glover, 1977) that the cross-sectional area of ducts be at least 0.2 m^2 for each 1 m^3/s of air that will pass through them. The exhaust side of the dryer should have openings at least twice this size or at least 0.4 m^2 for each 1 m^3/s. The normal duct loss when these guidelines are followed will be approximately 60 Pa (or 6 mm of H_2O) if 10 $m^3/min\ m^3$ is passing through the peanuts. It is important to have a large plenum so that the air velocity in the plenum is low and can be forced uniformly through the peanuts.

If the air flow is increased above the 10 $m^3/min\ m^3$ rate, the pressure drop through the system will increase and fan capacity and power must increase. Mayfield and Donald (1979) recommend using a fan capable of supplying 19 $m^3/min\ m^3$ against a static pressure of 250 Pa (2.5 cm of H_2O).

Centrifugal or axial flow fans are suitable for drying peanuts. Centrifugal fans have a wheel which is rotated within a scroll-type housing. Air enters the inlet axially, makes a 90 degree turn and is discharged from the wheel radially. Axial-flow fans consist of an axial-flow wheel supported by bearings within a cylinder.

Centrifugal fans suitable for peanut drying have forward-curved or backward-curved blades. Forward-curved blade fans are lighter and less expensive

but have the possibility of overloading the motor if the fan operates against static pressures lower than those used in the design of the system. This is undesirable for peanut dryers since the depth of peanuts during drying may vary from time to time. A backward-curved blade fan has the advantage of self-limiting horsepower which makes it unnecessary to provide excess motor capacity beyond that required for a normal load.

Axial-flow fans have a low initial cost, require a small amount of space, and are easily installed. However, in locations where fan noise is a factor, centrifugal fans should be considered.

Heat Requirements

Most peanut dryers utilize direct fired gas heaters. Natural and/or LP gas are appropriate fuels in most areas. The choice of fuel for a particular dryer depends upon availability and cost. Although electricity provides a clean source of heat, electrical heaters are usually more expensive to operate and may cause undesirable high-peak, short duration loads.

The heater capacity required for peanut dryers may be calculated from the air flow rate and temperature rise to be achieved. This may be described mathematically by:

$$Q = \ddot{m}\, C_p\, \Delta t \qquad (24)$$

where

Q = power requirement of heater, kW;
$\ddot{m}$ = mass flow rate of air, kg/s;
C_p = specific heat of air, kJ/kg K;
Δt = temperature rise to be achieved, K.

For heating of air at normal atmospheric conditions, this is approximately:

$$Q = \left(1.2 \frac{kJ}{m^3 K}\right) \ddot{V}\, \Delta t \qquad (25)$$

where

$\ddot{V}$ = volume flow rate, m^3/s.

Example:

If a peanut drying wagon having a cross-sectional area of 10 m^2 and a peanut depth of 1.5 m is to have an air flow rate of 10 $m^3/min\ m^3$, then the total volume of air through the wagon will be:

$$\ddot{V} = (10 m^2)(1.5 m)\left(10 \frac{m^3}{min\ m^3}\right)\left(\frac{1\ min}{60\ s}\right) = 2.5 \frac{m^3}{s}$$

and the heater power requirement for a 10 K temperature rise will be:

$$Q = \left(1.2 \frac{kJ}{m^3 K}\right)\left(2.5 \frac{m^3}{s}\right)\left(10\ K\right) = 30\ kW.$$

Energy Consumption

The energy consumption in peanut drying is highly dependent on initial moisture content of the peanuts, air flow rate, and ambient air conditions. In most peanut producing areas a large portion of the daytime drying can be accomplished without supplemental heat. However, at night and during high

Energy consumption of fans will increase with higher air flow rates and will be proportional to the length of time required for drying. Energy consumption of heaters (assuming a constant temperature rise) will increase with higher air flow rates and will be proportional to the time which heaters must operate.

The total energy consumption will depend on ambient weather conditions, air flow rate, temperature rise, and initial moisture content of peanuts. Blankenship and Chew (1979) presented regression equations for typical energy consumption rates for peanut drying in the Parrott, GA, area. For single trailer drying systems (consisting of 4.3m x 2.4m x 1.4m Peerless trailers with Model 153, 3.73 kW Peerless propane gas-fired dryers), the following equations were developed:

$$TEU = 1.786\ m_o - 17.536 \qquad (26)$$

and

$$TGU = 2.994\ m_o - 21.902, \qquad (27)$$

where

TEU = total electricity used, kWh/Mg;
TGU = total gas used, liters/Mg;
m_o = initial moisture content of peanuts, percent wet basis.

Based on equations (26) and (27), the energy requirements for drying 50% w.b. peanuts would be approximately 2.5 times as great as the energy requirement for 25% w.b. peanuts.

Mayfield and Donald (1979) have estimated the typical cost of drying peanuts from 20% w.b. to 10% w.b. to be $4.39/Mg. This estimate was based on fuel costs of 11.9 cents per liter for LP gas and 5 cents per kilowatt-hour for electricity. Their energy cost estimate was less than one-third of the total drying cost estimate of $13.79/Mg for a typical 4-wagon peanut drying system. The total drying costs include the depreciation, interest, maintenance, taxes, and insurance costs for owning the necessary drying equipment.

Methods for reducing energy consumption in peanut drying which have been suggested include: (1) reduced air flow rates, (2) intermittent operation of fans and heaters, (3) partial recirculation of drying air, and (4) drying to lower moisture contents in the field. Each of these suggestions has advantages and disadvantages, and further evaluation is needed to determine their economic feasibility.

Blankenship and Chew (1978) and Troeger and Butler (1980) have investigated the intermittent operation of fans and heaters and have concluded that intermittent operation can reduce energy requirements for drying low to medium initial moisture content peanuts without significantly increasing drying time.

Quality Evaluations

Evaluation of the market value of farmèrs stock peanuts is thoroughly treated in Chapter 15. Market value is one indication of the product quality, but it does not adequately evaluate some quality factors such as flavor and skin slippage which are indicative of improper drying treatments. Also, the current

grade factors do not adequately reward those growers who are doing a good job of maintaining peanut quality nor do they properly penalize those who continuously mismanage the harvesting and curing operations.

Alternative Drying Systems

Sack Drying. In some areas of the southwest, peanuts are placed in sacks when they are combined and the sacks are left in the field to complete the drying. If peanuts are to be field cured in sacks, they should be allowed to cure to approximately 15% moisture (w.b.) in the windrow before combining. The sack drying procedure eliminates the need for artificial drying facilities but increases handling operations and increases the risk of damage due to inclement weather.

Vacuum Drying. Vacuum drying of peanuts has been investigated by Kunze et al. (1968) and found to be effective for obtaining fast rates of moisture removal (up to 5%, dry basis, per hour), but the percentage of sound splits was excessive at these high drying rates.

Infrared Drying. Sorenson (1967) and Sorenson and Person (1967) have discussed experiments in which infrared heating was used for peanut drying. Peanuts at different levels of initial moisture content were dried by subjecting them to successive infrared heating, aeration and tempering treatments. Repeated infrared exposures of 0.6 to 1.0 minute per pass, at high intensity levels, were effective in reducing mold infestation, but were extremely detrimental to the quality of peanuts from the standpoint of germination, percentage of sound splits and flavor.

Heat Pump Systems. Drying of peanuts with heat pump systems has been investigated by Person et al. (1977). They investigated both driers where the air makes only 1 pass through the system and driers utilizing a closed-air principle. Their results indicated that energy efficiency ratios for the heat pump systems were in the range of 10 to 12. This means that heating with electrical resistance heaters would require 10 to 12 times more energy than did the heat pump systems.

The peanut quality from the heat pump systems was comparable to that from conventional systems. The primary disadvantage for the use of the heat pump system is the initial cost of the refrigeration equipment.

The economic feasibility of the heat pump systems will be determined by such factors as the comparative equipment costs, fossil fuel costs, and the availability of these fuels. As the demand for natural and LP gas increases and the supply decreases, the peanut industry may have to turn entirely to electrical heat. If this is the case, then the heat pump system would be much more practical than resistance heat due to the high energy efficiency ratios.

Solar Systems. Drying of peanuts with solar energy has been investigated by Troeger and Butler (1979, 1980b) and Troeger (1980). Solar energy was collected and stored in either water or rock for use in heating air for the drying of peanuts. Peanuts were then dried in conventional fashion using the solar heated air. Auxiliary heaters are necessary to serve as a supplement to the solar energy in periods of low solar insolation. Troeger (1980) has concluded that a solar peanut drying system that would provide at least 50% of the energy required to dry wagon lots of peanuts (4.72 Mg) from 20 to 10% moisture content (w.b.) on a 3-day schedule during the harvest season at Tifton, GA, would require a collector area of 156 m^2 with a rock storage volume of 56 m^3. The use of solar energy systems for peanut curing has been shown to be technically feasible, but economic feasibility will depend on initial and operating costs of the additional equipment required as well as the potential for other uses of the solar collecting equipment when peanut drying is not taking place.

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