# CURING SPANISH PEANUT PODS WITH DIURNAL CYCLING OF HIGH TEMPERATURE FORCED AIR

By

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# TEMPERATURE FORCED AIR

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# CHAPTER I

# BACKGROUND

## Introduction

After harvesting and before storage of peanut pods, moisture content must be reduced to approximately 10%. Storage at higher moisture contents provide an environment favorable to mold growth and insect attack. The most common method of reducing moisture content is to add supplemental heat to peanuts placed in deep bed dryers. Currently a major portion of the peanuts dried in the southwest are dried at commercial installations. Due to heavy demands placed on commercial dryers during peak harvest periods, maximum recommended drying temperature is often exceeded and a decrease in peanut quality results. The maximum constant drying temperature is generally accepted as 35 °C.

As a result of these quality losses, an increase has been noted in return to bag drying and in smaller on-the-farm drying installations. Under favorable weather conditions, bag drying is a good method of drying. The main concerns with bag drying are uncontrollable weather conditions, time required to dry, and high labor requirements. During unfavorable weather conditions, peanut pods may not dry below 20% moisture content. As previously mentioned, if peanuts are left at moisture contents above approximately 10% for sustained time periods, insect and mold damage may result.

Researchers from the United States Department of Agriculture Agricultural Research Station at Tifton, Georgia (4, 15) have shown that peanut pods may reach temperatures of 49 °C or higher for three hours or more per day under good weather conditions when field drying without flavor damage and only a slight increase in splits when compared to constant temperature deep bed drying. Their research suggest cycling periodic high and low temperatures may reduce drying time (compared to constant 35 °C drying) without significantly increasing damage.

Because of the current energy crisis, solar drying has recently been proposed as a method to dry peanuts. Use of a solar collector at recommended drying air flow rates in the southwest can easily produce drying temperatures in excess of 35 °C during drying season. Because of high temperatures reached, a laboratory experiment was needed to simulate a solar drying day. Results from these tests would be used to help determine maximum cycle temperature and time combination which would not significantly reduce quality. These results could also be used by commercial dryers to reduce drying time without affecting quality.

## Objectives

The specific objectives of this research were:

1. Determine whether diurnal cyclic drying decreases quality compared to constant 35 °C drying.
2. Determine whether diurnal cyclic drying decreases total drying time as compared to constant 35 °C drying.

## CHAPTER II

## REVIEW OF LITERATURE

### Mechanisms of Peanut Drying

Drying agricultural products is basically a heat and mass transfer process. Heat is applied to the product which causes an increase in the partial pressure of water vapor in the product. If the partial pressure of water vapor in the product is greater than the water vapor pressure in drying air, then a gradient exists and drying occurs. If the partial pressure of water vapor in the product is less than water vapor pressure in the drying air, then the direction of mass transfer is reversed and the product gains moisture. When the partial pressure of water vapor in the product and water vapor pressure in drying air are equal, no mass transfer occurs and the product is considered to be at its equilibrium moisture content.

Drying can be divided into two classes: constant-rate drying period and falling-rate drying period (7). In constant-rate drying period, the product contains so much water that liquid surfaces exist. When liquid surfaces exist, drying is comparable to the drying of water from a free surface. Wet sand, soil, and washed seed are examples of materials that initially dry at a constant rate (7).

Nearly all agricultural drying falls in the falling-rate period. Some products, such as washed seed, may initially dry at a constant rate, but compared to the total drying process this portion is negligible. In falling-rate drying period, moisture is initially transferred from within the product to the surface. After moisture has been transferred to the surface, the moisture is removed from the surface. This process is continued until the equilibrium moisture content is reached or until the material is removed from the drying environment.

Peanuts can be dried in either thin layers or deep beds. In thin layer drying, peanuts are placed in beds at depths two to three layers deep and heated air is then passed through the peanuts. In this method there are no drying zones and all peanuts are being dried at the same time.

In deep bed drying, peanuts are placed in beds of depths greater than 1 meter. Drying of peanuts in deep beds takes place in stages. Drying zones or fronts develop and move through the bed. A drying zone starts at the bottom of the bed and progresses upward through the peanuts as drying continues. However, if the air flow rate becomes large the complete bed may become the drying zone and then the drying process is similar to thin layer drying.

## Previous Research in Peanut Drying and Shelling

Previous research in peanut drying has been directed at improving drying procedures in order to increase peanut drying rate and quality. Some early work in peanut drying was conducted by Myers and Rogers (10). Myers and Rogers dried peanut pods in depths up to 1.2 meters (4 ft) and quantities up to 182 kilograms. Temperature effects were studied at 35 °C, 38 °C, 41 °C, 43 °C, 46 °C, 49 °C, 52 °C, 54 °C, 57 °C, and 60 °C. Air flow rate was held a constant 12.2 cubic meters per minute per square meter (40 cfm/ft$^2$) of drying area throughout the tests. After analyzing their data, Myers and Rogers concluded that drying temperatures should not exceed 46 °C. Since their research effort, other researchers have revised the maximum constant temperature to 35 °C.

In 1948, researchers at Texas A & M (8) dried peanut pods at temperatures ranging from 47 °C to 60 °C. A burner using butane and propane as fuels was used to heat the drying air. Their temperatures were not held constant due to varying gas pressure, but the range of temperature for each test was recorded. They concluded that the temperature of the air in the peanut pods can be as high as 54 °C for one hour without detrimental effects on germination. They did not study the effects of these temperatures on milling quality.

In 1949 Beattie (2) studied factors which affect splitting, breaking, and skinning of peanuts during shelling. Beattie determined that as the moisture content decreased the damage due to shelling increased. For final moisture contents between 7 and 13.5%, damage was approximately halved for each 3% increase in moisture content. Beattie also noticed a tendency for more damage at higher drying temperatures and faster drying rates.

McIntosh and others (9) investigated the effect of drying air temperature on splits and shelling efficiency based on weight of the peanuts shelled on the first pass. After harvesting and drying, peanut pods were stored in walk-in coolers at temperatures of 2 °C, 7 °C, 13 °C, and 18 °C. Each lot was stored in appropriate containers to prevent any change in final moisture content. When shelling was started, each lot was shelled at the same temperature ± (1.0 °C) that it was stored. It was determined that between 2 °C and 18 °C milling damage increased as peanut temperature decreased. However, for this same range of temperature shelling efficiency increased as peanut temperature decreased. For Spanish peanuts there was 1.8% difference between peanuts shelled at 18 °C and 2 °C. Shelling efficiency changed about 4.9% for this same temperature range. From these results McIntosh concluded that a compromise between splits and shelling efficiency was needed.

Tests performed by Person and Sorenson (11) at Texas A & M concluded that peanut pods dried quicker in inverted windrows than in conventional windrows. Their research also showed that peanut pods in conventional windrows which were exposed to direct sunlight and in contact with the ground reach temperatures of 54 °C during the day. Ambient temperature at this level was 36 °C. In inverted windrows the maximum temperature reached was 48 °C. This was obtained by those peanut pods exposed to direct sunlight. As can be seen from the above results, temperatures may exceed recommended maximums while field drying.

Butler, Pearman, and Williams (4) studied windrow configuration effects on peanuts. Their investigation included inverted and non-inverted or random windrows. A standard commercial digger-shaker was used for random windrows while an experimental chain-type inverter was used to create inverted windrows and keep the pods off of the ground. Thermocouples were used to measure temperature at various places in the windrows. These various places were the ambient air, the pods in contact with the ground, the pods shaded by the vine mass, but off of the ground, and the pods exposed to direct sunlight and off of the ground. Temperatures were recorded every 30 minutes during the day and every hour at night. Immediately after digging and each morning thereafter samples were taken from exposed, shaded, and exposed in contact with the ground pods.

It was determined that the widest range in temperature occurred in random windrows. Maximum temperature recorded was 54 °C and was measured from pods in contact with the ground. Pods exposed to the sun and off of the ground (inverted) reached 49 °C. Those shaded within the vines, but off of the ground, reached approximately 44 °C. The above values are all extremes; however, temperatures of 43 °C and 41 °C were commonly measured in the inverted and shaded peanuts, respectively. Also, kernel temperatures greater than 49 °C were not uncommon for peanuts exposed to the sun and in contact with the ground.

Person and Sorenson (12) studied the effects of air flow rate on drying time and fuel consumption. Their investigation concluded that increasing the air flow rate up to a point resulted in shorter drying times. Fuel consumption also increased as air flow rate increased. It was concluded that flow rates greater than 0.39 cubic meters per second per square meter (76 cfm/ft$^2$) had small and diminishing effects on the drying rate.

## Multiphase or Cyclic Drying

Beasley and Dickens (1) used a two-phased approach in their study of multiphase drying. The first phase was dried rapidly in order to help control or prevent mold and rot. Their second phase was dried at a slower rate in an effort to preserve milling quality and flavor.

Each test was performed by taking approximately 68 kilograms of peanuts and placing them 1.2 to 1.6 centimeters deep in a dryer. Temperature was held at 35 °C and the relative humidity lowered to 15%. Every two hours 2 kilograms were removed from the rapid drying environment, moisture content recorded, and placed in a slow drying environment at 21 °C and 60 to 70% relative humidity. After reaching approximately 10% moisture content, three 0.5 kilogram subsamples were taken from each sample and shelled. It was concluded that rapidly drying to 13 to 15% moisture content had very little effect on quality. Drying beyond this point increases milling damage; therefore, two-phase drying is feasible from a milling quality standpoint.

In 1967, Farouk (6) investigated a method of cyclic drying by alternately heating, tempering, and aerating peanuts. Farouk used two methods to accomplish his drying cycle. In one method, peanuts were heated, aerated and then tempered. For the other method, the peanuts were heated, tempered and then aerated. His investigations showed that at 49 °C the heating-tempering-aerating sequence produced faster drying rates than the heating-aerating-tempering sequence. At 38 °C there was negligible difference between drying rates. It was also shown that the heating-tempering-aerating sequence was more detrimental to germination at 49 °C while at 38 °C it was negligible. The milling test results also showed greater damage for the heating-tempering-aerating sequence. The most economical results were obtained by using the heating-aerating-tempering sequence and keeping the aerating period less than six hours per cycle.

Troeger and Butler (15) studied periodic high temperature drying of peanut pods during the 1966 to 1969 seasons. Troeger and Butler used a high temperature drying cycle and a low temperature drying cycle. The high cycle was defined as standard drying to 20% moisture content then continuous high heat. The low cycle is defined as continuous high heat until 20% moisture content is reached and then standard drying. 49 °C was the high temperature and standard drying was heat added whenever the relative humidity exceeded 65%, but maximum temperature held to 35 °C. The peanuts were dried in boxes with 0.093 square meters (1 $ft^2$) of floor area and 0.3 meters deep (1 ft). Air flow was 1.4 cubic meters per minute (50 cfm) for all tests. Wet and dry bulb measurements were recorded at one-half hour intervals and periodic weight recordings were made to determine the moisture content. After drying was completed, shelling and flavor tests were conducted.

By periodically cycling the drying air temperature the following drying times were observed. Standard drying required 77 hours to dry to final moisture content while continuous drying at 49 °C required 23 hours. The low cycle drying method required 61 hours to dry to final moisture content with 15 of these hours being at 49 °C. The high cycle required 50 hours to dry with 19 hours at 49 °C.

# CHAPTER III

## EXPERIMENTAL EQUIPMENT

A view of the drying equipment is shown in Figure 1. The equipment consists of an Aminco environment chamber, drying containers, platform scales, humidifier, supplemental air heater, temperature and humidity monitoring devices, and data recorders.

### Environment Chamber

The Aminco environment chamber is depicted in Figure 2. This environment chamber controls the conditioning of the drying air. Different air temperatures and humidities are obtained by controlling water temperature and dry bulb temperature. As shown in Figure 3 the water chamber temperature is controlled by heating and cooling coils along the bottom of the chamber. The nozzles spray a fine mist into the air bringing it to its desired dew point temperature and then passes over or around the air heating coils bringing it to its desired dry bulb temperature. Air leaves at the desired humidity and drying temperature through an insulated flexible duct at a rated 4.3 cubic meters per minute (150 cfm). This air passes through the peanut dryers and is then returned to the environment chamber and recycled.

### Dryers

The drying bins, see Figure 4, are constructed of steel drums and

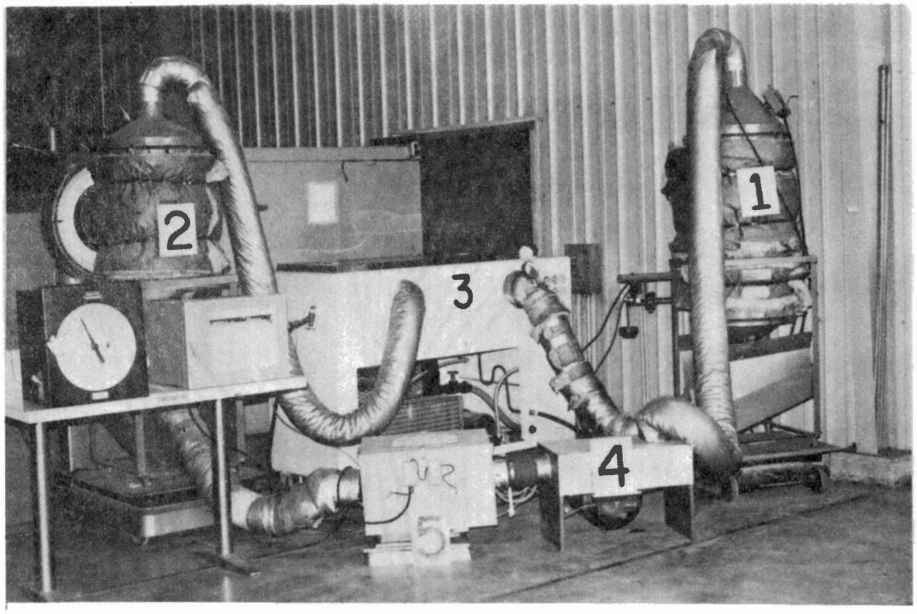

Figure 1. Drying Equipment. Numbers 1 and 2 - Dryers, Number 3 - Environment Chamber, Number 4 - Humidifier, Number 5 - Supplemental Air Heater, Recorders - Left Side of Figure Below Number 2.

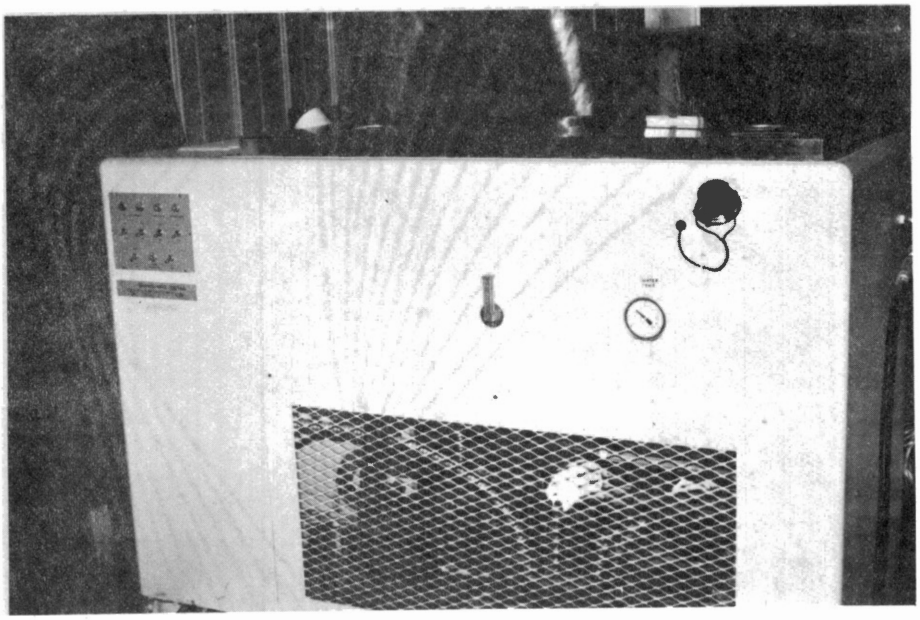

Figure 2. Aminco Environment Chamber. Control Panel at Left End, Water Temperature Dial Indicator with Set Point at Right.

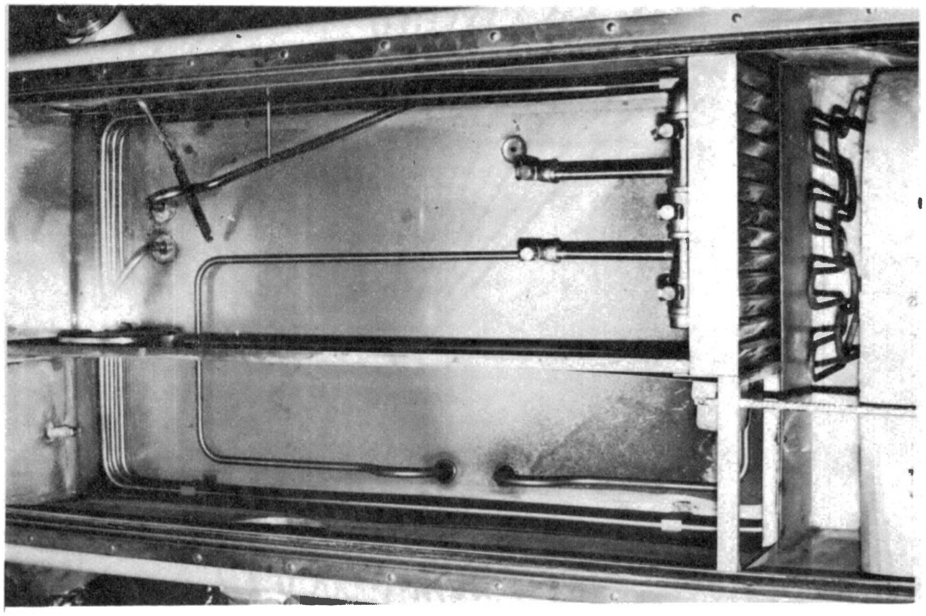

Figure 3. Environment Control Chamber. Air Heating Coils on the Left. Water Temperature Control Coils at the Bottom of the Water Tank and to the Right.

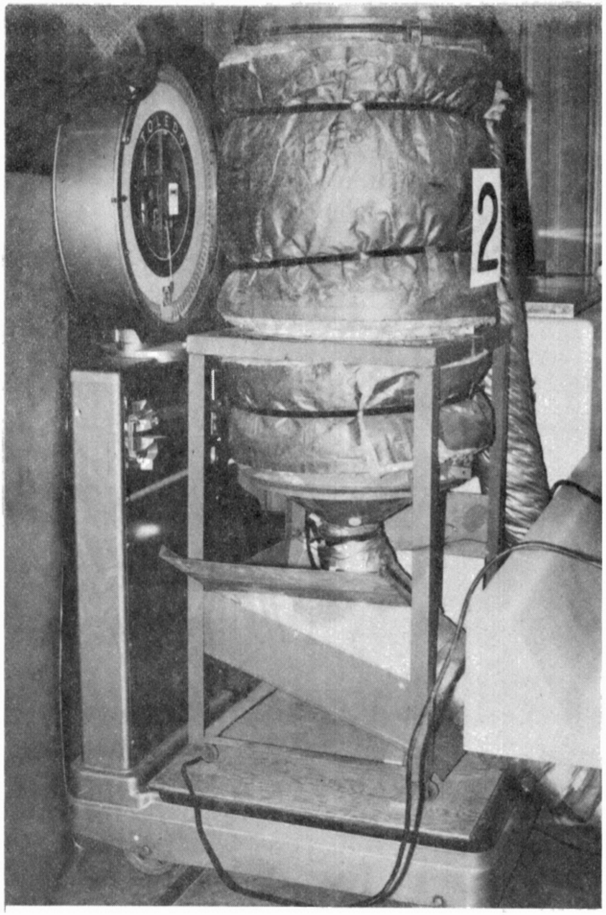

Figure 4. Dryer Located on Platform Scales.

hold from 45 to 55 kilograms of wet peanuts. The dryers were insulated with fiberglas insulation to minimize heat loss. Air enters the dryers at the bottom and exits at the top. Both the top and bottom are removable for ease of loading and unloading. The dryers are placed on platform scales so that periodic weight measurements can be taken. Data can be taken such that it is possible to determine the moisture content at various times during drying.

## Humidifier

The humidifier and supplemental air heater are shown as items 4 and 5, respectively, in Figure 1. The humidifier is used to resupply moisture to the exhausting air before it is reheated by the supplemental air heater. This reheated air is then used to dry a second container of peanuts (item 2) before the air re-enters the environment chamber.

## Temperature and Dew Point Monitors

Nickel-resistance temperature probes and dew point probes were used to monitor the condition of the air both entering and exiting the dryers. Figure 5 shows a temperature probe and dew point probe attached to a dryer. Both monitoring devices were checked for calibration by placing them in an environment controlled container, see Figure 6, under various conditions and comparing the known conditions against the instrument readings.

The dry bulb and dew point temperature were continuously recorded by a Honeywell multipoint recorder and circular temperature recorder, respectively. The recorders are shown in the left side of Figure 1.

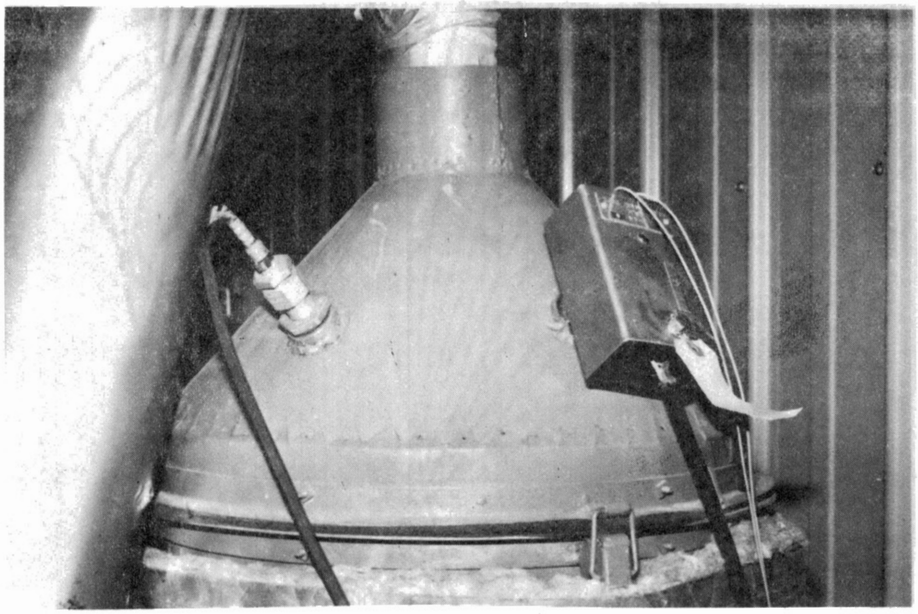

Figure 5. A Nickel-resistance Temperature Probe at the Left End and a Dew Point Probe on the Right.

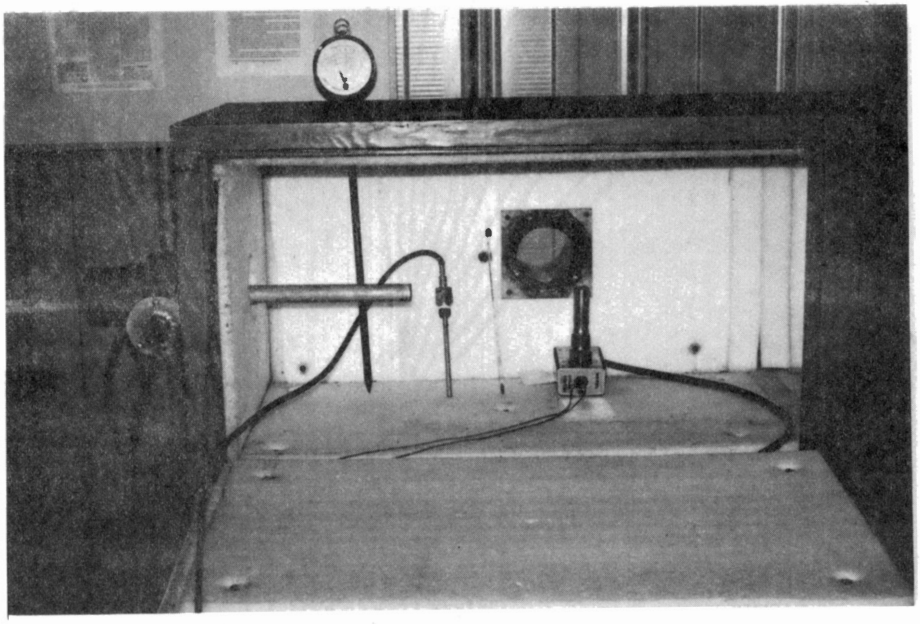

Figure 6. Environmental Controlled Calibration Container with Grain Probe, Nickel-Resistance Temperature Probe, and Dew Point Probe.

## Oven

All initial and final moisture contents were determined by the oven dried method. Sample sizes averaged approximately 175 grams. Temperature of the oven was 130 °C and the pods were left in the oven for approximately 12 hours.

## Sizer and Sheller

Upon completion of the tests, pods were removed from storage and milling tests were performed. A pre-sizer of the type shown in Figures 7a and 7b were used to size the peanut pods. The pre-sizer divides the pods into three size groups. The sheller shown in Figure 8 has three different sizes of shelling screens with each screen corresponding to one of the three pre-sized groups. The peanuts were sized and then placed in the appropriate shelling compartment. After shelling, United States Department of Agriculture grade factors were determined.

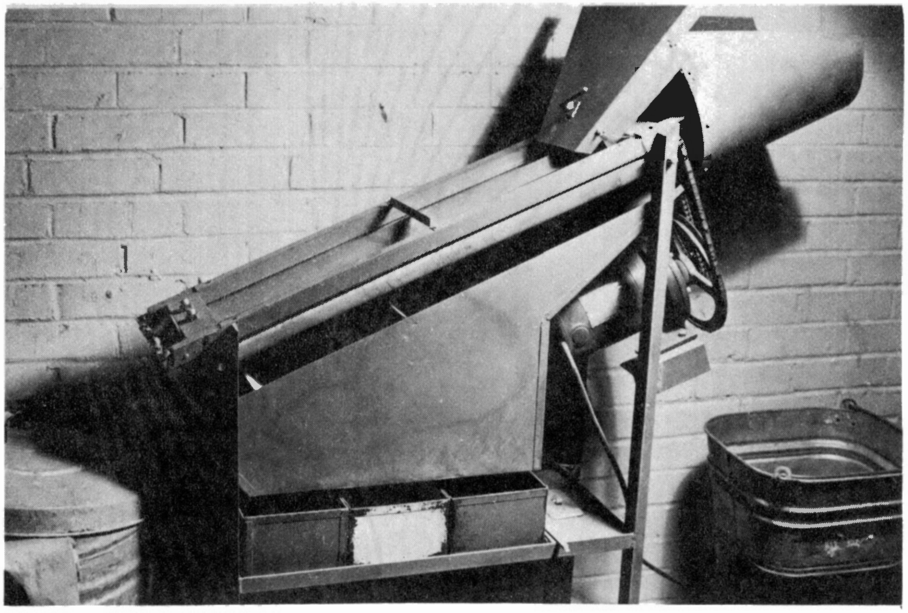

Figure 7a. Peanut Pre-Sizer, Side View.

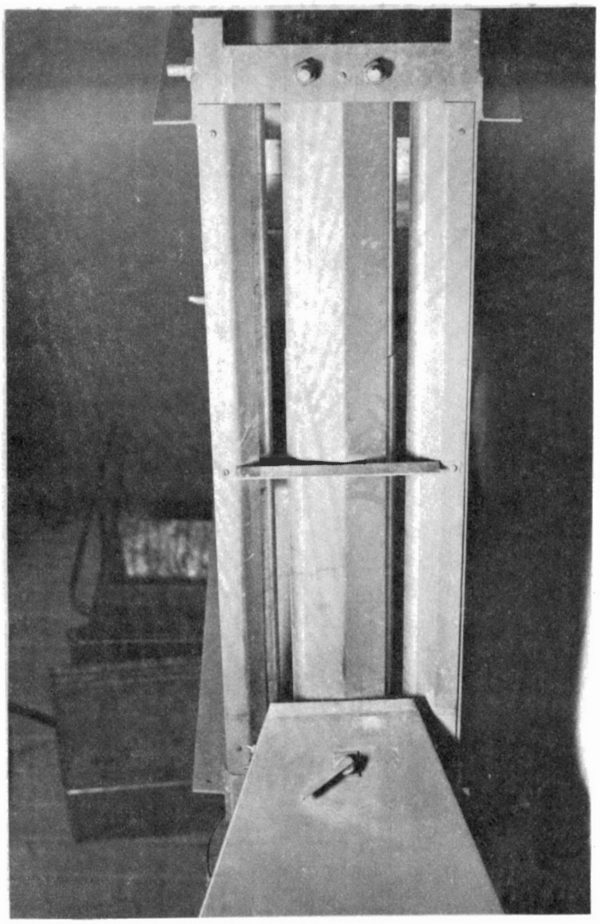

Figure 7b. Peanut Pre-sizer, Top View.

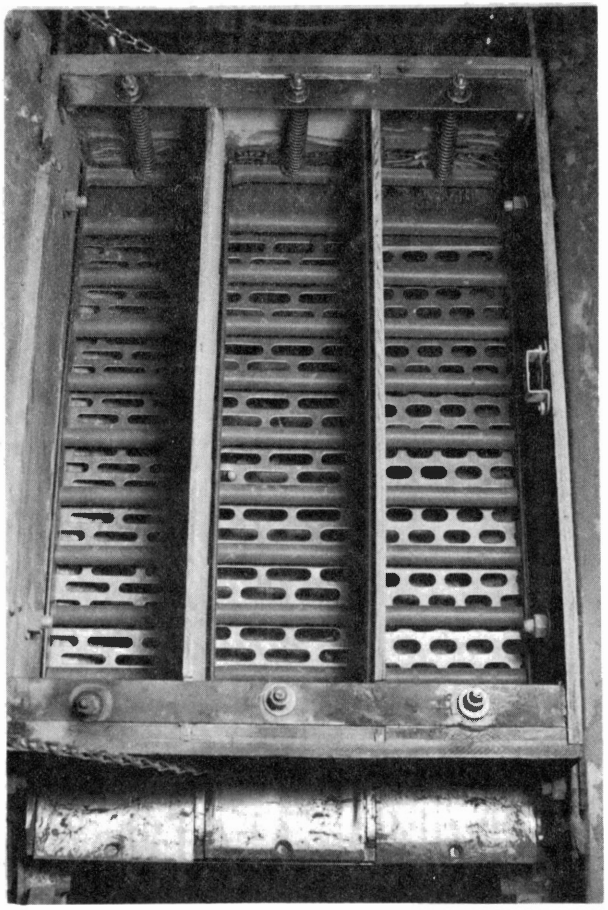

Figure 8. Peanut Sheller.

# CHAPTER IV

# METHODS AND PROCEDURE

## Experimental Design

Since temperature settings on the Aminco environment unit had to be made manually, a limited number of adjustments were made to simulate a solar drying day. A medium temperature rise occurring twice a day (treatment DM), a medium temperature rise occurring once a day, but for a longer period (treatment ML), and a high temperature rise occurring once a day for a short time (treatment HS) were the three treatments designed for use in this study. The three treatments are shown in Figure 9.

For all treatments, the environment chamber controlled temperature ranged between 35 and 57 °C. The combination of temperature greater than 35 °C and the time held above 35 °C (defined as the degree-hours) was the same for all tests. This was done in an effort to determine whether or not the manner in which the degree hours was obtained had any significant effect on peanut milling quality. 35 °C was used as a baseline, because previous research has shown this to be the maximum recommended constant drying temperature.

The initial relative humidity was 37% and decreased as the temperature increased in an attempt to simulate a drying day. The moisture content was measured throughout the test by weighing the drying samples

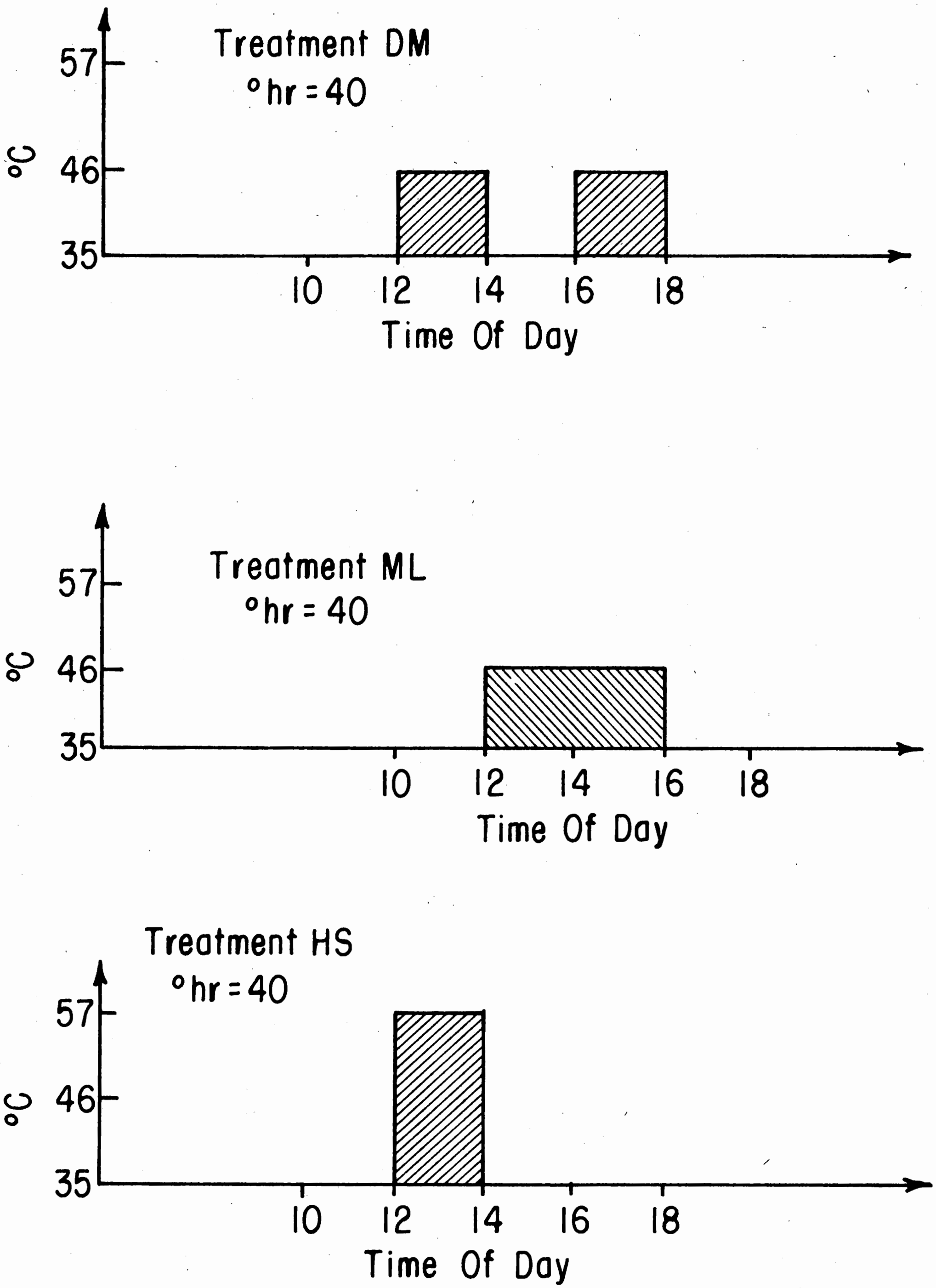

Figure 9. Experimental Design.

at regular intervals. The time required to dry the peanut pods was recorded and used to help compare different drying cycles. Throughout the test flow rate was a constant 14 cubic meters per minute per square meter (46 cfm/ft$^2$) and Spanish peanuts were the only variety tested. All peanuts for this study were obtained from the Oklahoma State University Agricultural Research Station at Stratford, Oklahoma, and the C. J. Collum farm near Perkins, Oklahoma.

## Drying Procedure

The following procedure was used to obtain the required drying data for each run:

1. Set environmental chamber to the predetermined temperature and humidity settings.
2. Take moisture samples of freshly dug peanuts.
3. Place peanuts in the drying containers.
4. Record weight of the peanuts placed in the dryers.
5. Change environmental conditions at the specified time intervals.
6. Make periodic weight measurements to determine the average moisture content.
7. Dry the peanuts until the moisture content is approximately 10% wet basis.
8. Remove the dried peanuts and take samples needed for milling tests.
9. Dry a sample to use as a base of comparison in quality analysis.

## Storage

Each sample was placed in a cloth bag, had two plastic bags around the cloth bag, and placed in a stainless steel container. The containers were then stored in a walk-in cooler at 4 °C. Under these conditions, further moisture loss is prevented.

## Shelling

After all drying tests were completed, milling tests were conducted to determine different treatment effects. A standard grading procedure was developed and is shown in Appendix A.

# CHAPTER V

# PRESENTATION OF ANALYSIS OF DATA

## Quality Analysis

As the drying season progressed, difficulty was encountered in controlling the drying temperature in dryer number two. One reason for this was a poorly designed supplemental heater (item 5, Figure 1). The heater box was not well insulated and whenever the room temperature changed the dryer temperature would also change. The dryer was used to dry excess peanut pods and prevent mold damage, but due to the uncontrollable drying temperature, the data obtained was not used.

Before comparison of treatments, an adjustment for grade changes was made. As can be seen in Figure 10, percent splits are affected by United States Department of Agriculture grade (defined as percent sound splits + percent sound mature kernels). The example in Appendix B shows how not correcting for grade could result in a 17% error, when grade ranged from 60 to 70%, in determining percent sound splits. To compensate for error due to grade changes, the splits were weighed by grade. The new variable to be used in place of splits was defined as SSR = (percent sound splits/grade) X 100.

It is known that final moisture content has a large influence on percentage splits; therefore, the data was placed in one data set and a least squares regression analysis was used to determine the

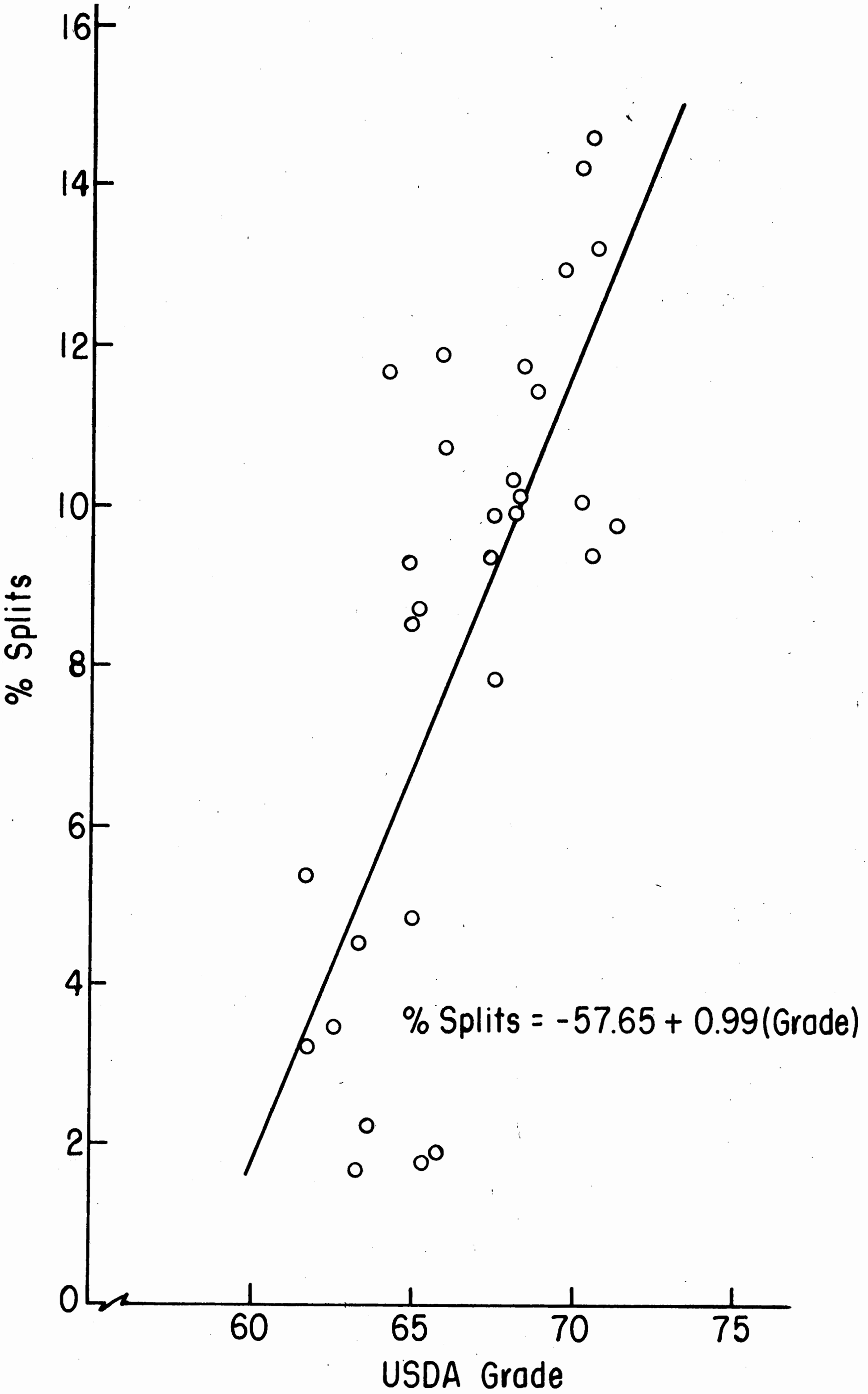

Figure 10. Effect of Grade on Percent Splits.

relationship between final moisture content and percent splits. The student "t" test was used to test significance of regression coefficients at the 90% confidence level. Transformations were made so that log-log and semi-log regressions could be compared with the standard linear regression. Comparison of standard error, correlation coefficients, and values of the student "t" indicated that the data fit a linear plot as well as the log-log or semi-log. This is because at the range for average final moisture content (6-10%) the drying curves become nearly straight lines. The linear regression model was selected due to its simplicity.

In order to prevent final moisture content from influencing the different treatments, it was desired to dry each treatment to the same final moisture content. However, difficulty was encountered in obtaining exact desired final moisture contents. The testing procedure used resulted in only an estimate of final moisture content; therefore, all peanuts had to be adjusted to the same final moisture content before comparison of percent splits.

To correct for differences in final moisture content, a correction equation was developed that adjusted each data point along an imaginary line parallel to a fitted slope. This procedure, shown in Figure 11, allowed each point to be adjusted to the desired final moisture content and at the same time preserved deviations from the mean.

It was desired to have one general correction equation. In order to do this, it was necessary to run a least squares regression on each treatment and determine whether or not a common slope existed. Equation [1] is the general form of the regression model.

$$SSR = b_0 \, (FMC) + b_1 \qquad [1]$$

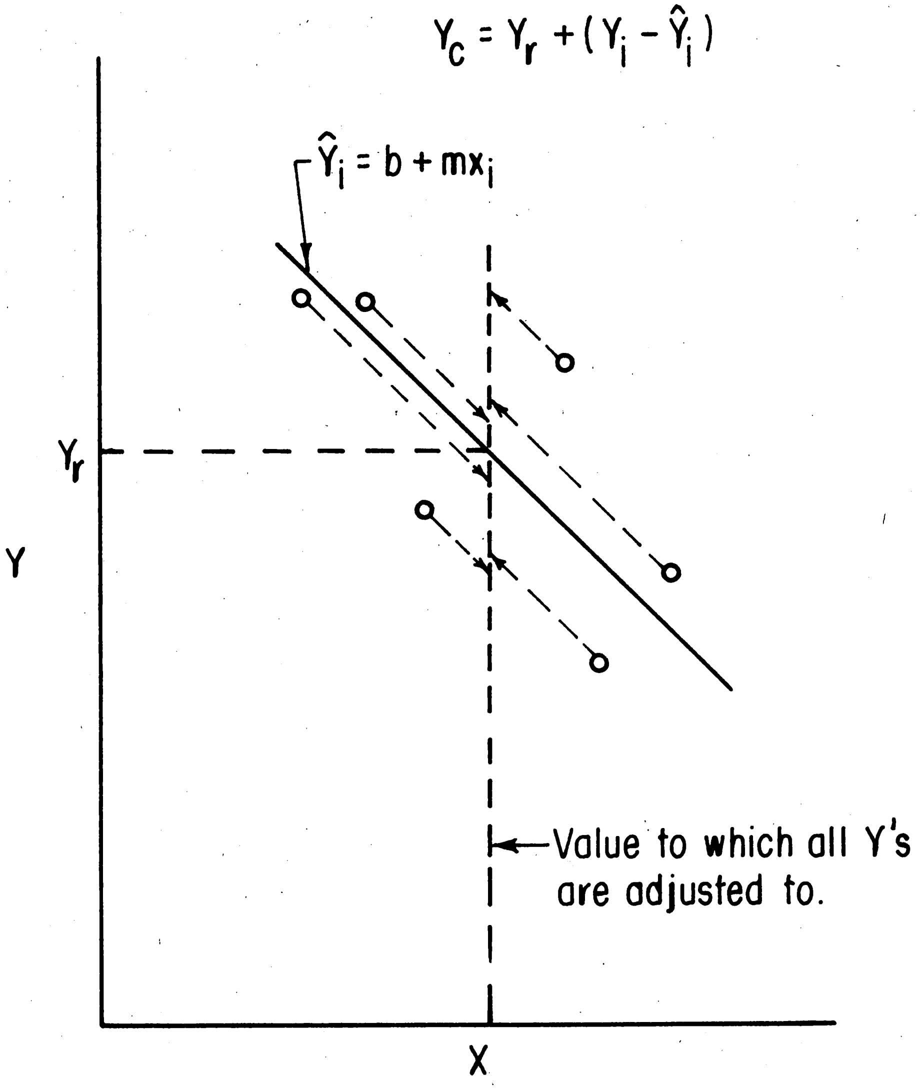

Figure 11. Correction Equation Development. $Y_c$ = Corrected Value of Y, $Y_r$ = Reference Y = Value of Y for a Predetermined Value of x to Which All Data is to be Adjusted, $\hat{Y}$ = Predicted Value of Y, b = Intercept for Y, m = Slope for Y Equation.

where

SSR = (Percent sound splits/grade) X 100

FMC = Final moisture content

$b_0$, $b_1$ = Regression coefficients

Data was placed in subsets, each subset being one treatment. Each treatment was adjusted for time of harvest and final moisture content as described previously. If the student "t" test revealed non-significant regression coefficients, then no adjustment for moisture content was made. Table I shows the regression coefficients that were significant at the 90% confidence level, correlation coefficients, and standard errors for equation [1].

TABLE I

REGRESSION COEFFICIENTS AND STATISTICS OF FIT FOR EQUATION 1

| Treatment | $b_0$ | $b_1$ | $R^2$ | S.E. |
|---|---|---|---|---|
| ML | 32.50 | -2.78 | 0.822 | 3.04 |
| HS | 41.13 | -3.62 | 0.970 | 1.40 |
| Standard | 37.10 | -3.35 | 0.811 | 1.94 |
| All Data Combined | 33.24 | -2.86 | 0.800 | 2.29 |

The correlation coefficient ($R^2$) shown in Table I is defined as the sum of squares due to regression divided by the total sum of squares corrected for mean. It measures the proportion of total variation about the mean explained by regression.

The standard error (SE) term of Table I is defined as

$$SE = \left[\frac{\Sigma(x_i - \overline{x})^2}{n-1}\right]^{1/2} \qquad [2]$$

This is a measure of the variation of each data point about the mean of the data points.

Before a common slope could be determined, a confidence interval for each treatment slope was needed. The confidence intervals were constructed according to the procedure described by Draper and Smith (5). The confidence interval for the regression coefficient $b_1$ (slope) was determined by equation [3].

$$CI = b_1 \pm (t \times SE) \qquad [3]$$

where

CI = Confidence interval for $b_1$

$b_1$ = Regression coefficient (slope)

t = Tabulated value of student "t" at n-2 degrees of freedom

SE = Estimated standard error of $b_1$

Table II lists the confidence intervals of $b_1$ for each treatment and the confidence interval of $b_1$ for the combined data. Figure 12 is a graph of the confidence intervals. As can be seen, the confidence interval of $b_1$ for the combined data includes values contained in the confidence intervals of $b_1$ for each individual treatment. For this

## TABLE II

## CONFIDENCE INTERVALS FOR REGRESSION COEFFICIENT $b_1$

| n | Treatment | $b_1$ | Est. Std. Error of $b_1$ | t 0.1 Level | C. I. 90% |
|---|---|---|---|---|---|
| 39 | All Data | -2.86 | 0.235 | 1.685 | -2.46<br>-3.26 |
| 6* | DM | -0.63 | 1.180 | 2.132 | 1.89<br>-3.15 |
| 9 | ML | -2.78 | 0.490 | 1.895 | -1.85<br>-3.71 |
| 6 | HS | -3.62 | 0.320 | 2.132 | -2.94<br>-4.30 |
| 18 | Standard | -3.35 | 0.235 | 1.685 | -2.46<br>-3.26 |

* Treatment DM 1 regression coefficient was non-significant at the 0.1 level.

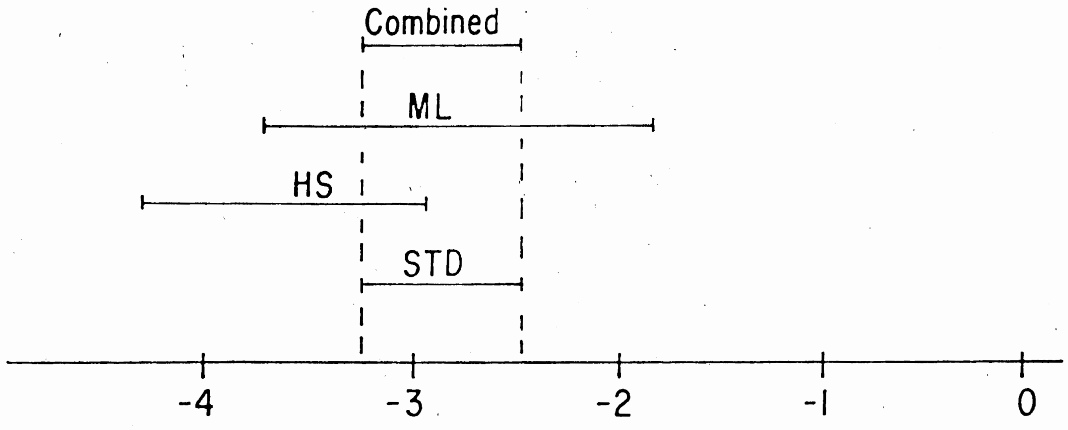

Figure 12. Confidence Intervals.

reason, the equation resulting from the combined data was used to develop a single general correction equation. Equation [4] is the general correction equation that was developed to correct the final moisture content of each treatment of 9% wet basis and to correct for grade. 9% was arbitrarily selected because it is in the range of safe storage moisture contents.

$$SSAJ = 7.52 + [SSR - (33.24 - 2.86\ (FMC))] \qquad [4]$$

where

SSAJ = Percent sound splits adjusted for grade and moisture content
SSR = Split ratio = (splits/grade) X 100
FMC = Percent final moisture content

Table III shows the actual average final moisture content of each treatment, the standard deviation of the average final moisture content, the average percent splits after adjusted by equation [4] for each treatment, and the standard deviation of the adjusted splits. Figure 13 is a bar graph showing the results from Table III.

Two methods were used to test for statistically significant differences between treatments shown in Figure 13. Initially, the difference between treatment means with unknown and unequal population variances was used to determine any significant difference. The procedure used is described in detail by chapter 7 of Remington and Schork (13).

Table IV gives the results of the difference between means analysis. To interpret Table IV, the absolute value of the calculated "t"

## TABLE III

## COMPARISON OF AVERAGE FINAL MOISTURE CONTENT, AVERAGE ADJUSTED PERCENT SPLITS ADJUSTED TO 9% MOISTURE CONTENT, AND THEIR RESPECTIVE STANDARD DEVIATIONS

| Treatment | Avg. Final M. C. | S. D. Final M. C. | Avg. % Splits Adjusted | S. D. % Splits Adjusted |
|---|---|---|---|---|
| DM | 6.23 | 0.45 | 5.73 | 1.45 |
| ML | 7.51 | 2.20 | 7.35 | 2.85 |
| HS | 8.30 | 1.96 | 9.05 | 1.96 |
| STANDARD | 6.88 | 1.06 | 7.69 | 1.97 |

## TABLE IV

## TEST OF SIGNIFICANT DIFFERENCE BETWEEN TREATMENT MEANS

| Compared Treatments | | t-Cal. | t-Tab. (0.1) | Confidence Interval (90%) |
|---|---|---|---|---|
| DM | ML | -1.449 | 1.761 | 0.350<br>-3.600 |
| DM | HS | -3.341 | 1.796 | -1.537<br>-5.111 |
| DM | STANDARD | -2.601 | 1.746 | -0.645<br>-3.277 |
| ML | HS | -1.368 | 1.753 | 1.003<br>-4.401 |
| ML | STANDARD | -0.318 | 1.796 | 1.565<br>-2.237 |
| HS | STANDARD | 1.476 | 1.812 | 3.036<br>-0.310 |

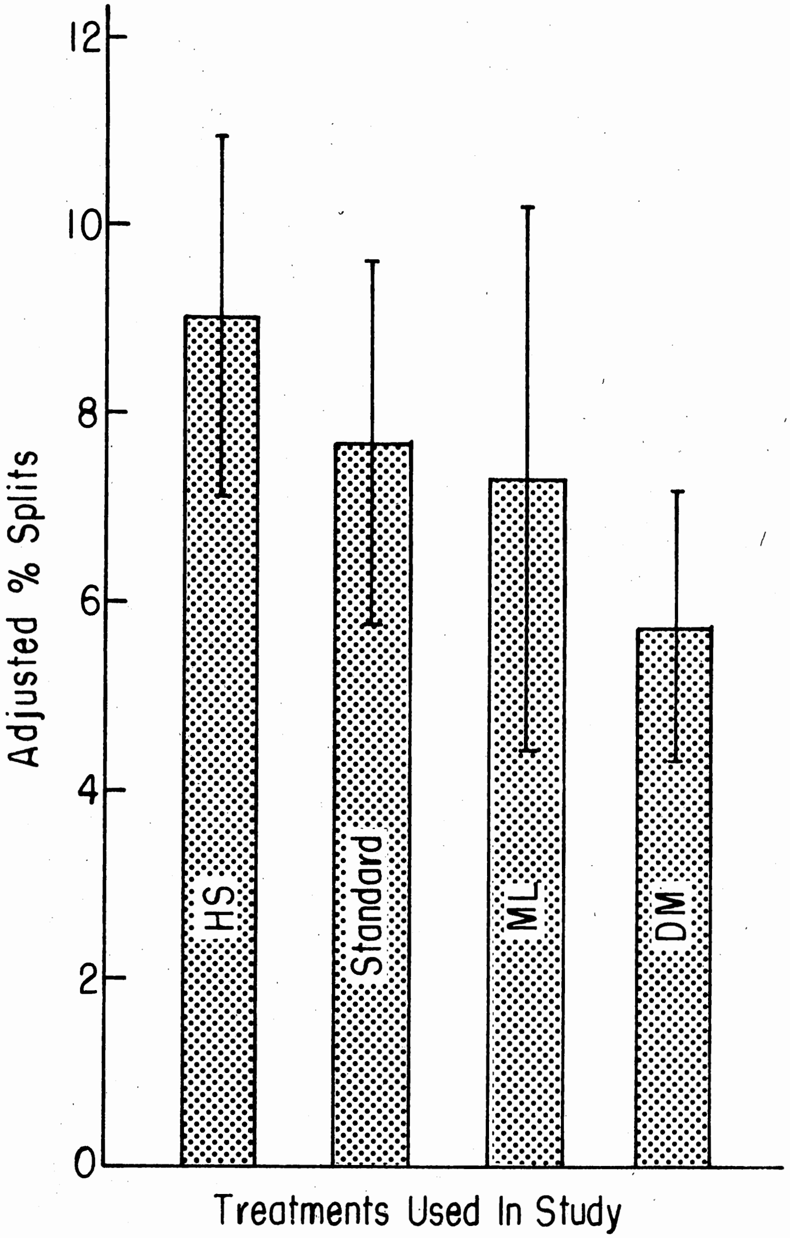

Figure 13. Effect of Treatment on Adjusted Percent Splits and the Standard Deviations. Values for Standard Deviations are Listed in Table III.

and the tabulated value of the student "t" at the desired level of significance are compared. If the absolute value of t-calculated is greater than t-tabulated, then significant difference has been shown at the significance level of t-tabulated. An inspection of the confidence interval is another way of testing the significance. To use the confidence interval an inspection is made to determine whether or not zero is included within the interval. If zero is not included within the interval, then the treatment means have been shown to be significantly different. As can be seen in Table IV, treatments DM and HS have been shown significantly different at the 90% confidence level and treatments DM and standard have been shown significantly different at the 90% confidence level.

The second method used to test for significant difference was the conducting of an analysis of variance (AOV). The Statistical Analysis System (SAS) was used to perform the AOV. Table V is the results of the AOV used to test for significant difference between runs and treatments. By use of an AOV, significant difference between treatments could not be shown. However, significant difference between runs was shown. This shows that the experimental error was greater than the sampling error. As explained in chapter 7 of Steel and Torrie (14), this is not an unexpected result. The experimental error may contain an additional unidentified source of variation causing it to be greater than the sampling error. In this study, the variation due to experimental error was the variation among peanuts treated alike and the variation of peanuts for the different treatments. If the peanuts did not vary from lot to lot, then the order of magnitude of the two variations mean squares should be the same and experimental error would not be expected to be larger than the sampling error. However, peanuts do vary from lot to lot because of different growing conditions, harvesting conditions, and other uncontrollable factors; therefore, as expected, the experimental error is greater than the sampling error.

TABLE V

ANALYSIS OF VARIANCE FOR TEST OF SIGNIFICANT DIFFERENCE BETWEEN RUNS AND TREATMENTS

| Source | DF | Sum of Squares | Mean Square | F | LSD (0.1) |
|---|---|---|---|---|---|
| Run (Treat) | 6 | 110.24 | 18.37 | 13.31* | 4.16 |
| Sampling Error | 20 | 27.61 | 1.38 | | |
| Treatment | 3 | 35.11 | 11.70 | 0.64 | |
| Experimental Error | 6 | 110.24 | 18.37 | | |

* Indicates significance at $\alpha$ = 0.1 level.

Figure 14 graphically depicts the results of the AOV. As can be seen by observing the least significant difference (LSD), significant difference between treatments cannot be shown by this method of analysis. The least significant difference is a statistical method of determining how great the difference between two observed means must be in order to be statistically significant. For example, for

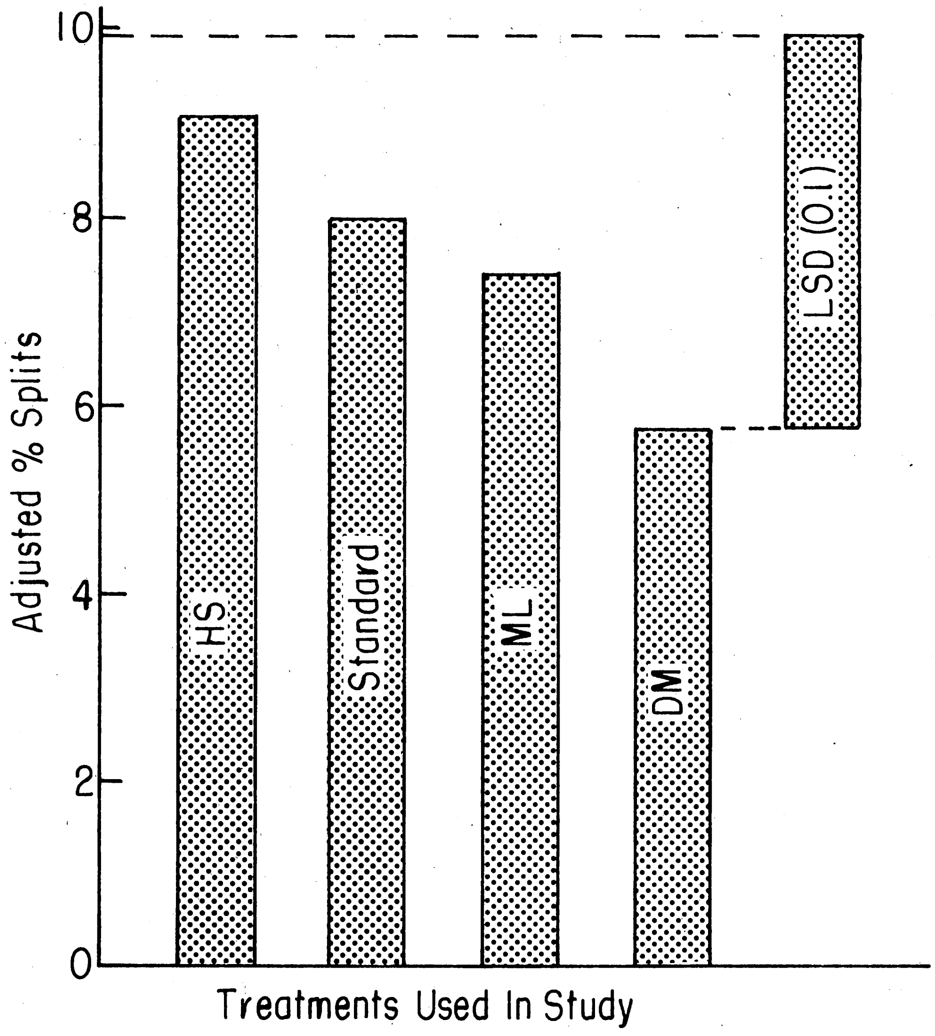

Figure 14. Effect of Treatment on Adjusted Percent Splits, and the Statistically Determined Least Significant Difference. LSD (0.1) = 4.164.

any two treatments to be significantly different, their difference between respective means would be greater than the least significant difference block shown in Figure 14. The LSD would have to be calculated at the 0.17 level before a significant difference could be observed.

The reasons why the two statistical methods used produced different results may be explained as follows. The difference between treatment means with unknown and unequal variances looks at only two treatment means at a time and does not take into account for any interaction among treatments. When the AOV was performed, it was found that variation among replications was such that significant difference between treatments could not be shown at the 90% confidence level. As mentioned previously, variation among replications is largely due to experimental error and peanut population variance and is explained in detail by chapter 7 of Steel and Torrie (14).

## Drying Analysis

Since each lot of peanuts had a different initial moisture content and equivalent final moisture contents were not achieved, a moisture ratio was used in comparing drying times. The moisture ratio is defined by equation [5].

$$MR = \frac{MC - ME}{MI - ME} \qquad [5]$$

where

MR = Moisture ratio

MC = Percent moisture content wet basis at any desired time

ME = Percent equilibrium moisture content wet basis = function (air relative humidity and air temperature)

MI = Percent initial moisture content wet basis.

At the beginning of a drying test, MC is equal to MI and moisture ratio = 1.0. When MC is equal to ME, moisture ratio is zero. Drying time in hours was computed from a moisture ratio of 1.0 down to an arbitrary 0.3.

The equilibrium moisture content used in determining the value of the moisture ratio is explained in detail by several investigators (1, 7) and is defined by equation [6].

$$(1 - rh) = \exp(-KTM^n) \qquad [6]$$

where

rh = Relative humidity expressed as a decimal

exp = Base of natural logarithms

T = Absolute temperature (°R)

M = Equilibrium moisture content percent wet basis

K = Constant

n = Constant

Beasley and Dickens (1) obtained values for K and n for different conditions and their values used in this study were $K = 3.81 \times 10^{-5}$ and $n = 1.85$.

Figures 15 and 16 are plots showing the time required for each treatment to dry peanuts to a desired moisture ratio. Replication 1 is not shown because treatments ML and HS were mistakenly stopped before the moisture ratio reached the desired level.

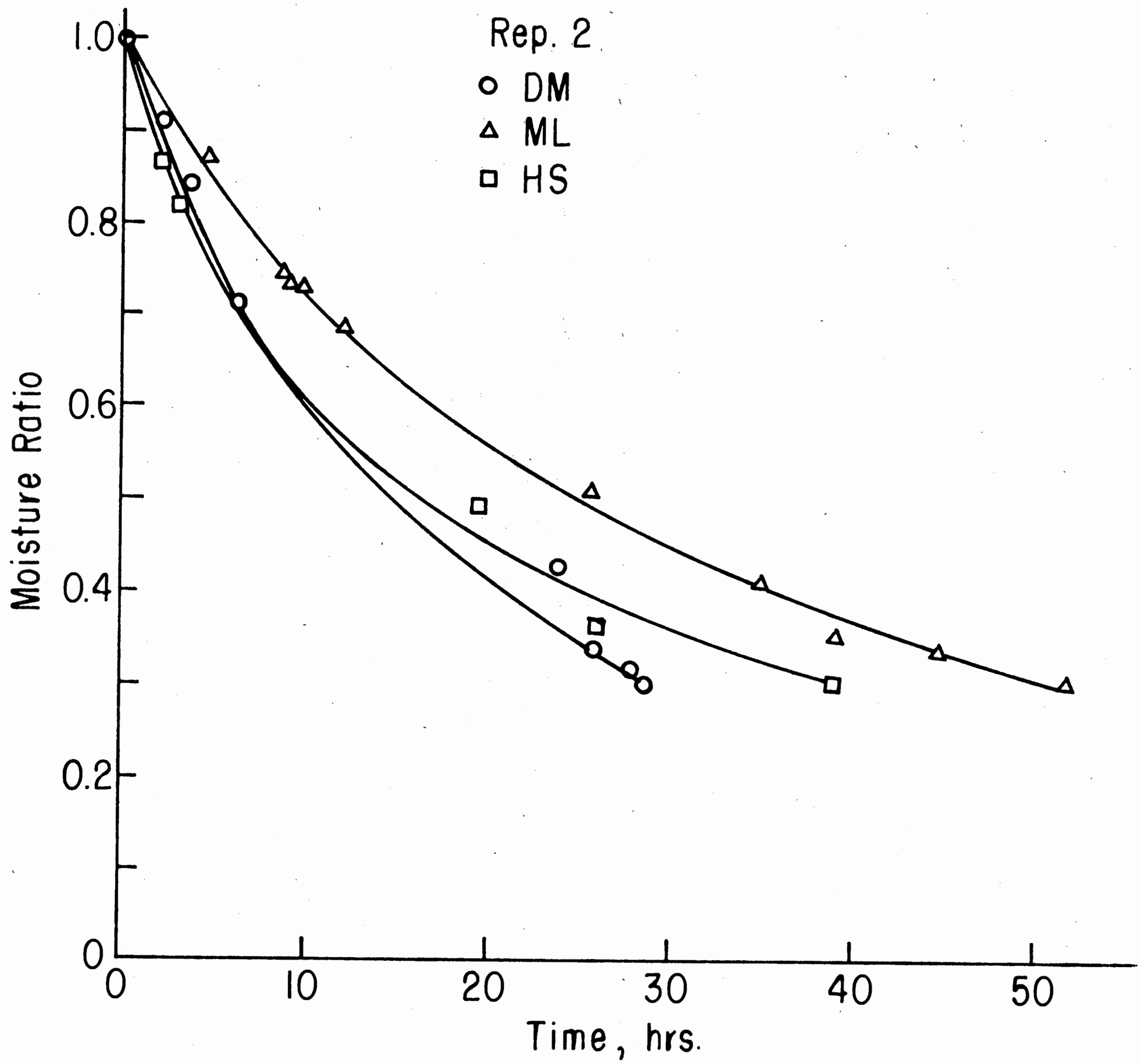

Figure 15. Time Necessary to Dry Replication 2 to a Moisture Ratio of 0.3.

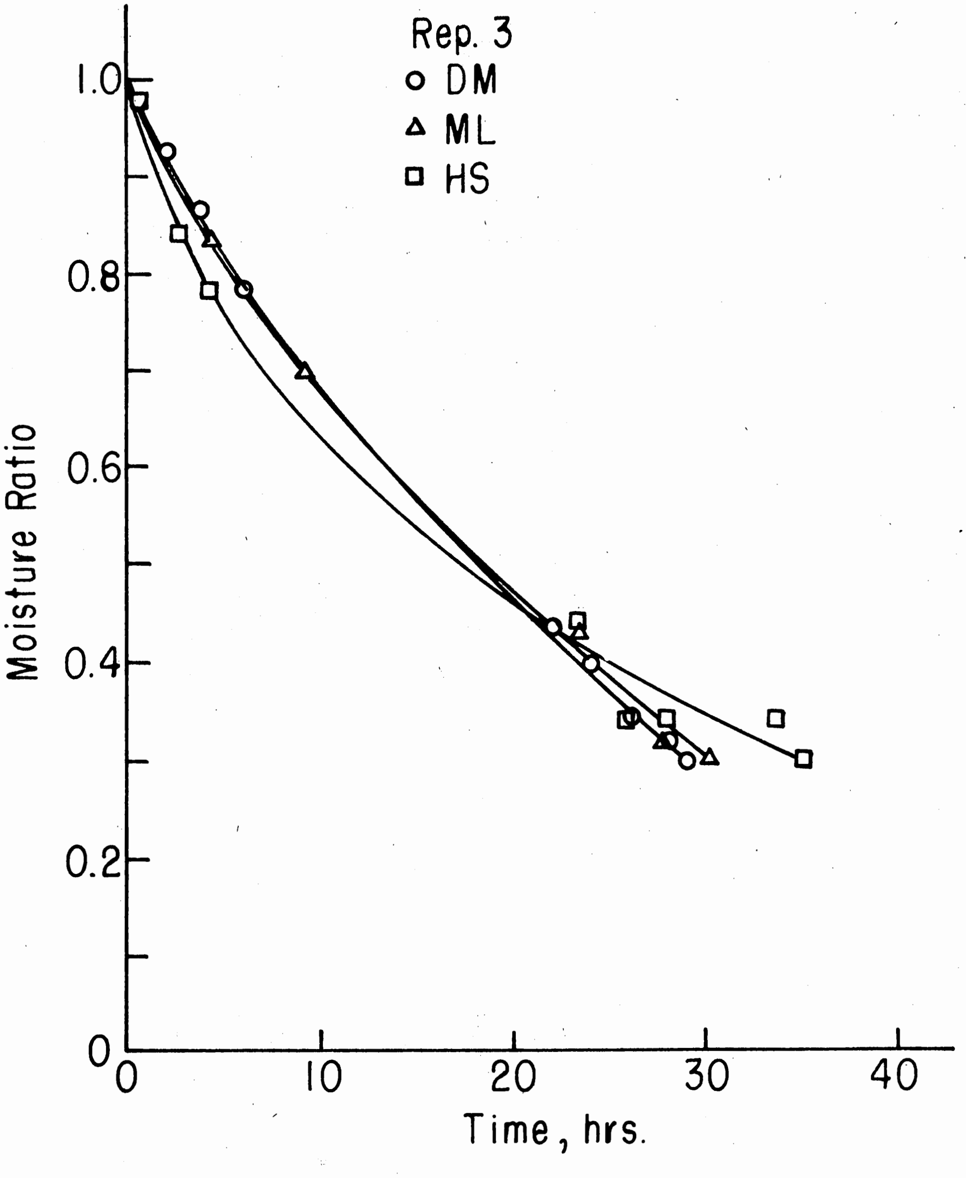

Figure 16. Time Necessary to Dry Replication 3 to a Moisture Ratio of 0.3.

Table VI presents the results of the difference between means statistical test for drying time required to reach a moisture ratio of 0.3. The table is interpreted the same way as Table IV discussed in the quality analysis section. As can be seen, no statistical difference (at the 90% confidence level) can be shown between drying times for any treatments.

TABLE VI

TEST OF SIGNIFICANT DIFFERENCE BETWEEN DRYING TIMES BY DIFFERENCE BETWEEN MEANS ANALYSIS

| Compared Treatments | | t-Cal. | t-Tab. (0.1) | Confidence Interval (90%) |
|---|---|---|---|---|
| DM | ML | -0.620 | 2.132 | 17.98<br>-32.74 |
| DM | HS | -0.687 | 2.243 | 7.99<br>-15.05 |
| ML | HS | 0.346 | 2.353 | 30.05<br>-22.35 |

Table VII is an AOV used to test for significant difference in drying time required to reach a moisture ratio of 0.3. The AOV also shows no statistical difference between drying times at the 90% level. Figure 17 is a bar graph showing the results of the time required to dry each treatment to a moisture ratio of 0.3 and the least significant difference at the 0.1 level.

## TABLE VII

## ANALYSIS OF VARIANCE FOR TEST OF SIGNIFICANT DIFFERENCE BETWEEN DRYING TIMES

| Source | DF | Sum of Squares | Mean Square | F | LSD (0.1) |
|---|---|---|---|---|---|
| Treatment | 2 | 65.68 | 32.84 | *0.346 | 20.77 |
| Residual | 4 | 379.68 | 94.92 | | |

* Indicates non-significance.

One reason for the large standard deviation for treatment ML is the different conditions under which treatment ML was harvested. Treatment ML replication 3 was harvested similar to the other lots and has a very similar drying time. A typical harvest for these tests consisted of digging the peanuts one day, threshing the next, and placing in the dryers the third or fourth day. When treatment ML replication 2 was harvested, a delay was encountered due to weather conditions. After digging, a 0.4-inch rain fell on the freshly dug peanuts. The peanuts were not threshed until the field became dry enough to support the threshing equipment (approximately two days after the rain had ended). The drying time for replication 2 was much longer thereby causing the average and standard deviation to be larger.

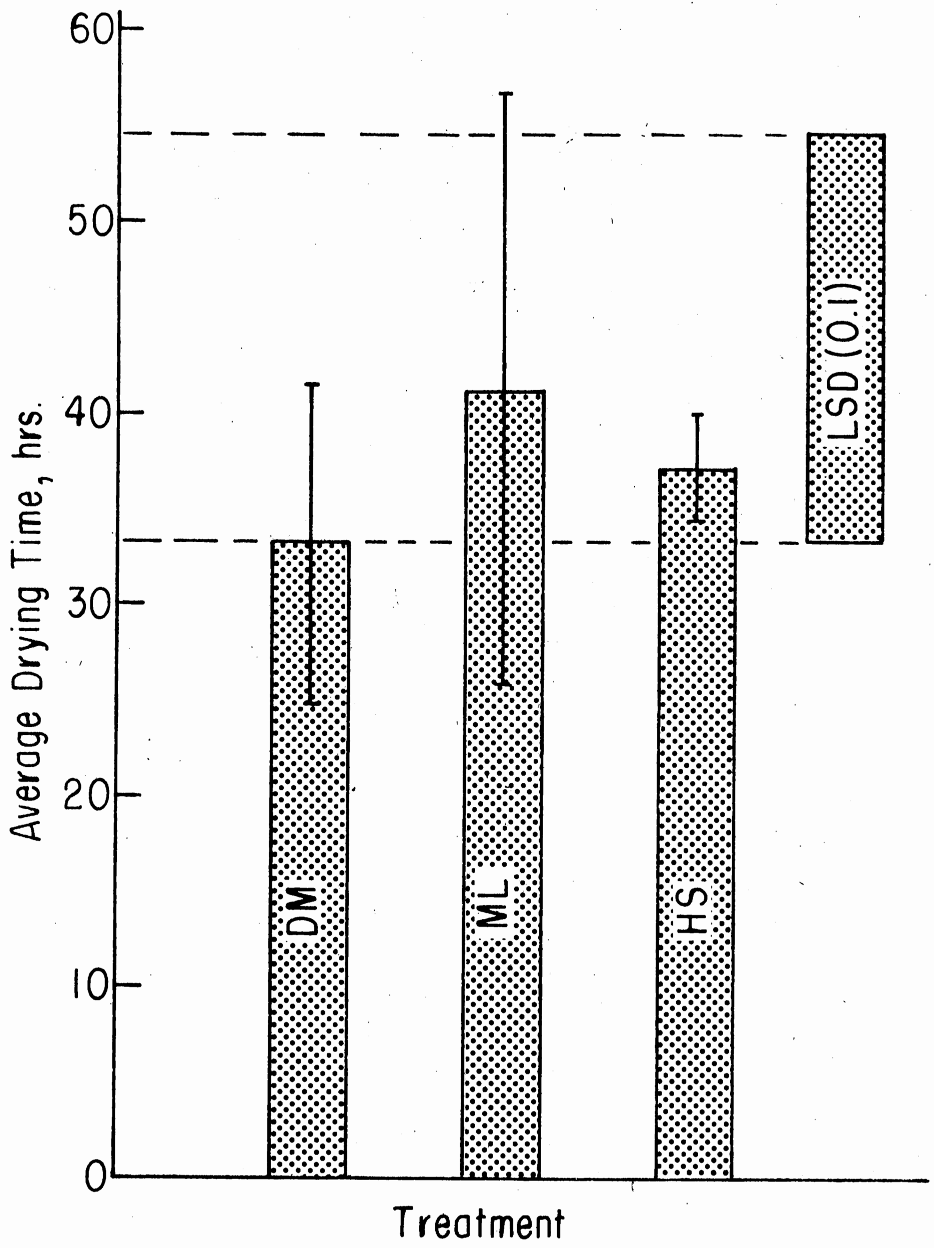

Figure 17. Average Time to Dry From MR of 1.0 to MR of 0.3 and the Standard Deviations, The Standard Deviations are: DM = 8.11, ML = 15.46 and HS = 2.98.

Figures 18 through 31 show the effect of introducing high temperatures for short durations during the drying of Spanish peanut pods. The even numbered figures show how a sudden change in drying temperature causes a change in equilibrium moisture content which in turn causes the sudden shift in moisture ratio. The odd numbered figures show how the drying rate increases whenever the drying temperature is suddenly increased. The net result of this cycling is a decrease in the overall drying time. It took approximately 52 hours to dry a load of Spanish peanuts when drying at a constant 35 °C, as seen previously, in Figure 17. All high temperature cycled treatments averaged shorter drying time.

Table VIII is the results of the difference between means statistical test for drying rate and Table IX is an AOV for the same. Both statistical tests show no significant difference between drying rate at the 90% confidence level.

Figure 32 is a bar graph showing the average drying rate from a moisture ratio of 1.0 to 0.3, standard deviations, and the least significant difference required to statistically show significant difference at the 0.1 level. As noted previously, significant statistical difference between treatment drying rates could not be shown at the 0.1 level.

## Discussion of Results

By using a difference between means statistical test, a significant difference was shown between treatments DM and HS and between treatments DM and standard. When testing for significant difference by using an Analysis of Variance (AOV) no significant difference

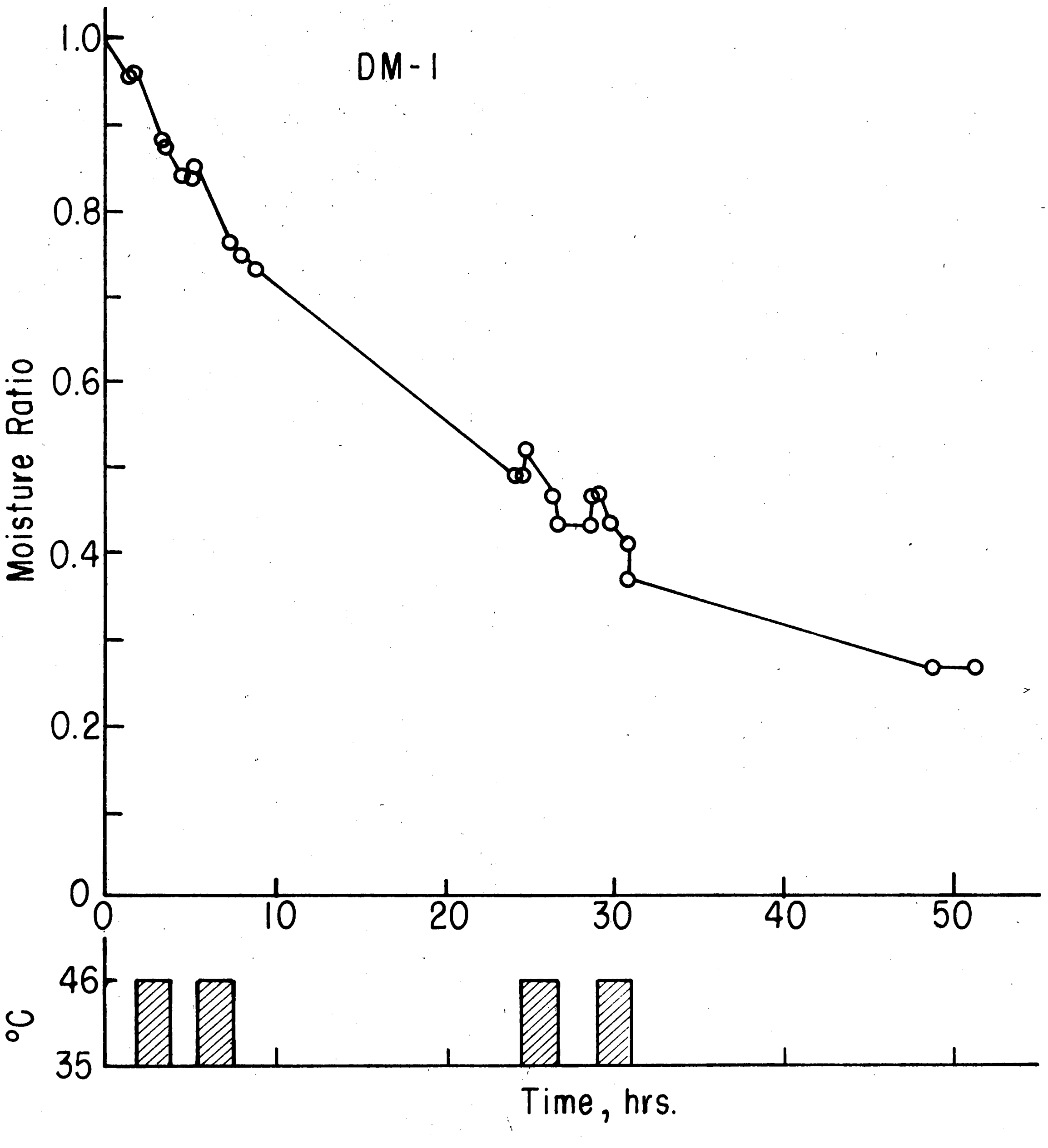

Figure 18. Effect of High Temperature Cycling on Moisture Ratio for Run DM-1.

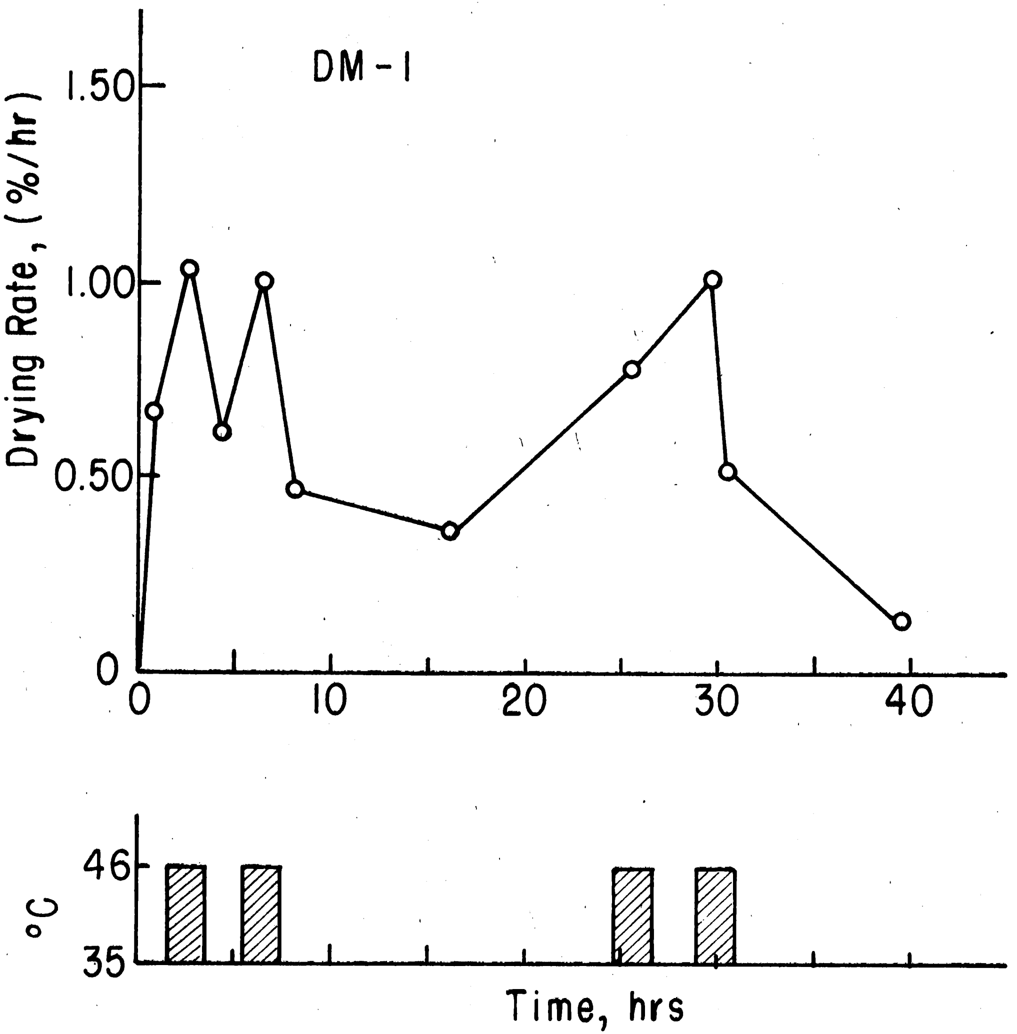

Figure 19. Effect of High Temperature Cycling on Drying Rate for Run DM-1.

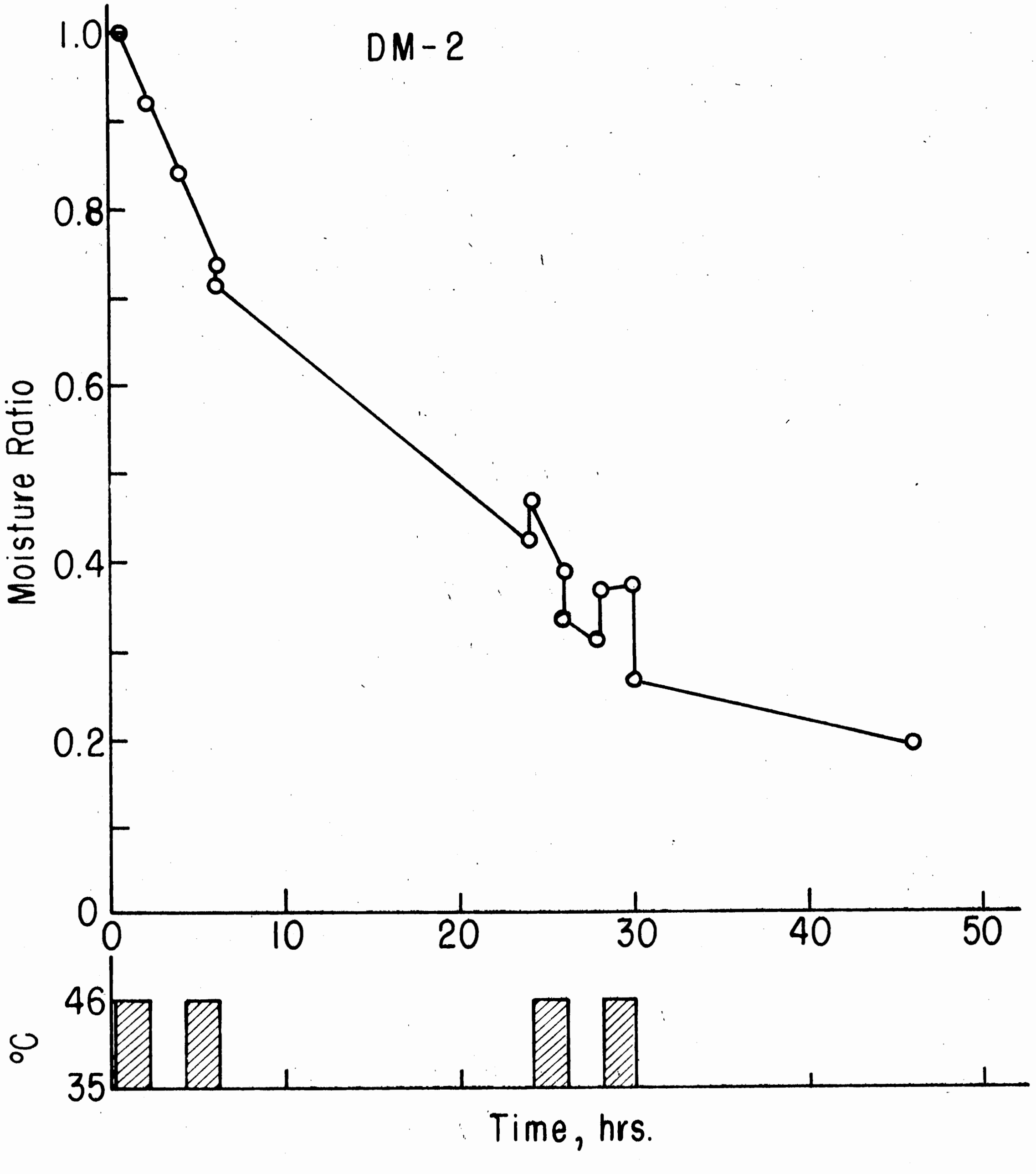

Figure 20. Effect of High Temperature Cycling on Moisture Ratio for Run DM-2.

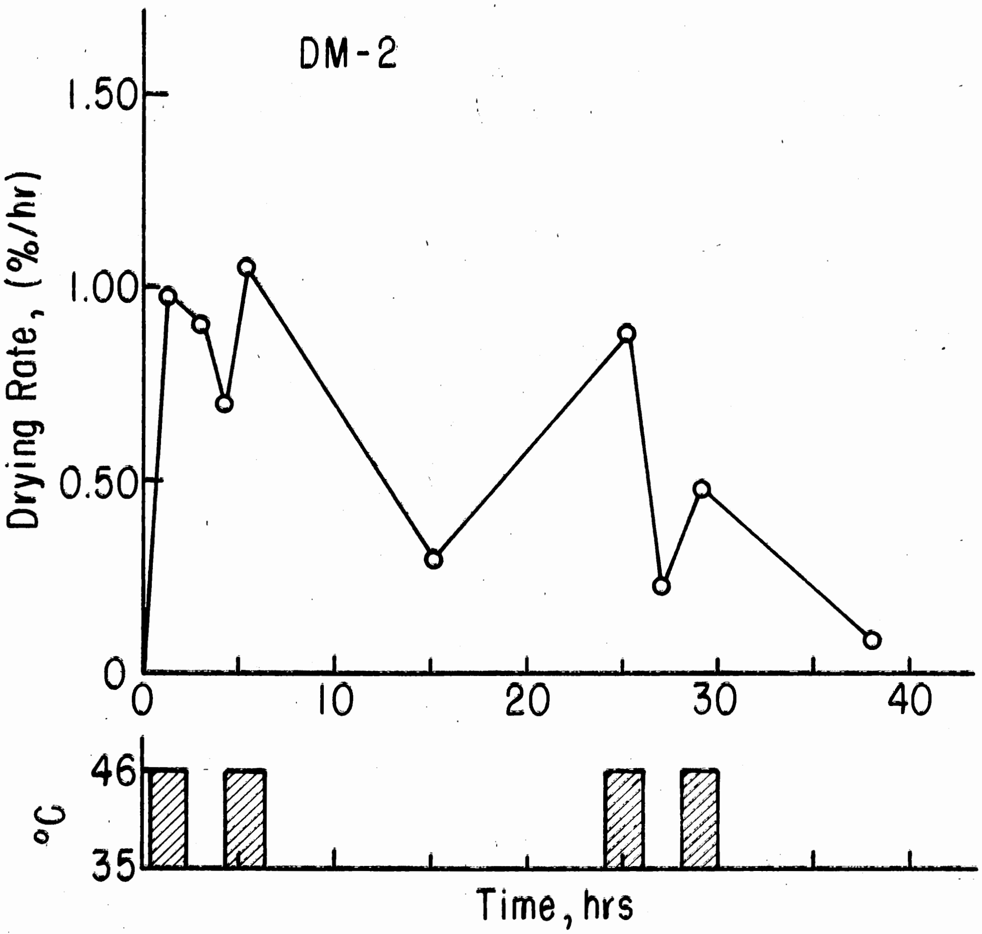

Figure 21. Effect of High Temperature Cycling on Drying Rate for Run DM-2.

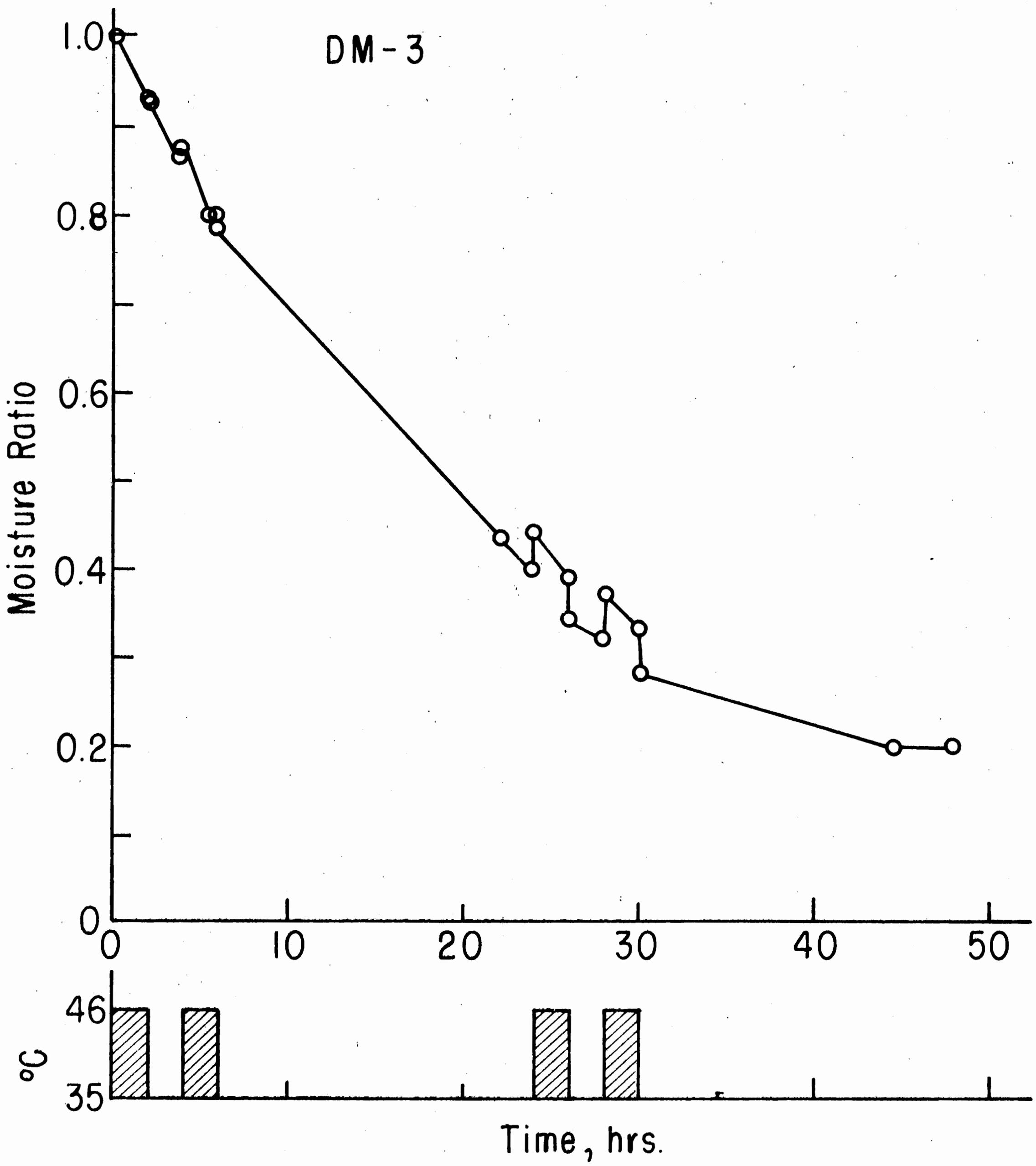

Figure 22. Effect of High Temperature Cycling on Moisture Ratio for Run DM-3.

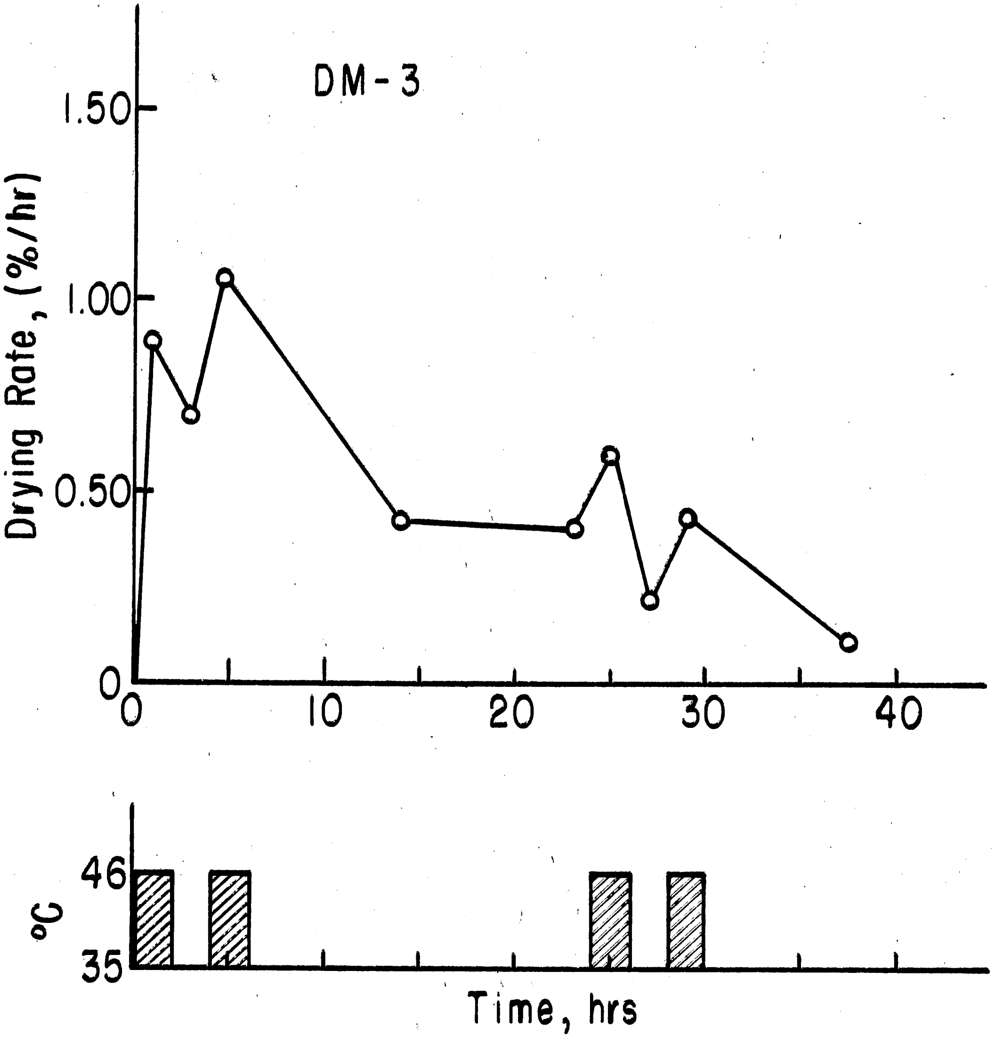

Figure 23. Effect of High Temperature Cycling on Drying Rate for Run DM-3.

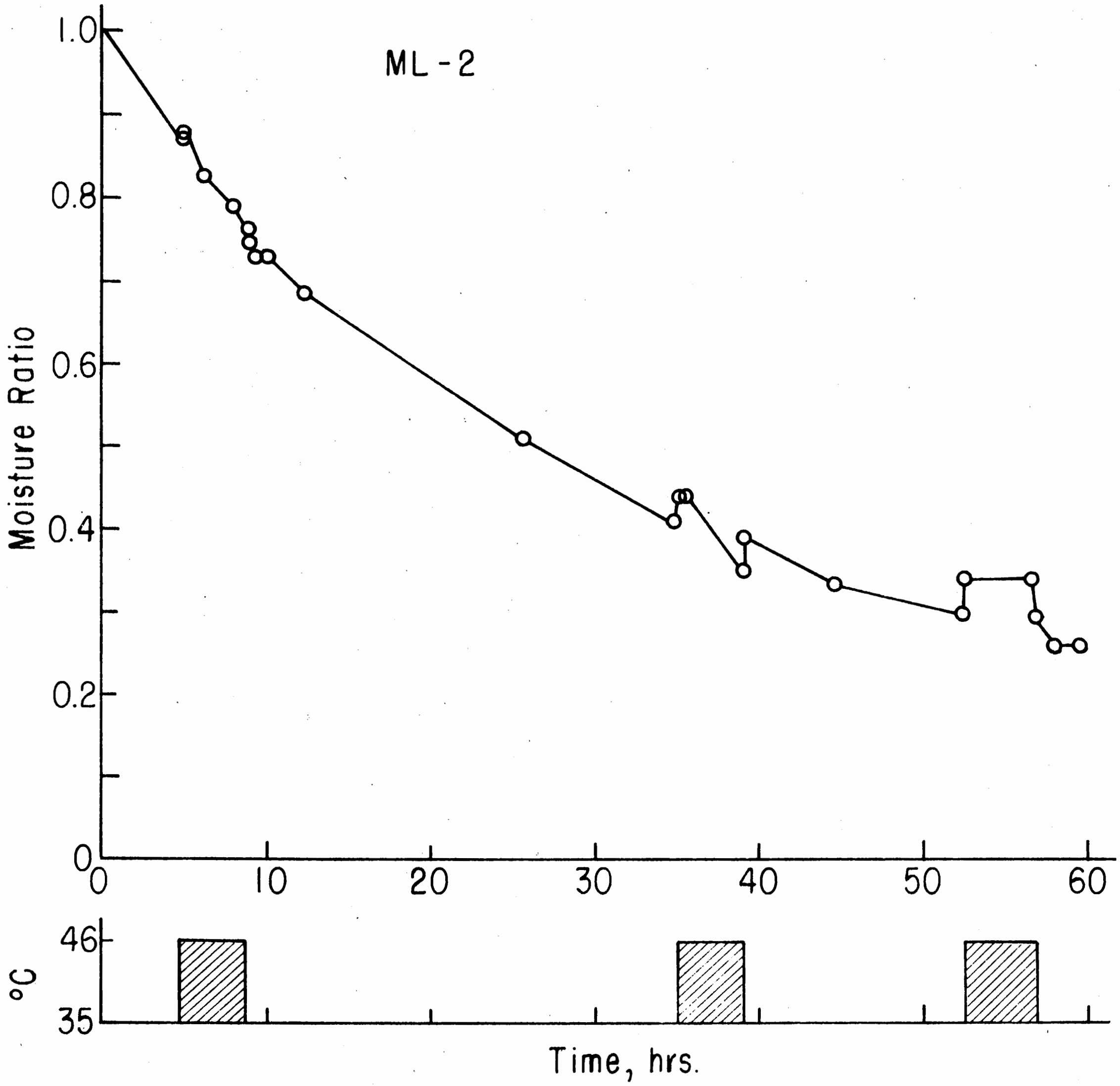

Figure 24. Effect of High Temperature Cycling on Moisture Ratio for Run ML-2.

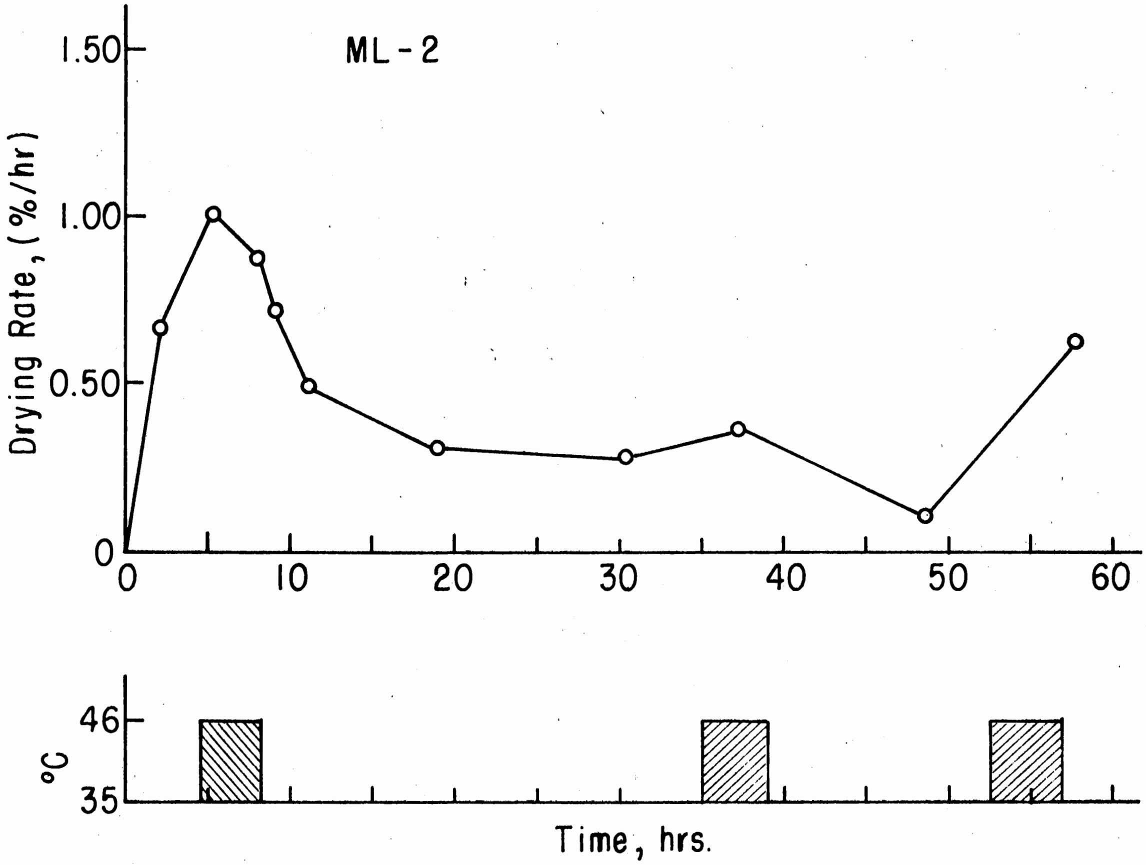

Figure 25. Effect of High Temperature Cycling on Drying Rate for Run ML-2.

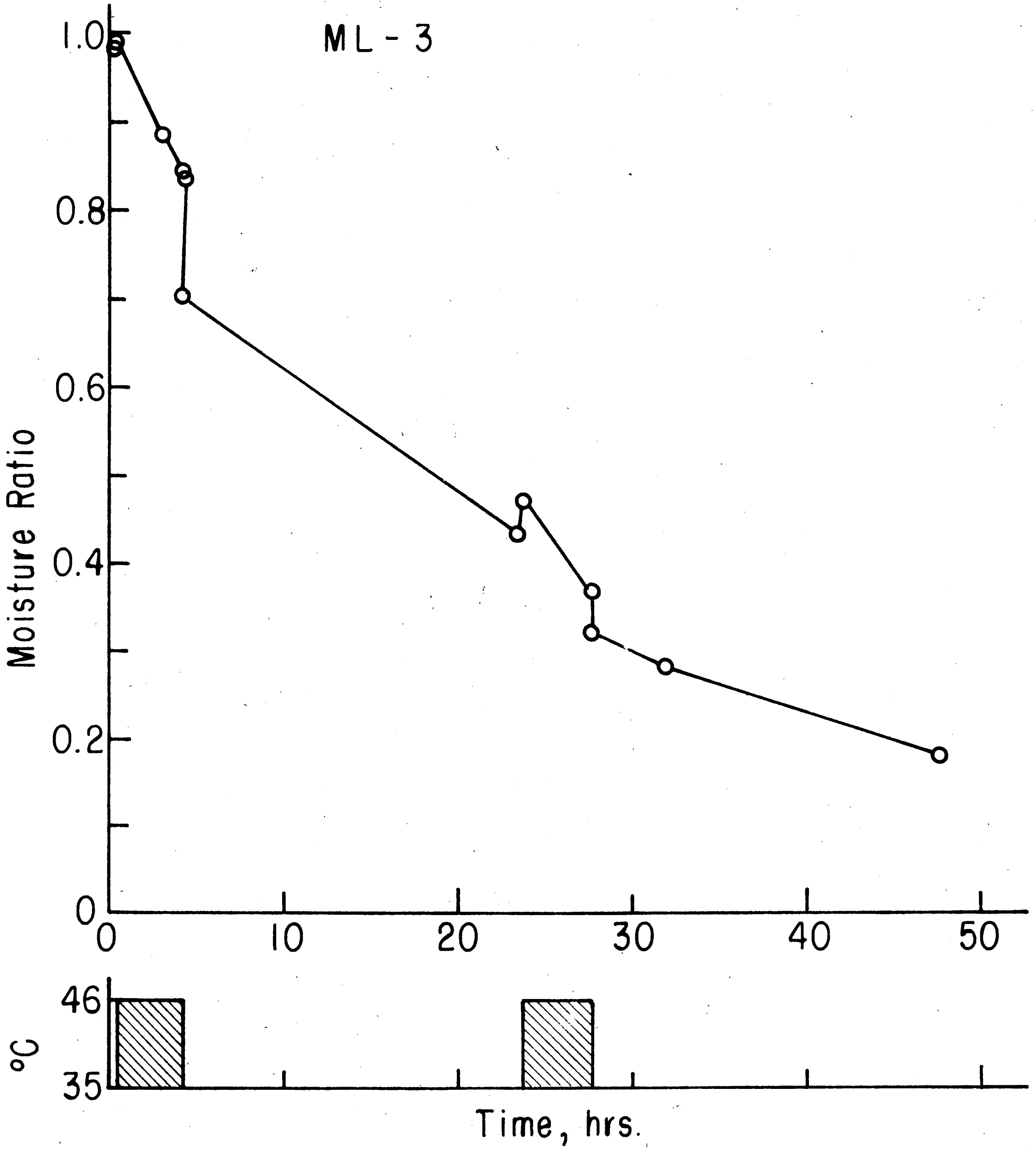

Figure 26. Effect of High Temperature Cycling on Moisture Ratio for Run ML-3.

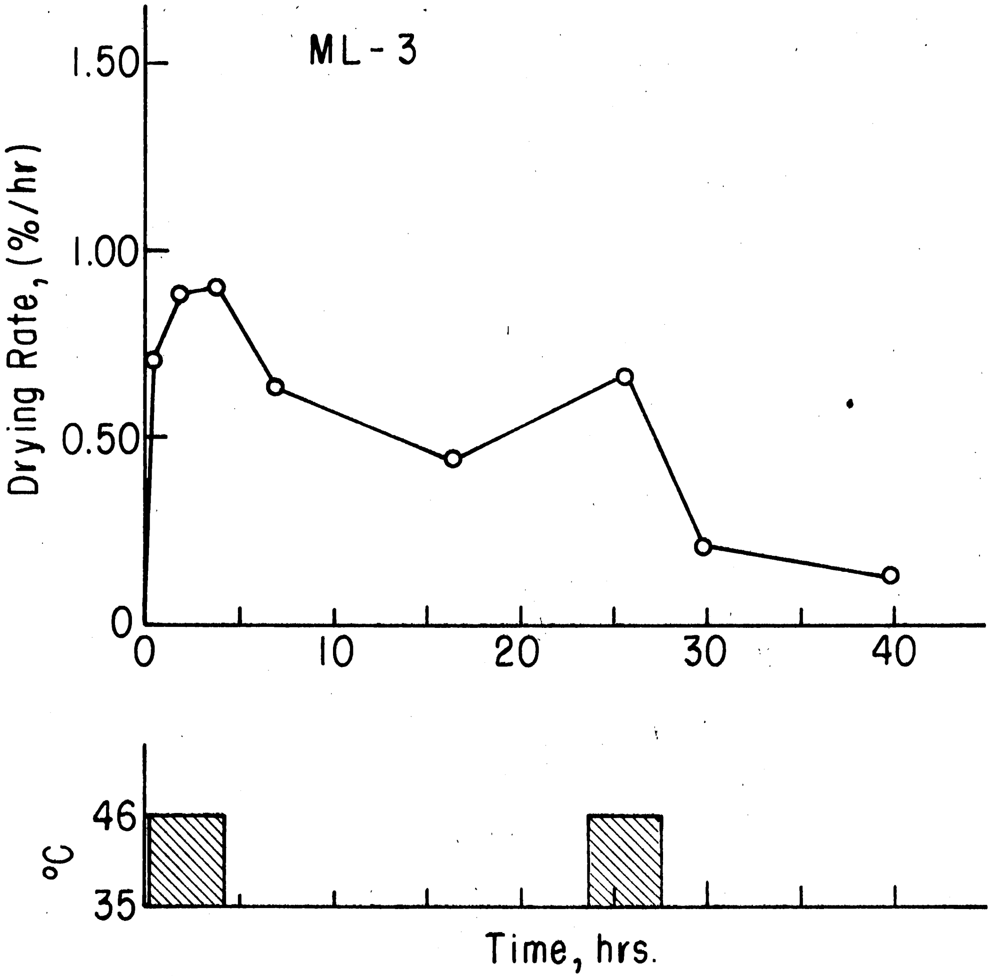

Figure 27. Effect of High Temperature Cycling on Drying Rate for Run ML-3.

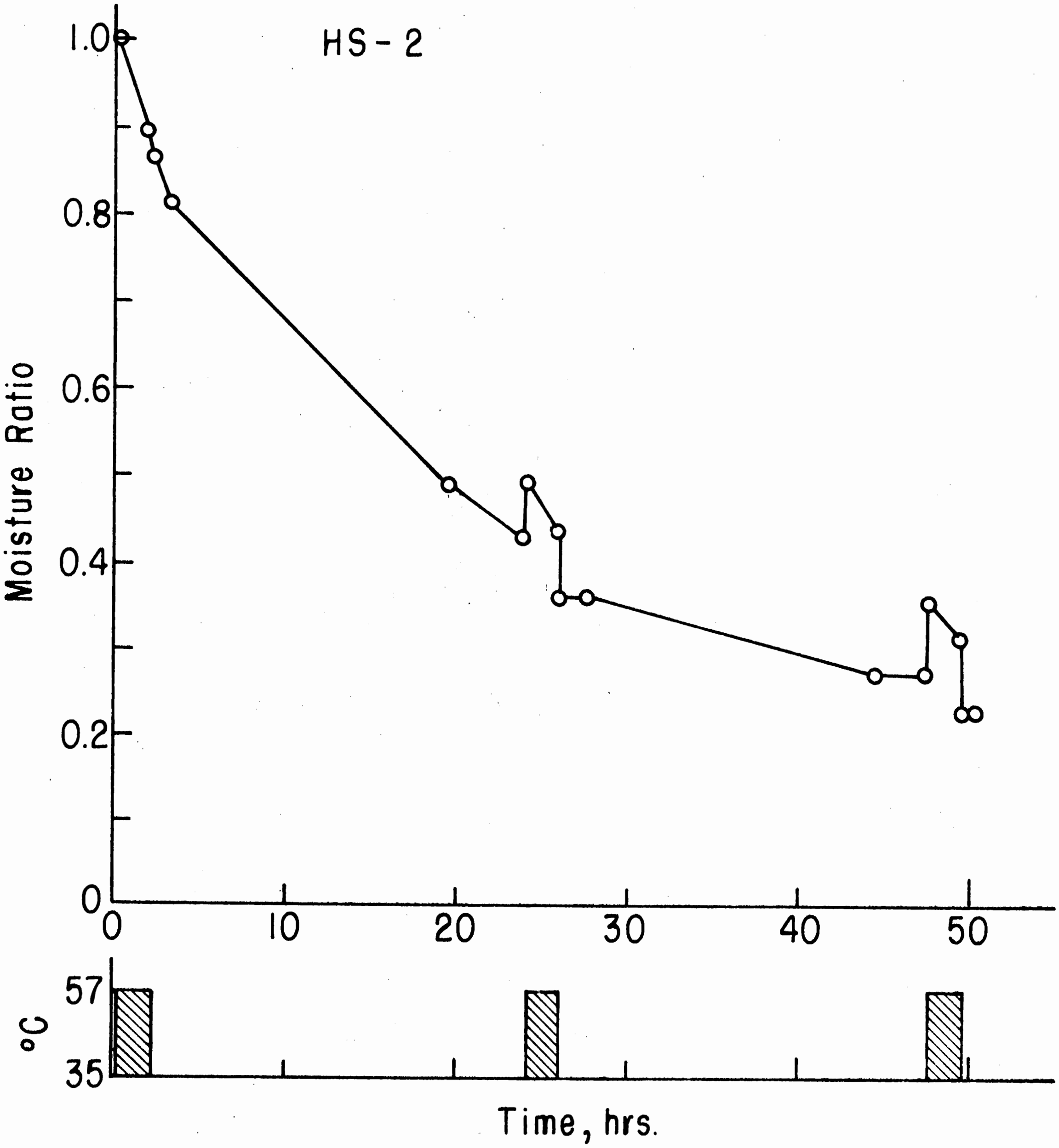

Figure 28. Effect of High Temperature Cycling on Moisture Ratio for Run HS-2.

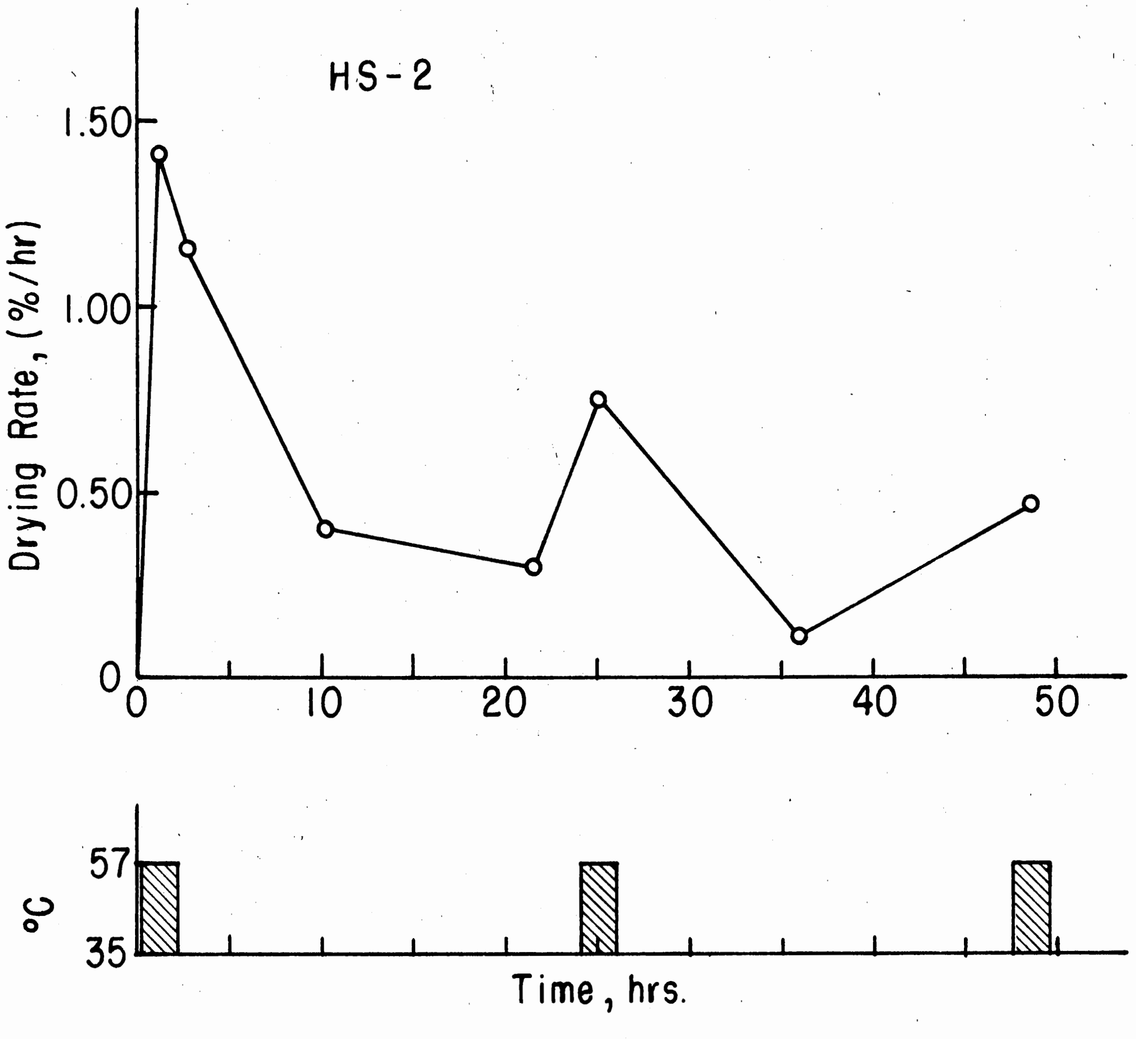

Figure 29. Effect of High Temperature Cycling on Drying Rate for Run HS-2.

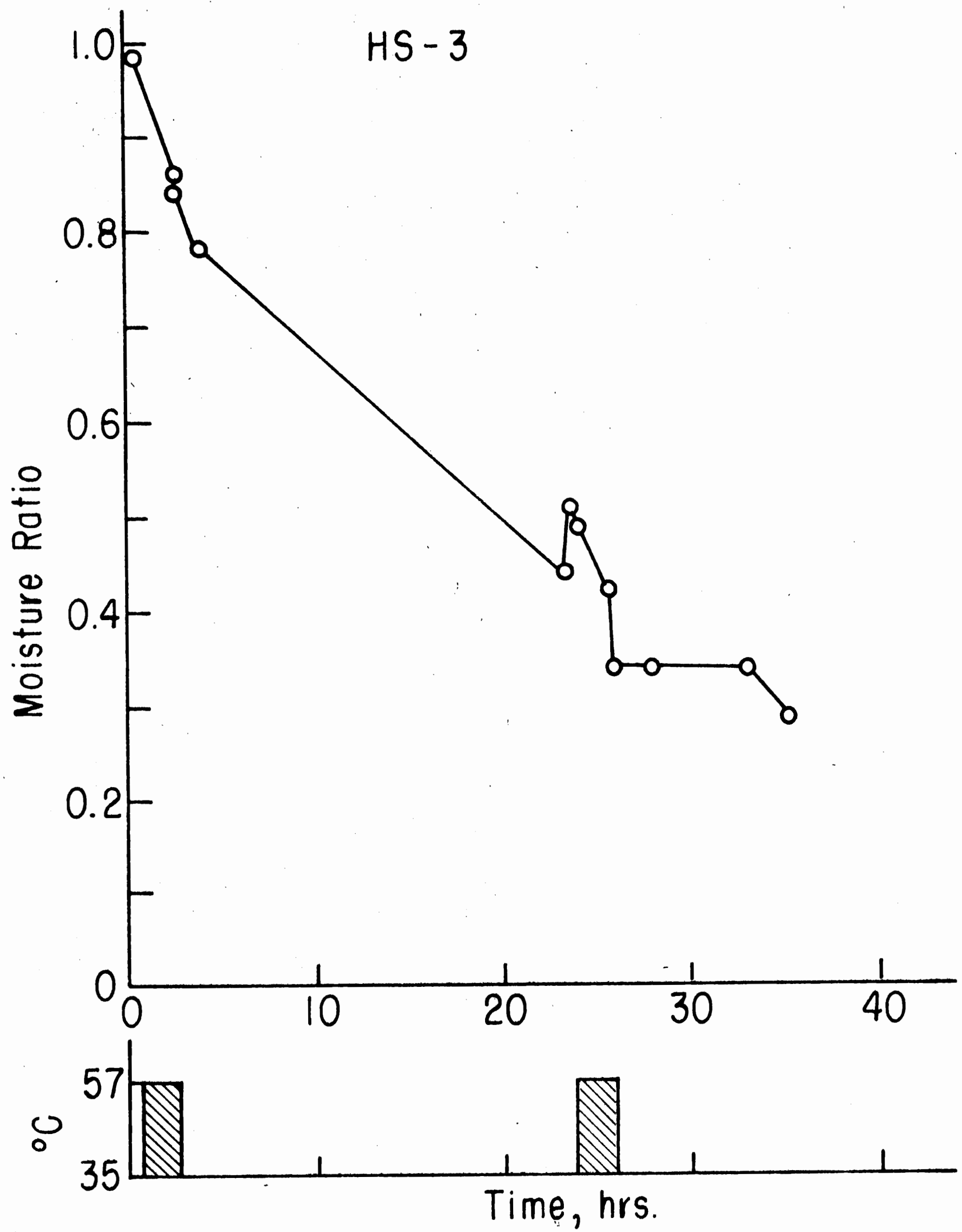

Figure 30. Effect of High Temperature Cycling on Moisture Ratio for Run HS-3.

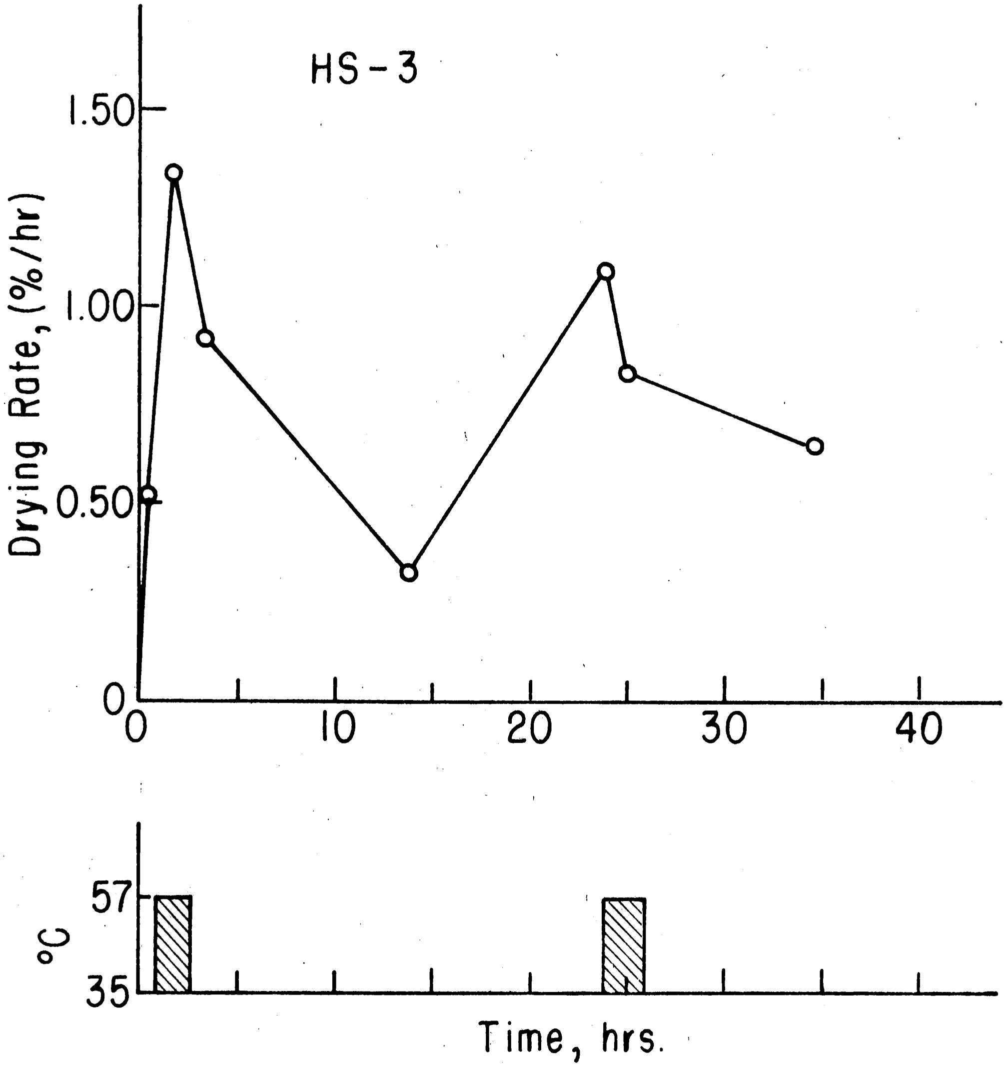

Figure 31. Effect of High Temperature Cycling on Drying Rate for Run HS-3.

## TABLE VIII

## TEST OF SIGNIFICANT DIFFERENCE BETWEEN DRYING RATES BY DIFFERENCE BETWEEN MEANS ANALYSIS

| Compared Treatments | | t-Cal. | t-Tab. (0.1) | Confidence Interval (90%) |
|---|---|---|---|---|
| DM | ML | 0.146 | 4.617 | 0.505<br>-0.474 |
| DM | HS | 2.777 | 2.920 | 0.171<br>-0.004 |
| ML | HS | 0.668 | 6.314 | 0.714<br>-0.572 |

## TABLE IX

## ANALYSIS OF VARIANCE FOR TEST OF SIGNIFICANT DIFFERENCE BETWEEN DRYING RATES

| Source | | Sum of Squares | Mean Square | F | LSD (0.1) |
|---|---|---|---|---|---|
| Treatment | 2 | 0.00884 | 0.00442 | 0.67731 | 0.17221 |
| Residual | 4 | 0.02609 | 0.00652 | | |

* Indicates non-significance.

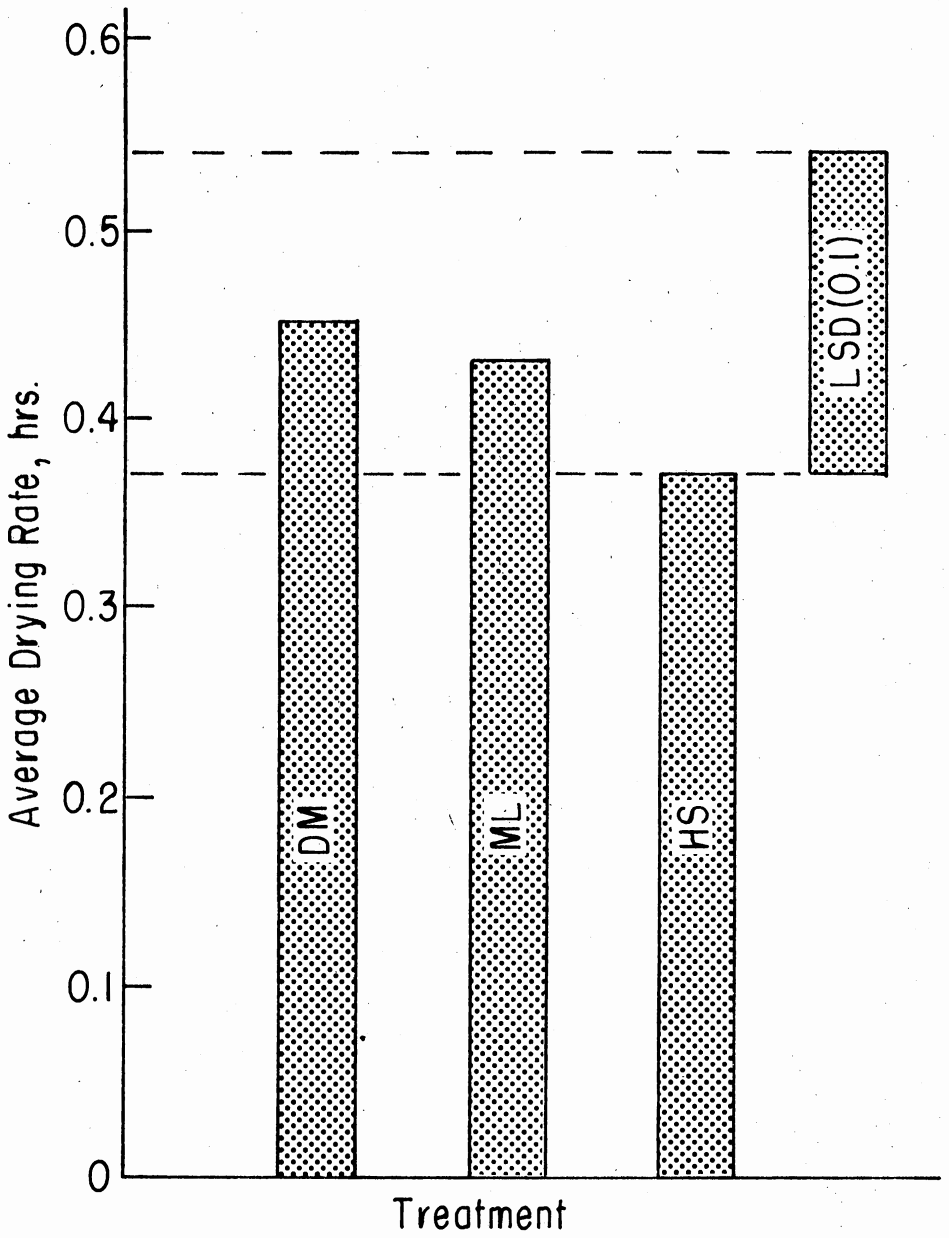

Figure 32. Average Drying Rate from Moisture Ratio of 1.0 to 0.3 and the LSD (0.1) = 0.172. Standard Deviations are: DM = 0.052, ML = 0.144, and HS = 0.005.

was shown. These two different results were obtained because of the difference in the manner that the methods treat the data. The difference between means analysis does not take into account any interaction. It looks at two treatments at a time and ignores any other treatments or effects. The AOV looks at the complete test and accounts for interaction. In the AOV, the variation among replicates sum of squares was so large that no significant difference could be shown at the desired confidence level.

The analysis for average drying rates and average drying times revealed no significant difference at the 90% confidence level. However, the experimental error was large as indicated by the amount of time reduction necessary to show a significant difference at the 0.1 level. To dry from a moisture ratio 1.0 to 0.3 the average drying time would have to be reduced by 21 hours to be significantly different. Twenty-one hours could be significant to a farmer or commercial dryer, but due to large experimental error this time reduction was not enough to be statistically significant at the 0.1 level.

In an attempt to reduce this large experimental error, any future work needs to be designed so that more replicates can be obtained and each treatment can be performed on the same lot of peanuts. This could be accomplished with a manifold design and more drying bins. With more replicates the statistical analysis could be performed with greater confidence that outliers and uncharacteristic data would not significantly affect the final results.

# CHAPTER VI

# SUMMARY AND CONCLUSIONS

## Summary

This study was concerned with drying peanut pods with daily short durations of temperatures greater than 35 °C and the effect of this drying method on quality and drying time. Freshly harvested peanut pods were placed in drying bins and the drying environment controlled by an Aminco environment chamber. After drying to approximately 10% wet basis, the pods were stored in a cooler at approximately 4 °C until shelling tests could be performed.

When the difference between means statistical test was used in the quality analysis to test for significant difference between treatments, significant difference was found between certain treatments. When the AOV was used, the experimental error, due to large variations among peanut lots, was so great that significant difference between treatments could not be shown.

A moisture ratio was used in the drying analysis to allow for comparing peanut pods with different initial moisture contents. Drying curves were made showing the immediate effect of temperature increases on the moisture ratio. Average drying times were reduced, but not significantly different statistically, when compared to constant 35 °C drying, by introducing the daily high temperature cycle. Treatment MS was not proven statistically different for either quality or drying time reduction due to large experimental error. However, its average percent splits was highest and drying rate lowest indicating that this is likely to be a commercially unacceptable procedure. Treatments DM and ML were not statistically different for either quality or drying time reduction and could possibly be acceptable to commercial installations. This result is supported by the findings of Farouk (6).

## Conclusions

1. Experiments relating to peanut quality are subject to large experimental error due to variations in variety, climatic and soil conditions, and maturity.
2. Final moisture content is difficult to control due to continued transfer of moisture from kernel to hull after drying is stopped.
3. Comparisons of percentage sound splits are more meaningful when corrected for United States Department of Agriculture grade.
4. Experimental error may have masked statistical significant differences between treatments.

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# APPENDIX A

# SHELLING PROCEDURE

1. Draw samples from load.
2. Weigh samples for determining percent of foreign material and LSK (need 1500 grams).
3. Pick out any foreign material and weigh.
4. Find percent of foreign material.
5. Pick out LSK, weigh and record.
6. Find percent of LSK.
7. Weigh 500 gram sample of cleaned kernels for content analysis.
8. Pre-size and shell in the mechanical sheller previously described. Be sure to collect hulls as well as kernels.
9. Inspect hulls to remove any kernels.
10. Weigh and record percent of hulls.
11. Determine moisture content of kernel by oven dry technique.
12. Screen the kernels through 15/64 X 3/4 screen (for Spanish peanuts).
13. Weigh and record weight of kernels which ride the screen.
14. Examine those riding the screen for any damaged kernels.
15. Weigh and record the damaged kernels.
16. Determine and record percent of SMK by subtracting damaged from total riding the screen.
17. Pick out sound splits from kernels passing through the screen. Weigh and record (also remove damaged splits).
18. Add SMK and SS to get grade.
19. Weigh and record rest of peanuts that passed through the screen. Determine percent and record as other kernels.
20. Weigh damaged and dirty splits, add to damaged kernels which rode the screen, and find percent damaged.

21. Check accuracy by adding SMK, OK, damage, and hull percentages. Should equal approximately 100%. If sum is not approximately equal to 100%, an error in weighing or calculations has been made. Samples were saved so that reweighing and calculations could be made, if necessary.

# APPENDIX B

## EXAMPLE OF ERROR OCCURRING WHEN CALCULATING PERCENT SOUND SPLITS IF COMPENSATION FOR VARYING GRADE IS NOT MADE

## EXAMPLE

Effects of USDA grade change on percent sound splits: Given: 500 gram sample of peanut pods. Assume grade = 60, then there are 500 X 0.6 = 300 grams of possible sound mature kernels (SMK). Suppose 20% of these possible SMK split due to treatment effects. 300 X 0.20 = 60 grams = amount of sound splits. United States Department of Agriculture percent sound splits = (60/500) X 100 = 12%. Now assume grade = 70, then there are 500 X 0.7 = 350 grams of possible SMK. For an identical treatment the percentage of SMK that split should be the same, or 20% of SMK would split. 350 X 0.20 = 70 grams = amount of splits. United States Department of Agriculture percent sound splits = (70/500) X 100 = 14%. The difference in percent sound splits due to grade difference is $\frac{14 - 12}{12}$ X 100 = 17%.

# VITA

## Russell Alan Rogers

Candidate for the Degree of

Master of Science

Thesis: CURING SPANISH PEANUT PODS WITH DIURNAL CYCLING OF HIGH TEMPERATURE FORCED AIR

Major Field: Agricultural Engineering

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