DRYING PEA BEANS INTERMITTENTLY AT 100°F

By

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AN ABSTRACT

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Approved by Carl W. Hall 11/20/56.

The safe storage of pea beans requires that they be dried to about 15 percent (w.b.) moisture content. Since unfavorable weather conditions have frequently been encountered during the harvesting season, it is necessary that artificial drying be provided. Different from most farm products, pea beans tend to crack during the drying process, especially when heated air is used, and it is a challenging job to agricultural engineers to find a way to dry the product quickly and yet without excessive cracking.

An attempt was made to give a mathematical analysis based on simplified conditions to illustrate the cracking problem. Also efforts have been directed to obtain experimental data to find a way to dry the product from about 20 percent (w.b.) moisture content, which is the usual moisture content when harvested, to about 15 percent (w. b.) moisture content efficiently but avoiding the commercial limit of cracking percentage.

Based on the experimental data obtained, it is suggested that a drying process followed by a 4-hour resting period, followed by another drying process, is a possible solution that can be used in practical drying. The first drying process proposed consists of:

(1) a first heating period of 15 minutes during which the beans are heated with high humidity air so as no drying might take place,

(2) a first drying period of 30 minutes in which heated air is used to remove moisture from the beans,

(3) a second heating period of 10 minutes during which the beans are reheated without change in moisture content, and

(4) a second drying period of 30 minutes.

The second drying process as proposed by the author utilizes the same procedure except that the drying period is shortened to 20 minutes each.

By the above procedure, pea beans will be dried from 20 percent (w.b.) moisture content to 15 percent (w.b.) moisture content with a cracking percentage range from 1.3 to 1.4 percent. Since the actual drying time is less in the above procedure, less heat will be needed which can be generated from fuel oil or other heat sources. However, on the other hand, the resting period will likely cause some trouble in handling.

Beans used in all tests were dry beans wetted artificially by nearly saturated heated air. Beans so treated may not possess the same drying characteristics as those that become wet in the field due to natural moisture and temperature conditions.

It was found that the heating of pea beans by a nearly saturated heated air is not the cause of cracking of the skin.

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THESIS

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INTRODUCTION

An increasing quantity of beans has been produced in the past years. It has become an important part of the agricultural production all over the world. But because unfavorable weather conditions are frequently encountered during the harvesting season, the drying of beans is a serious problem. Beans are usually harvested at 20 percent (w.b.) moisture content and are usually stored at 15 percent (w.b.) moisture content. Excess moisture itself is not the direct cause of storage problems. However, excessive moisture provides one of the necessary conditions that are highly favorable to the development of undesirable organisms, both plant and animal.

The removal of moisture or drying of agricultural products is generally classified into two main types:

(1) natural drying in the field,

(2) artificial drying.

Utilization of the wind velocity, or fan-forced air with or without heat added are commonly used artificial means.

During past years, more attention and emphasis have been given to the use of fan-forced heated air as a drying medium. Its dependability, and quick drying rate has won recognition from both the researchers and farmers. This is particularly true in an area like the United States where the agricultural production is dependent mostly upon mechanical power since less man power is available to handle the farm products.

One factor that makes the drying of beans different than the drying of other small grains is its larger size and tender seed coat. Because of the size of beans, it is difficult to move the moisture content in the center portion efficiently and yet without excessive cracking on the surface of the beans.

OBJECTIVE

The chief interest was concerned with the drying of white pea beans containing excessive moisture for safe storage over a prolonged period.

The main objective was to find a method of removing the excessive moisture from the pea beans quickly and still avoid excessive cracking. The problem has been analyzed from a theoretical point of view and the experiment was performed under the guide of theoretical analysis.

REVIEW OF LITERATURE

Theoretically there are two types of moisture in the pea beans that must be removed in the drying process. As stated by R. H. Reed and George H. Dungan[1], solids contain water in two general forms, namely: (1) free and capillary moisture is that moisture which is held between and on the particles or fibers of a material. This moisture does not generally affect the structure of the material to any great extent and its removal is relatively easy. (2) Hygroscopic, or absorbed moisture is that moisture which a material will absorb if exposed to air containing water vapor. This moisture is intimately associated with the physical nature of the material and its removal may be accompanied by physical changes.

The word "drying" is usually defined by researchers as the removal or evaporation of water from a certain material. An evaporation process is governed by the law of evaporation, "for a given condition of atmospheric movement, the rate of evaporation is proportional to the difference in vapor pressure between the liquid and the vapor of that liquid in the immediate vicinity"[2]. As we all know, beans that possess a certain moisture content will exert vapor pressure to the surrounding air[3] and the problems connected with the drying of grains might be approached from the standpoint of vapor pressure.[4]

Referring to a psychrometric chart, we find that the heating of air has nothing to do with the vapor pressure of the air. Heating may change the relative humidity of air, its moisture-carrying ability, but the heating of air alone can not change the vapor pressure difference between the drying air and the pea beans to be dried, and no change in the rate of drying can be made by this method.

The above statement is supported by most of the experiments conducted to date.[5,6,7,8,9] And we might say it has been accepted by the majority of agricultural engineers that grain temperature is of greatest importance in affecting vapor pressure and is the greatest single factor in grain drying. Vapor pressure within a grain increases at an increasing rate as the grain temperature is increased. Grain moisture content also affects the vapor pressure but is of much less importance than grain temperature. At a certain temperature the vapor pressure exerted by the grains to the surroundings will change with a change in its moisture content up to approximately 20 percent, and for higher moisture content than that, the vapor pressure of the same grain will behave almost like a free water surface.

As stated by F. C. Fenton[4], the principles of grain drying are:

(1) grain absorbs or releases moisture because of the vapor pressure difference between the grain and the surrounding air. If the vapor pressure of the grain is higher than the vapor pressure in space surrounding the grain, moisture will flow out

of the grain. If the reverse is true, moisture will flow into the grain. (2) The rate at which moisture is gained or lost is approximately proportional to the magnitude of the vapor pressure difference which prevails between the grain and the surrounding space. This rate is affected by the resistance to the movement of moisture vapor set up by the surface layers of the grain.

Pea beans, like other hygroscopic materials, have a tendency to maintain an equilibrium condition with the atmosphere in which they are exposed. An equilibrium moisture content of beans at a certain temperature and relative humidity might be obtained by maintenance of a constant temperature and humidity over a prolonged period. To remove moisture from beans, a non-equilibrium condition of vapor pressures is artificially maintained. The most effective way of doing this is to raise the vapor pressure of the beans by raising its temperature. Barre[10] emphasizes the fact that pressure difference in drying with heated air are obtained by an increase in vapor pressure of the grain and not by a decrease in that of the surrounding air. In other words, the drying process is accomplished because the heating of grain cause its temperature and therefore its vapor pressure to raise.

Another important fact in drying should be noted. To evaporate water, a certain quantity of heat is needed. Evaporation from a free water surface requires approximately 1000 B.T.U. per pound of water evaporated; the exact amount will depend upon the temperature at which the evaporation takes place. Gallaher[6] has worked out an equation to compute the amount of latent heat that will be needed to vaporize a pound of water from grain. In a drying process, a considerable amount of heat must be supplied to the grains, both to raise the grain temperature and to provide latent heat that is needed for evaporization.

Kelly[11] heated the grain directly and obtained a faster drying rate which he attributed to a greater vapor pressure difference between the inside and outside of the grain causing the moisture to move out. Kelly conceived that warming the inside of the grain caused the difference in vapor pressures. He found also that 57 to 60 percent of the drying took place in the first minute and that 43 percent of the total temperature drop took place in the first minute. The drying rate slowed considerably as the temperature of the grain decreased.

Several other researchers have tried some other methods, but usually the general practice is to use the air as a medium to carry the heat to the grains and carry the evaporated vapor away simultaneously.

ANALYSIS OF PROBLEM

Since heat is needed in the drying process, the supplying of heat to the grain is evidently the predominant factor in designing an artificial drying method. In drying grains of large size like pea beans, the large size of beans makes it more difficult to transfer heat from the surrounding air to the whole kernel.

Consider a cross-section of pea bean that is being dried artificially. Two ways have been used by researchers to supply heat to the grains for drying. One is to use heated air and the other is to heat the grains directly. In either way, the skin of the beans will receive heat first. The rise in temperature of the outer part will be the result of receiving heat, and an increase in vapor pressure will be the result of temperature rise. The increase in vapor pressure will cause a difference in vapor pressure between the outer part of bean and the surrounding, and drying will begin. But at the same time, a difference in vapor pressure between the outer and inner part of the beans will be created by the increasing of vapor pressure in the outer part so that the movement of moisture at the beginning of the drying process must be both ways.

Hygroscopic matter tends to shrink when it loses its moisture and the degree of shrinkage is dependant upon the amount of moisture lost. Thus, from the above reasoning, it can be seen that the skin will tend to shrink more at the beginning of the drying process. But as the drying proceeds, the outer part, especially the skin, will be quite dry. This will be particularly true if we use forced air of a large quantity, because the internal resistance to the movement of moisture is always greater than that offered by the surface to surrounding.

So, briefly, it can be said that throughout the drying process, there will exist a difference between the percent moisture contained by the outer and inner part of the beans. Since there is a discontinuity of matter between the skin and the kernel, the difference of moisture content will make these two parts to shrink differently.

A mathematical analysis based on some simplifications and assumptions is presented as follows:

(1) The product under investigation is of homogeneous material,

(2) The product is assumed to have a spherical shape,

(3) The change of moisture content and temperature is assumed to be the same in the skin or the kernel.

Consider a pea bean in perfect spherical shape, coated with its skin. Let

α_{sm} = contraction coefficient of the skin due to loss of moisture content, inch/percent of moisture loss per inch length of skin;

α_{st} = thermal expansion coefficient of the skin, inch/degree of F-inch;

E_s = modulus of elasticity of the skin, inch/lb. of force;

μ_s = Poisson's ratio of skin material;

α_{km} = contraction coefficient of the kernel due to loss of moisture, inch/percent of moisture loss-inch;

α_{kt} = thermal expansion of the kernel of bean, inch/degree F-inch;

E_k = modulus of elasticity of the kernel of bean; inch/lb. of force;

μ_k = Poisson's ratio of kernel material;

ΔT = temperature change, degree F/time unit;

ΔM = change in moisture content, percent degree F/ time unit.

When the product is subject to both a temperature and a moisture content change, the combined coefficient of shrinkage will be

$$\alpha_s = 1 - (1 - \alpha_{st} \Delta T)(1 - \alpha_{sm} \Delta M)$$

$$\alpha_k = 1 - (1 - \alpha_{kt} \Delta T)(1 - \alpha_{km} \Delta M)$$

In drying problems, since it is known that the skin shrinks more than the kernel, assume that $\alpha_s > \alpha_k$.

Consider the contraction of the kernel only. The change in radius due to temperature and moisture removal is

$$\Delta R_{mt} = R \alpha_k$$

But since $\alpha_s > \alpha_k$, the kernel will be subjected to compression force applied by the skin, and the change in radius due to this effect is,

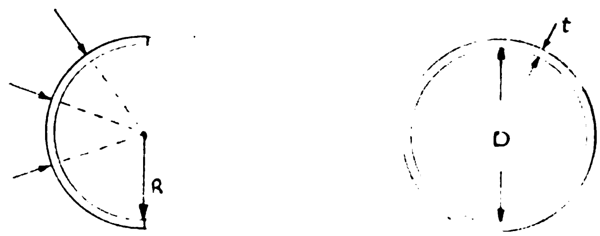
$$\triangle R \text{ comp.} = \frac{R}{E_k} \quad (P - \mu_k P - \mu_k P) = \frac{R}{E_s} \ (P - 2\mu_k P)$$

where P is the force exerted by the skin to kernel, whose unit is lb./unit area.

The total shrinkage per unit length of radius is

$$\triangle R = \triangle R_{mt} + \triangle R_{comp} = \alpha_k + \frac{1}{E} \ (P - 2\mu_k P)$$

Now consider the force that acted on the skin; let S_s be the stress in skin



Then if P is the force applied by the skin to the kernel because of the unequal shrinkage,

$$\pi D t S_s = P \frac{\pi D^2}{4} \qquad\qquad S_s = \frac{PD}{4t} = \frac{DR}{2t}$$

Since elongation $= \frac{S}{E}$, the expansion due to the force will be

$$\frac{1}{E_s} \left[\frac{PR}{2t} - \mu_s \left(\frac{PR}{2t}\right) \right] = \triangle R'_p$$

If the sphere is made of skin material alone, its shrinkage $\triangle R/R$ will be equal to α_s . But since the force due to the unequal shrinkage is elongating the skin by an amount of $\triangle R'_p$

the resultant

$$\Delta R/R = \alpha_s - \frac{1}{E_c}\left[\frac{PR}{2t} - \mu_s\left(\frac{RP}{2t}\right)\right]$$

But contraction of kernel = contraction of skin,

$$\therefore \alpha_k + \frac{1}{E_k}\left[P - 2\mu_k P\right] = \alpha_s - \frac{1}{E_s}\left[\frac{PR}{2t} - \mu_s\left(\frac{PR}{2t}\right)\right]$$

In the above equation P is the only unknown and can be found provided the constants are known. Theoretically, it means that for a certain time period it can be determined if the skin is going to crack or not, provided that the moisture and temperature changes are known in both the skin and the kernel.

DESCRIPTION OF APPARATUS

The testing apparatus used consists basically of two parts. The first part included a blower, a heater, a steam inlet and a mixing box. The second part consists of a drying box. The whole apparatus is shown in the following sketches (Figures 1 through 4).

Air was blown through the heater by the blower and was mixed with steam in the mixing box. A hand-operated globe type valve was used to adjust the amount of steam to be mixed with air. The air temperature was controlled by an on-off type bi-metal air switch placed in the mixing box. The temperature controlling switch was calibrated at 100°F (±4°F), and the steam inlet valve was adjusted each time to get the wanted relative humidity of the air.

The drying box was placed on a scale and was connected by a thin-walled rubber tube with great flexibility.

A thermometer was hung at the outlet of the drying box to check the air temperature at that point. A relative humidity meter was used to check the relative humidity of drying air leaving the drying box, and the variation of weight of beans being dried was read directly from the scale.

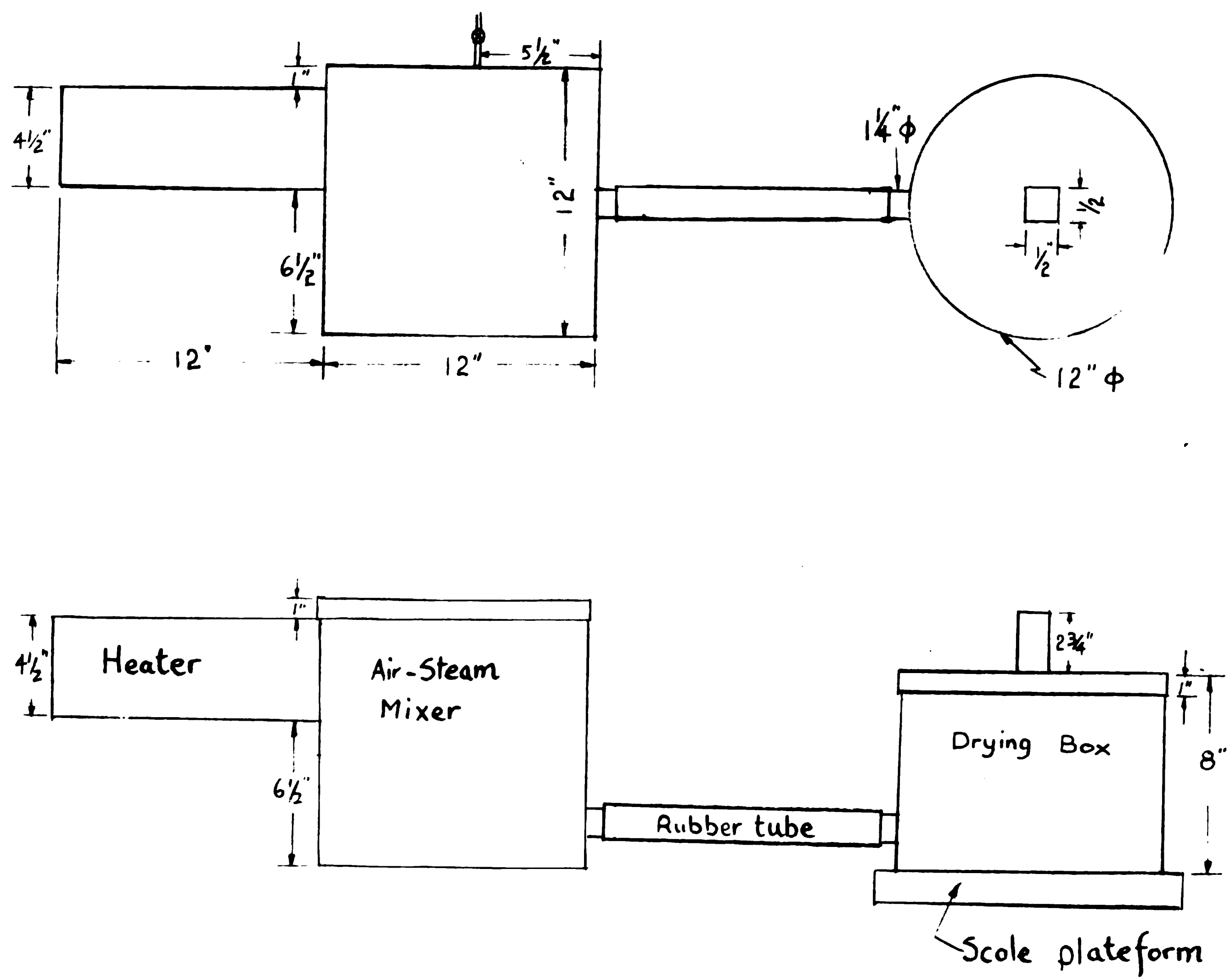
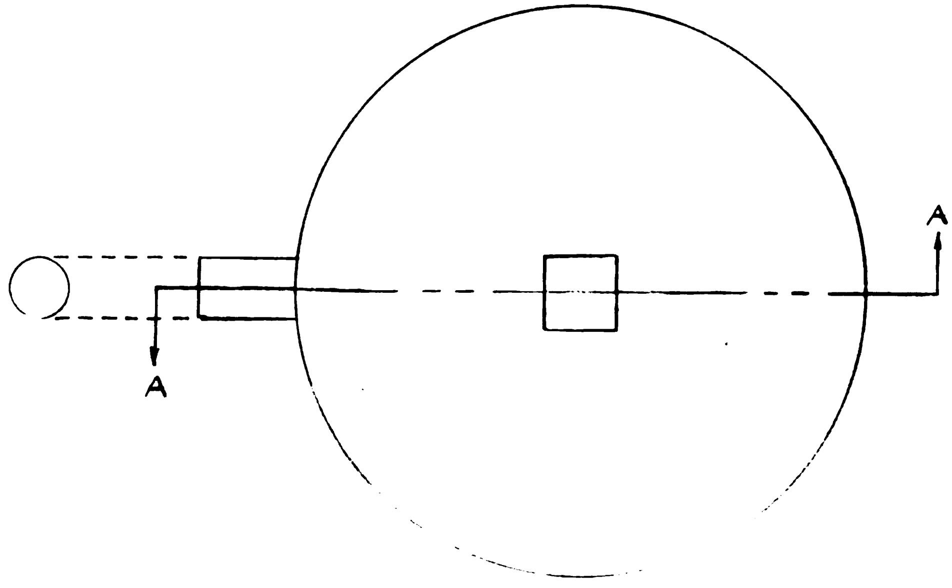
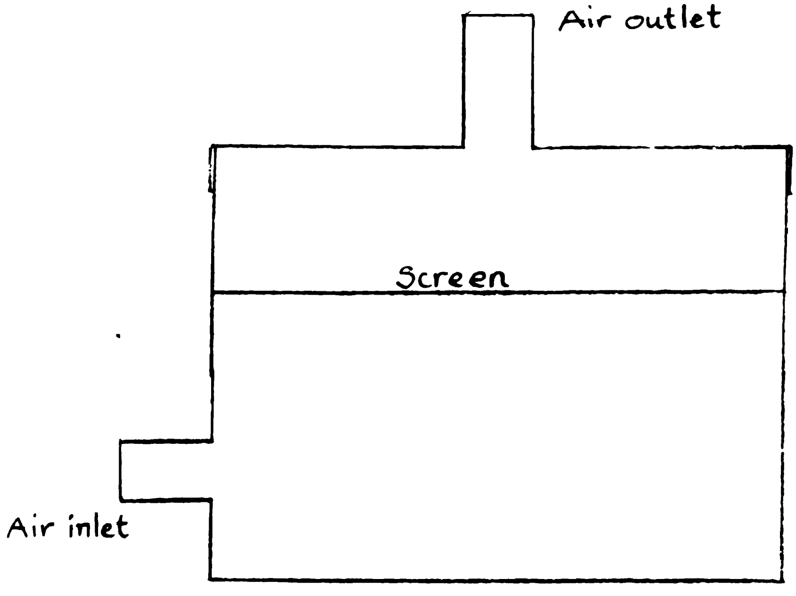


Figure 1. Assembly View of Testing Apparatus

SCALE 1" = 8"



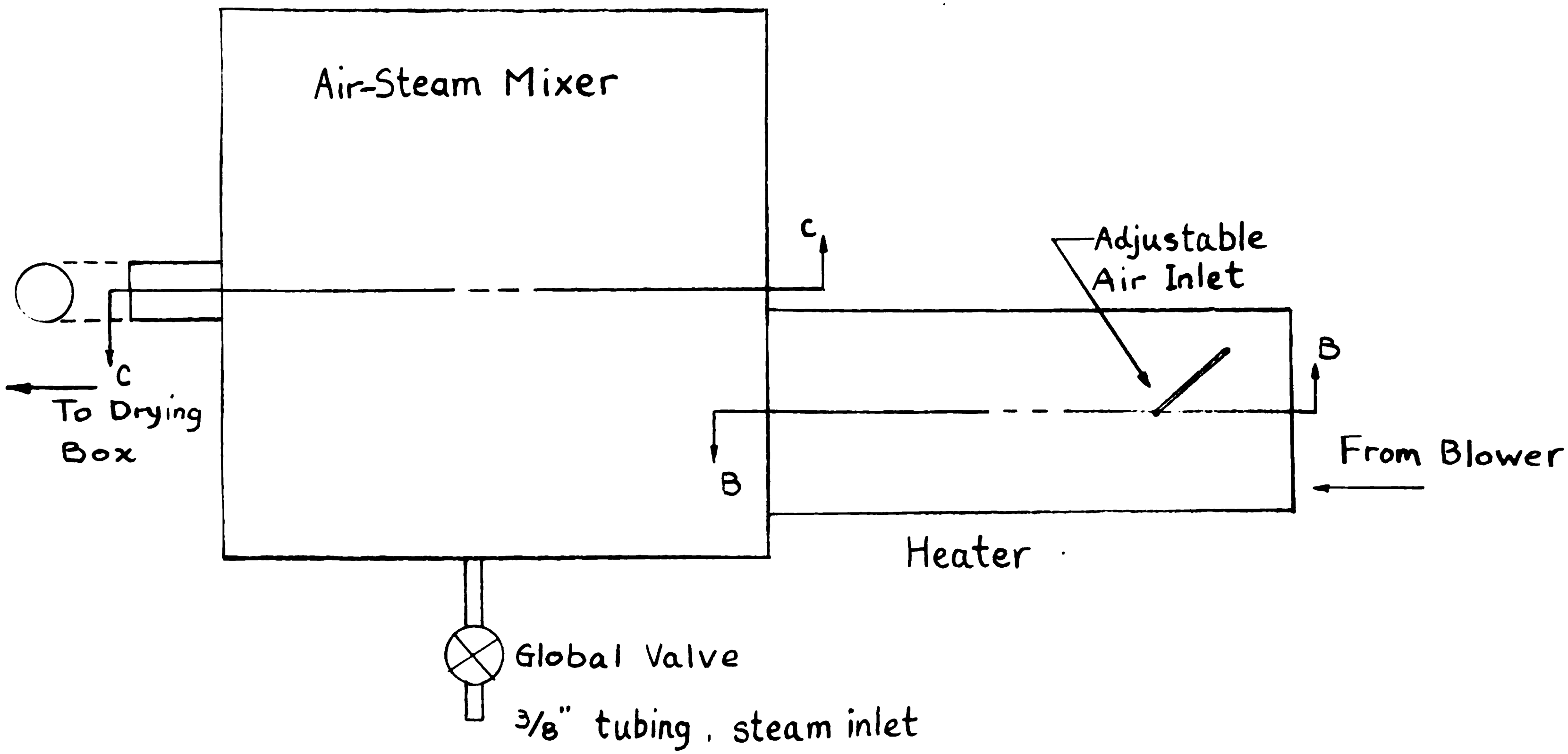
Top view of drying box



Section A-A

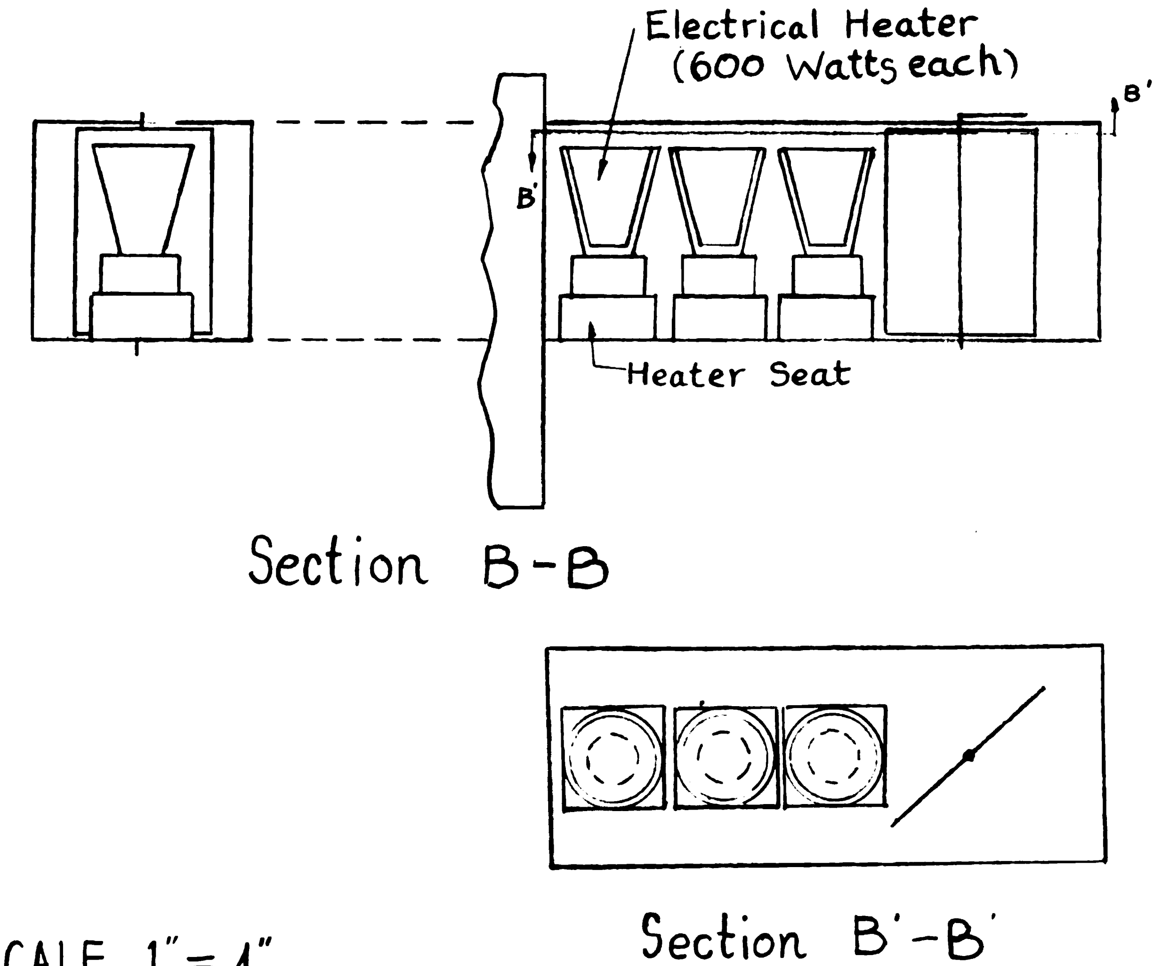
Figure 2. Sketch of Drying Box

SCALE 1" = 4"



SCALE 1" = 4"

Figure 3. Top View of Heater and Air-Steam Mixer



SCALE 1" = 4"

Figure 4. Sectional View of Heater

PRESENTATION AND DISCUSSION OF DATA

Preparation of Samples

The beans that were used as testing samples were stored at 13 percent (w.b.) moisture content and were conditioned before the test to get a higher moisture content.

The method used was as follows: the sample of beans was placed in the drying box and heated air with high relative humidity (100°F, 95 percent to 98 percent relative humidity) was blown through the sample. It took five or six hours for the samples to absorb enough moisture to obtain 20 percent (w.b.), and the samples were left in a closed container for two or three days to distribute the absorbed moisture evenly within the bean kernels.

The moisture content of beans was determined by oven method. The sample was placed in a 212°F oven for three days and was weighed before and after the oven-drying to determine the amount of water evaporated.

A sample of 2000 grams of Michelite pea beans with known moisture content was used for each test.

Heating, Drying and Resting Period

Beans were placed in the drying box and were heated by high humidity air at 100°F from the mixing box. This is called "the heating period". During this period, the relative humidity or the amount of steam to be mixed with the heated air was regulated in such a manner that the vapor pressure of the air was equal to the equilibrium vapor pressure of the beans at that temperature. During the heating period, no moisture movement occurred between the air and the sample and the beans were heated without change in their moisture content.

During the drying period, heated air without being mixed with steam, was used. The air was at 100°F, about 50 percent R.H., and the rate of movement was 28.5 CFM/ft^2.

At the resting period, the samples were left in a closed container for a certain length of time between a drying and heating period. The purpose of this period was to give time for the re-equalization of the moisture content within the individual kernels.

It was assumed that the samples were at the same temperature with the heating air during the heating period when the temperature of the air read the same at inlet and outlet of the drying box. It was assumed that the consistancy of temperature at the inlet and outlet was an accurate means to show evidence that there was no heat being transferred between the beans and the heated air.

A drying period would follow the heating period. Changes in the temperature and relative humidity of the drying air at the outlet of the drying box, and variation of the weight of the sample, were recorded at certain time intervals.

Tests and Testing Data

Several tests were conducted to see whether the heating of pea beans by high humidity air would cause the beans to crack. Regular samples were heated for 10, 15, 20 and 30 minutes. Cracking percentage was checked, but data obtained from those tests showed no indication of cracking that could be caused by the treatment of heating period. Also from these trial tests, a heating period of 15 to 20 minutes seemed adequate to heat the sample from room temperature to 100°F. (See Figure 5) Because of the high air rate (28.5 CFM/ft^2), a 15-minute heating period was used in subsequent tests by the author.

Different combinations of drying times have been tried to find the longest drying time and largest amount of moisture that could be removed in a single operation and yet without excessive cracking.

Tests with a heating period followed by a 5, 10, 15, 20, 30, and 40-minute drying period were conducted. Figure 6 shows that the drying rate was high at the beginning, but dropped quickly in the first five minutes and tended to level off after 15 or 20 minutes of drying (Figure 7).

A further look at the data shows that the temperature readings at the drying air outlet in the drying box tended to drop quickly at the first two or three minutes. The drop in temperature slowed down with the drop in drying rate. Usually after 10 minutes, the drying rate was so low that the temperature of the drying air (measured at the outlet of the drying box) would start to rise. This occurred because when the drying rate is high, the amount of latent heat needed by the evaporation is high, so the temperature of the beans would be low, and the air must yield part of its heat content to the beans. But when drying rate is low, the latent heat required is low, and while part of the heat transferred from the air to the beans will be consumed as latent heat, the rest of the heat received by the beans will raise the temperature of the beans, thus lowering the heat-transferring rate between the air and beans. The increase of temperature in the drying air served as an indication of the decrease of drying rate. But as the drop of the drying rate can be explained only as a lowering of the difference of vapor pressure between the air and the surface of the beans that were being dried, it indicated that the moisture content of the skins was getting low and the skins were under stress when the temperature of the drying air rose. As has been said before, the greater difference in the moisture content between the surface and the inner part of the beans, the more stress the surface portion receives, consequently, more cracking would be apt to occur. Figure 8 shows the temperature of drying air tends to rise after about 10 minutes of drying (for 20 percent w.b. sample), and this tendency was growing steadily after about 30 minutes of drying. A check of the cracking percentages in those tests verified the use of 30 minutes as the longest drying period in a single operation.

Tests without a heating period were conducted. Figure 9 shows the change of weight in two 2000-gram samples of 20 percent (w.b.) moisture content. One sample had a 15-minute heating period before drying, the other was dried without added heat. The curve that represents the one without a heating period shows a gradually slow changing slope. The curve that represents tests with a heating period shows a much steeper slope in the first five minutes but leveled off after that time. Furthermore, the slopes of these two curves are about the same after ten minutes of drying, and this indicates that the influence of the heating period was disappearing after ten minutes of drying. This phenomenon might be explained as follows: the rapid drying that occurred in the first five to ten minutes consumed a large percentage of the heat that was in the kernel part of the beans and lowered the temperature in the kernel. Since the vapor pressure of the beans at certain moisture contents varies with the temperature, the lowering of the temperature certainly will result in a lowering in the vapor pressure difference between the kernel and skin (or between the inner and outer part), which again will cause a lowering of the rate by which moisture was transferred from the inner part to the skin. The rate would keep dropping until it reached a stage where no influence remained from the heating period.

At this time, if the increasing of drying rate were desired, it might be done by increasing the temperature of the drying air. The higher temperature of the drying air might change the heat transferring rate from the air to the skin, raise the temperature of the skin, and finally raise the vapor pressure of the skin temporarily. As stated previously, the moisture transferring rate from the inner part to the skin has been lowered as the consequence of lowering the temperature in the inner part of the beans, this will further lower the moisture-transferring rate and leave more strain on the skin. It is clear that if this process were continued for a length of time, excessive cracking could be expected.

The above reasoning suggests that a second heating period would be more helpful. If some moisture could be removed from the beans rapidly and without excessive cracking by a single operation of the combination of heating and drying periods, more drying without cracking should be done.

Averaging of the data from several tests produced Figure 10. It shows the temperature rising curve for the second heating period. The second heating period was conducted immediately after the first drying period. It was very difficult to maintain a constant weight during the second heating period. The outer part of the beans was very dry and easily absorbed moisture from the air. The steam inlet valve was very carefully adjusted so that the increasing of sample weight was not excessive. A time of ten minutes has been chosen for the second heating period after several trials, and an increasing of sample weight of three grams per two thousand grams sample was allowed in this period. The temperature might rise more quickly, if heating air at higher relative humidity were used, but increasing weight would result. On the other hand, a longer period might be needed if less increase in sample weight were desired.

The drying period will be denoted by (D), and heating p period by (H). Thus, 15(H) - 20(D) - 10(H) - 20(D) means a 15-minute heating followed by a 20-minute drying period, followed by a 10-minute second heating period, followed by another 20-minute drying period.

Several tests of 15(H) - 30(D) - 10(H) - 30(D) and 15(H) - 20(D) - 10(H) - 20(D) were performed. Data obtained were compared with the drying operation for the same length of time but without any heating period. (Figures 11 and 12) Figure 13 shows the comparison as Figure 12 except the second heating period was more carefully controlled, and the increase in sample weight was only 2 grams per 2000 grams sample.

Data in these two figures indicate that for a 15(H) - 20(D) - 10(H) - 20(D) drying operation the amount of moisture removed from the beans was the same as if done by continuous

drying without a heating period. But the gain by the 15(H) - 30(D) - 10(H) - 30(D) drying operation over continuous drying is apparent.

Table 1 shows the cracking percentage after each drying operation.

TABLE 1

MOISTURE REMOVED AND CRACKING PERCENTAGE OF DIFFERENT DRYING PROCESSES

Drying Process	Weight of Moisture Removed per 2000 Grams Sample, grams	Percentage of Cracking
Continuous for 85 minutes	58	2.0
15(H)-20(D)-10(H)-20(D)	49	0.8
15(H)-30(D)-10(H)-30(D)	68	1.3

Usually the beans are harvested at about 22-25 percent (w.b.) moisture content and have to be dried to 15-18 percent (w.b.) moisture content for safe storage. In a sample of 2000 grams and 20 percent (w.b.) moisture content an amount of 118 grams of moisture has to be removed to get its moisture content down to 15 percent (w.b.) moisture content.

In a 15(H) - 30(D) - 10(H) - 30(D) drying operation, 68 of the 118 grams of moisture can be removed. Some other means has to be provided to remove the remaining excessive moisture. The results in Table 1 show an average cracking of 1.3 percent after a 15(H) - 30(D) - 10(H) - 30(D) drying operation. The length of the drying operation will certainly lead to more cracking. For the above reason, it is evident that before further drying of the samples, the strain that had been present in the outer part of the beans must be removed or at least decreased. Since the strain was caused mostly by the difference in moisture content between the kernel and the skin and partly because of the temperature difference between them, a re-equalization or redistribution of the moisture and heat content so as to achieve an equalized distribution of both the temperature and moisture content within the kernel of beans seems to be most desirable at this stage of drying.

If only time is given, moisture will move from the wetter part of a kernel of the bean to its drier part until equilibrium condition is established. A resting period was used to provide the needed time for this re-equalization. Tests with 6, 5, 4 and 2 hours of resting periods were performed to find out a suitable resting period. During these tests, a drying operation of 15(H) - 30(D) - 10(H) - 30(D) was conducted before the resting period and another 15(H) - 20(D) - 10(H) - 20(D) drying operation followed the resting period. The results obtained from the second operation were compared with the previous data in Figures 14 and 15.

Data obtained from 6 or 5 hours resting period are practically the same as those obtained from a 4-hour resting period. Through the comparison shown in Figure 14 and 15, it can be seen that there was no difference between the two curves except for the first five minutes. Also the comparison between the drying curves of a second drying operation after a three-hours testing period and 4-hour resting period is shown in Figures 14 and 15.

TABLE 2

COMPARISON OF MOISTURE REMOVED AND CRACKING PERCENTAGES BETWEEN SAMPLES BEING DRIED AFTER DIFFERENT RESTING PERIODS AND SAMPLES AT 17 PERCENT (w.b.) WHICH HAVE NOT BEEN PREVIOUSLY DRIED

Drying Process	Weight of Moisture Removed per 2000 Grams Sample	Percentage of Cracking
15(H)-30(D)-10(H)-30(D) 3 hours rest 15(H)-20(D)-10(H)-20(D)	25 grams	1.45
15(H)-30(D)-10(H)-30(D) 4 hours rest 15(H)-20(D)-10(H)-20(D)	29 grams	1.35
15(H)-20(D)-10(H)-20(D) with 17.62% w.b. sample	33 grams	
15(H)-30(D)-10(H)-30(D) 5 or 6 hours rest 15(H)-20(D)-10(H)-20(D)	30 grams	1.35
15(H)-30(D)-10(H)-30(D) with 17.31% w.b. sample	45 grams	0.95

From the above comparison it seems that the drying rate was dropping with the shortening of the resting time. On the other hand, the cracking percentage starts to increase with the shortening of resting time. The decreasing in drying rate and increasing of cracking was both small from the 5 and 6-hours resting period to 4-hour resting period since it compared to the difference between the 3-hour and 4-hour resting period. Therefore a resting period of 4 hours is recommended.

The comparison between a 15(H)-20(D)-10(H)-20(D) drying operation and a 15(H)-30(D)-10(H)-30(D) drying operation, both to be dried from a moisture content of about 17 percent (w.b.) is shown in Figure 16.

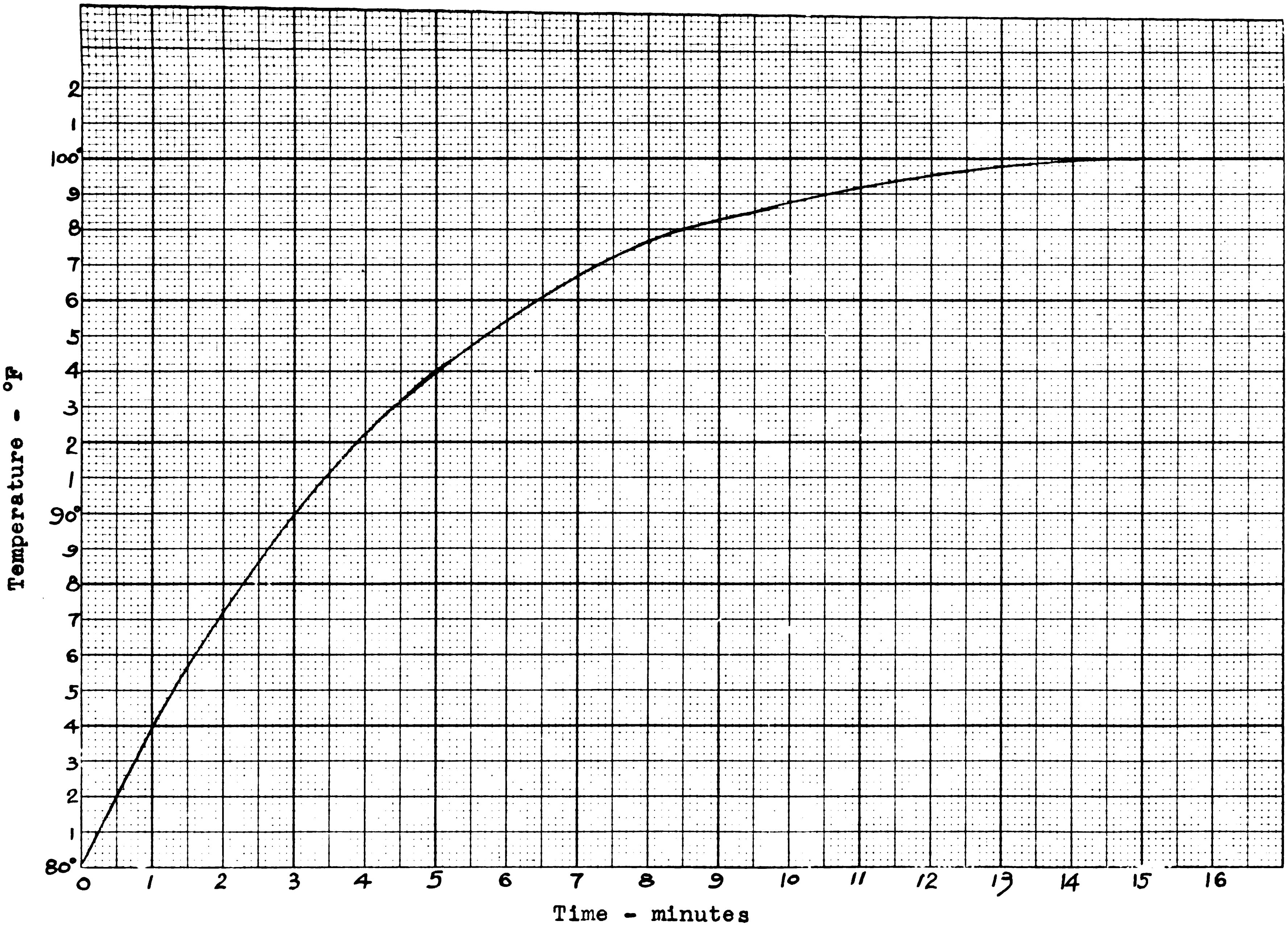


Fig. 5. Temperature change of samples at first heating period.

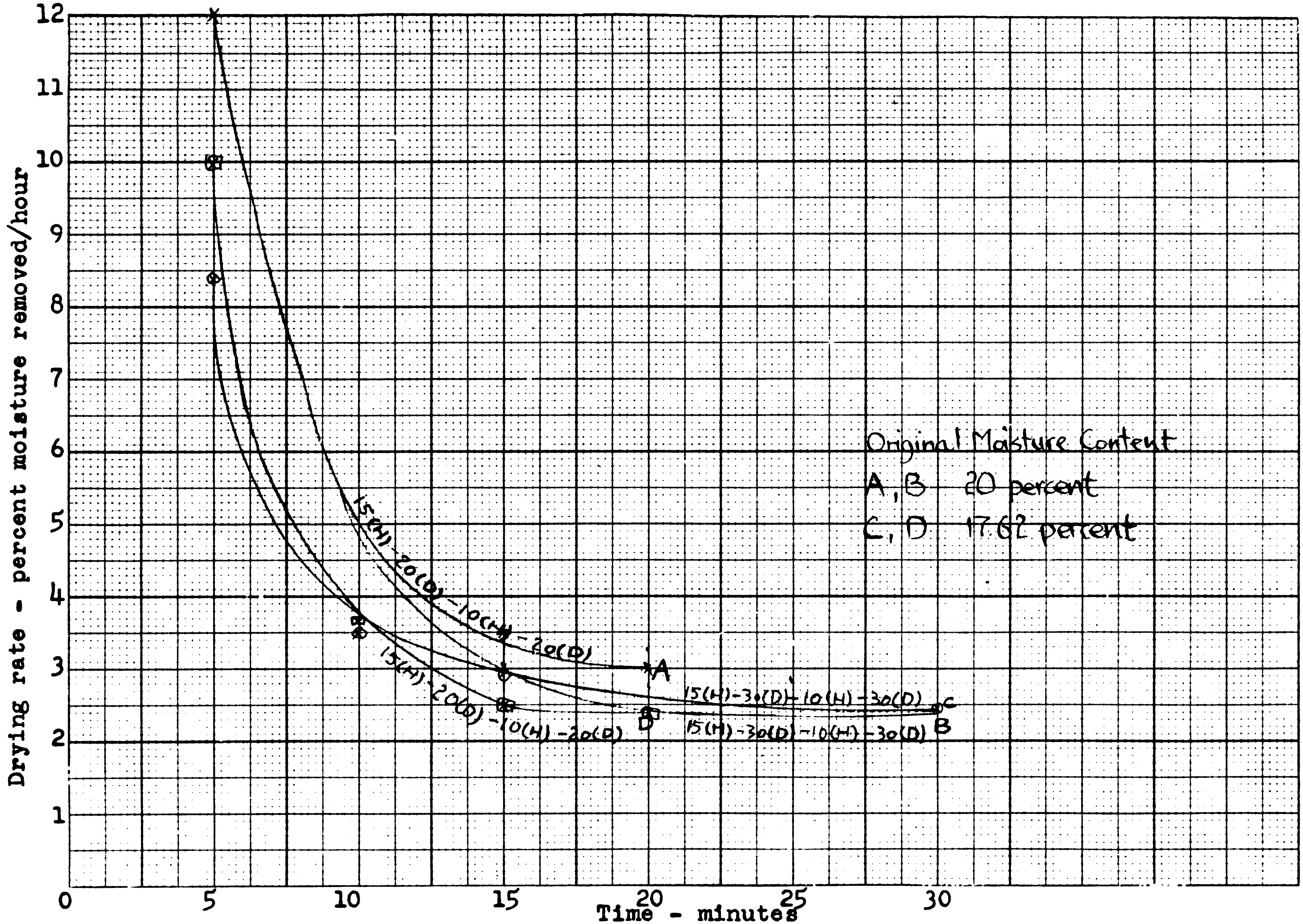


Fig. 6. Change of drying rate in first drying period (data averaged for five-minute period).

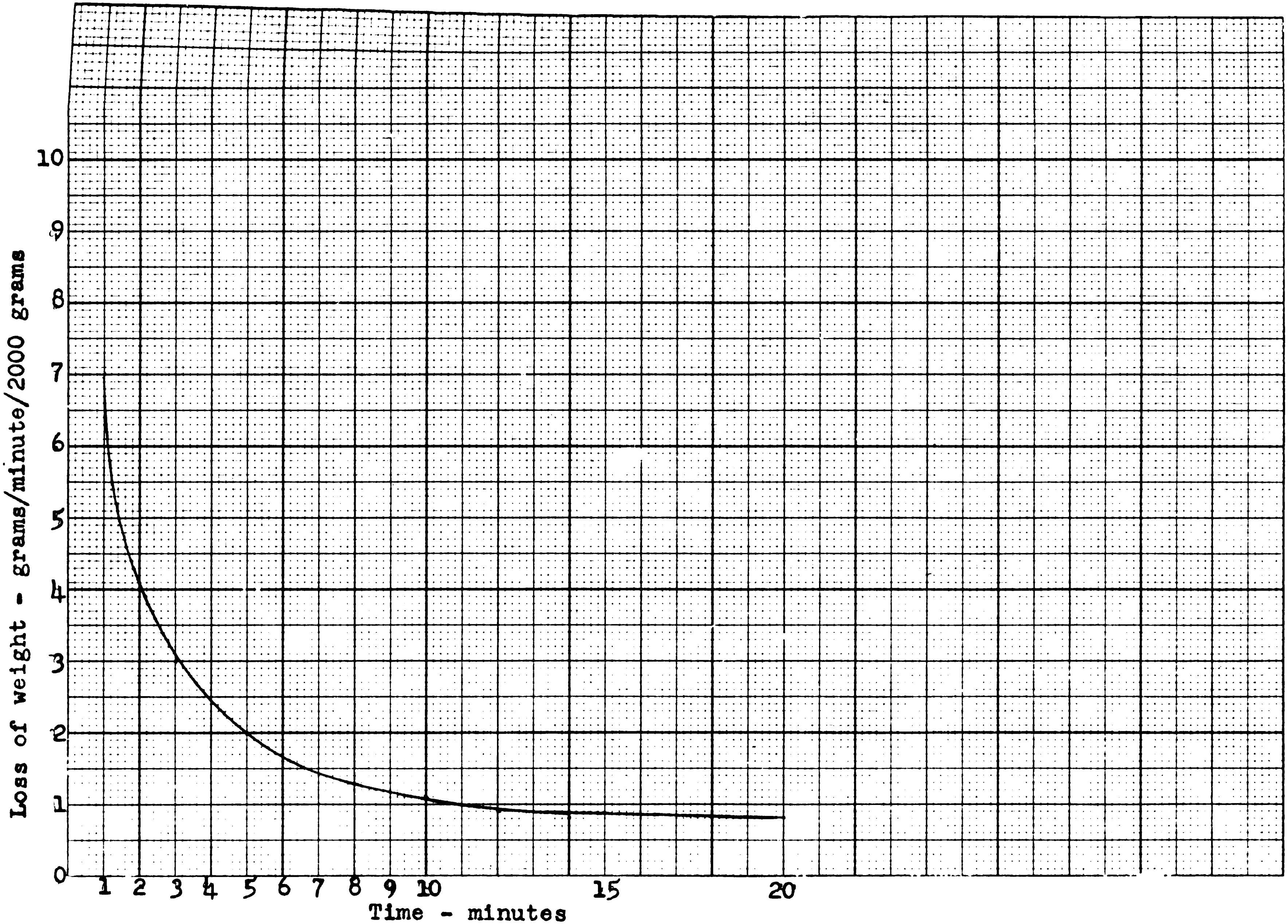
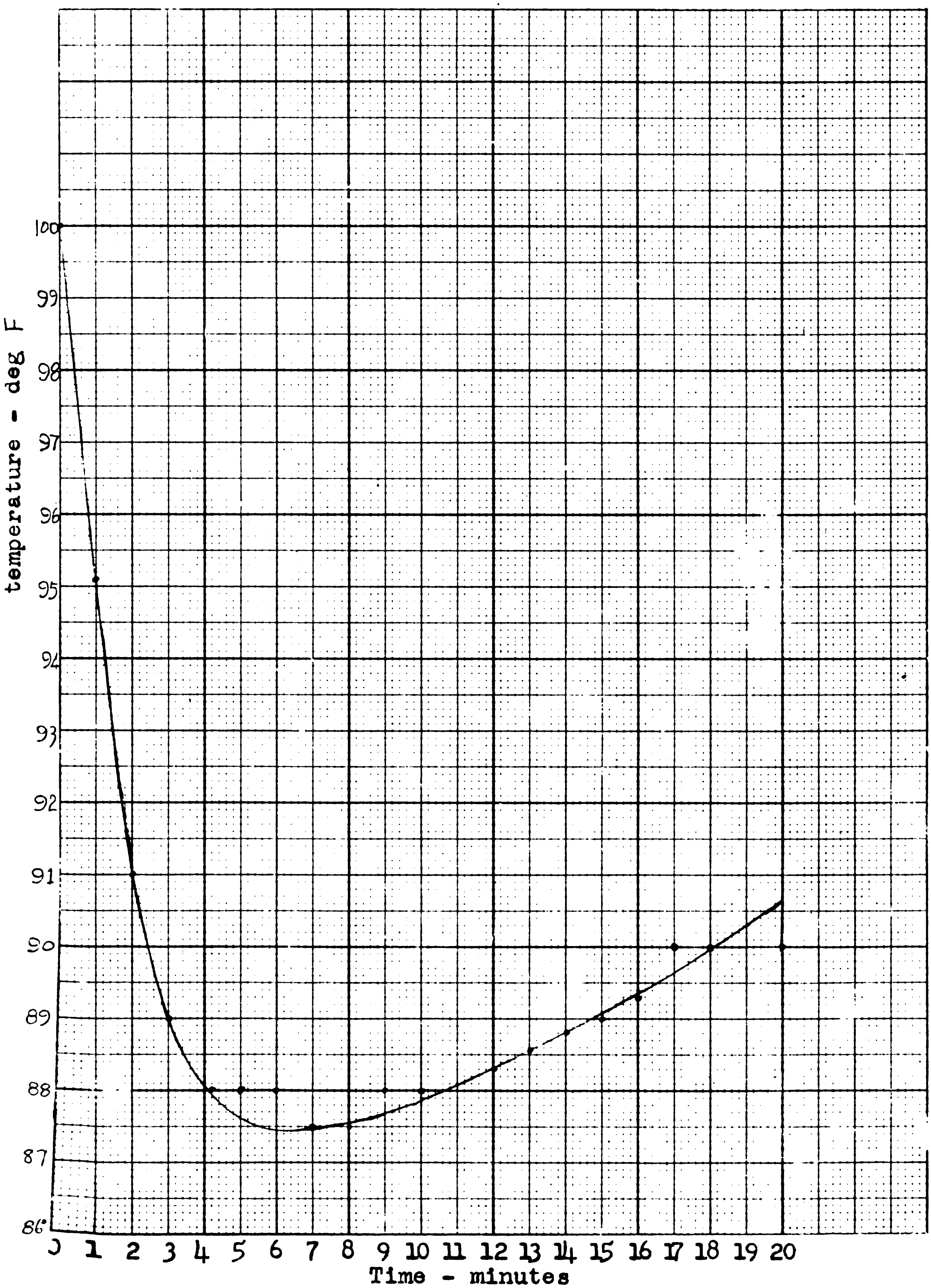


Fig. 7. Change in weight per 2000 grams of beans in the first 20 minutes of drying, sample at 20 percent (w.b.). Curve shows the average value.

Fig. 8. Temperature change in first drying period



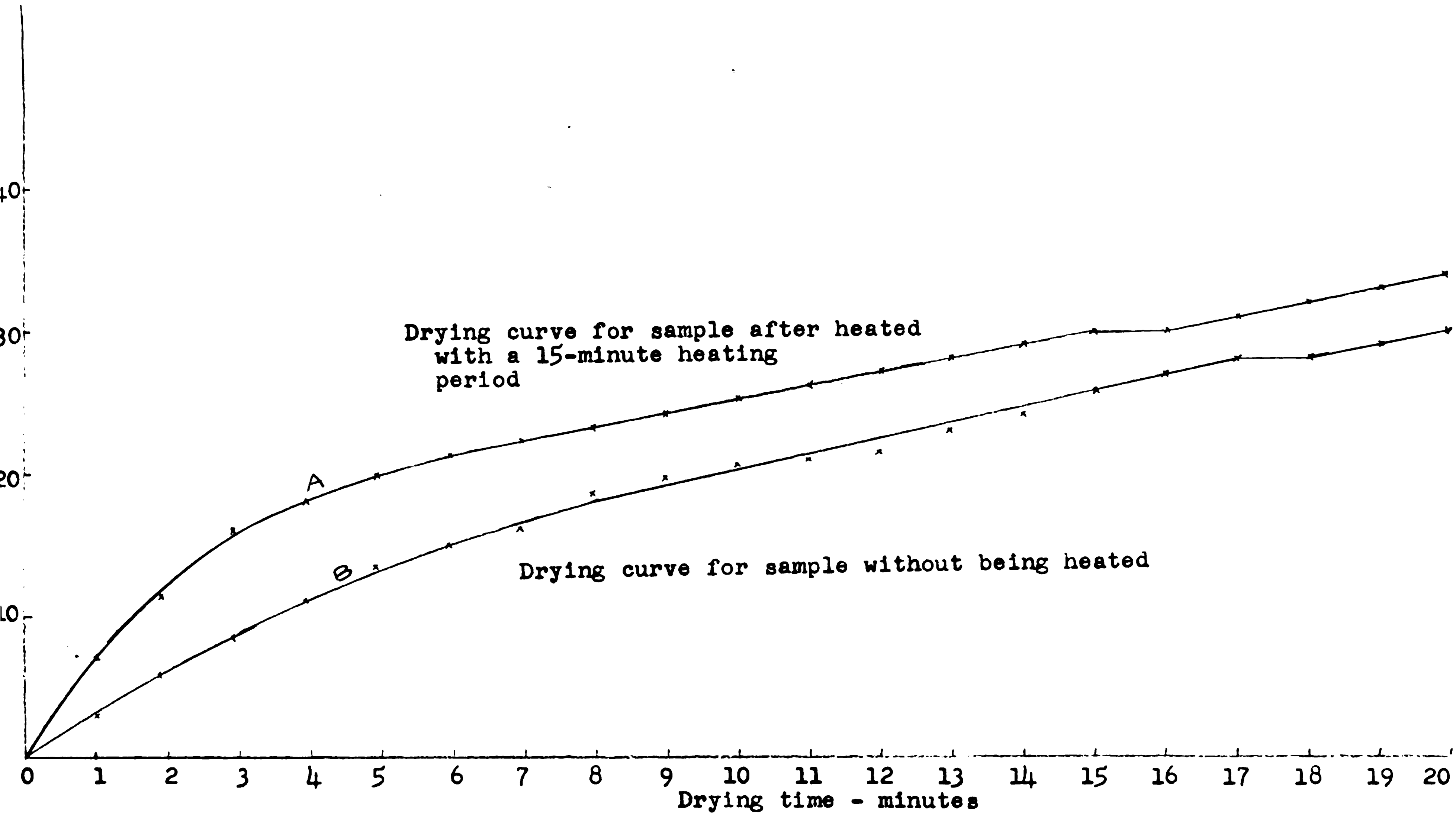


Fig. 9. Comparison of drying curves in a 20-minutes drying period and when the heating period is excluded.

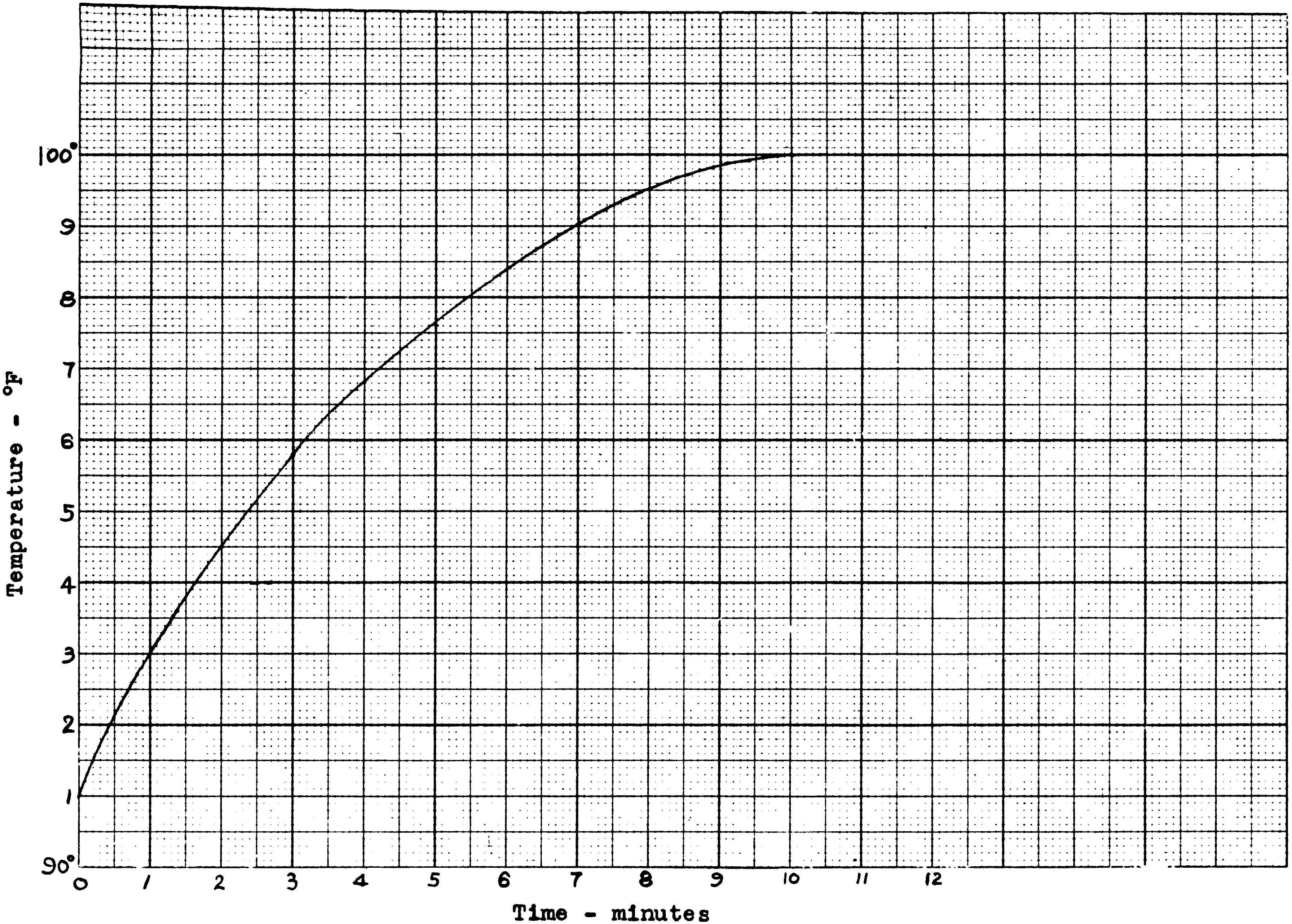


Fig. 10. Temperature change of samples during second heating period.

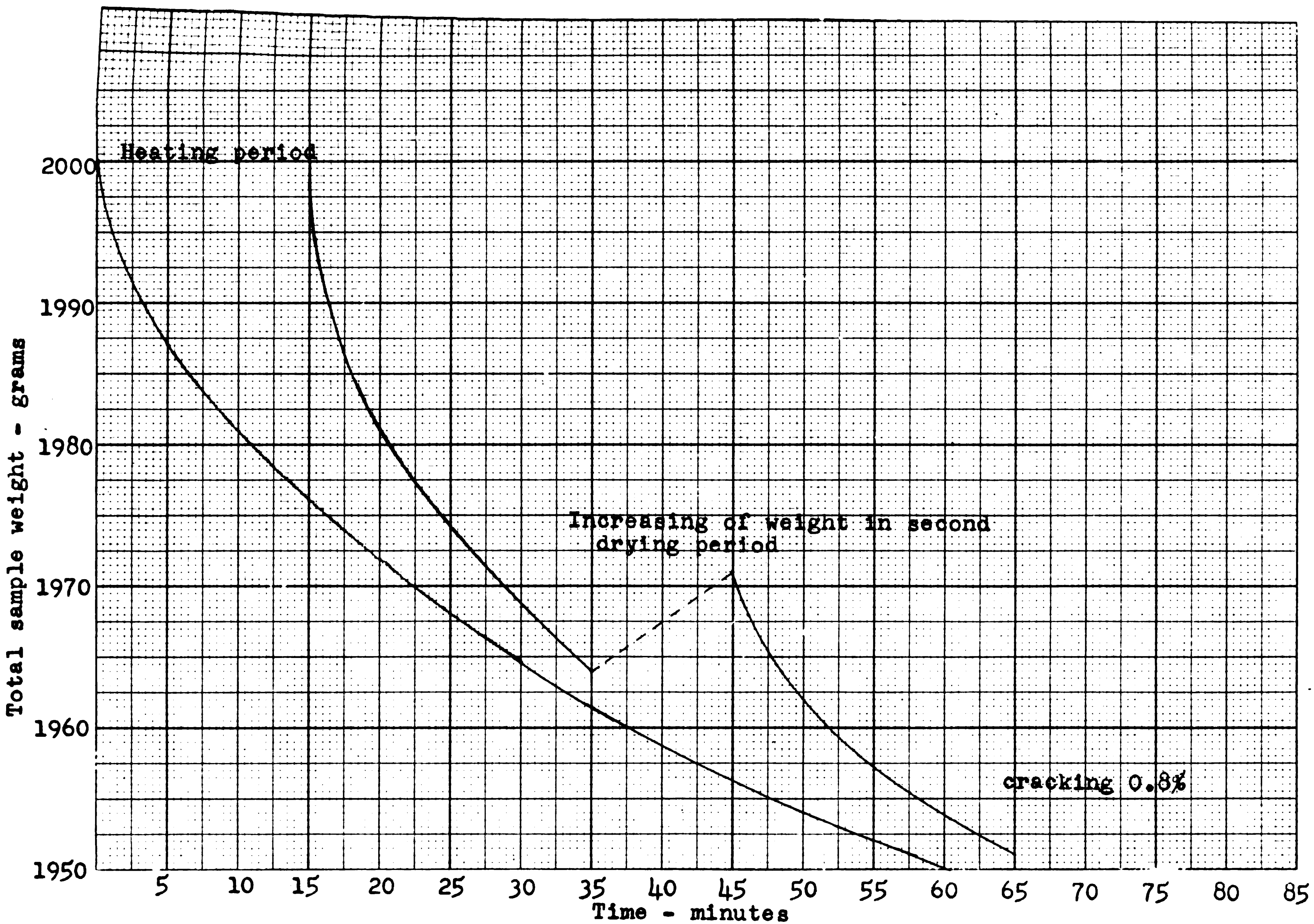


Fig. 11. Comparing drying curves between a 15(H)-20(D)-10(H)-20(D) drying operation and the drying with heated air but without heating period.

A – contineous drying, 2 percent cracking.
B – 15(H)-20(D)-10(H)-20(D), 0.8 percent cracking.
C and D – 15(H)-30(D)-10(H)-30(D), 1.3 percent cracking.

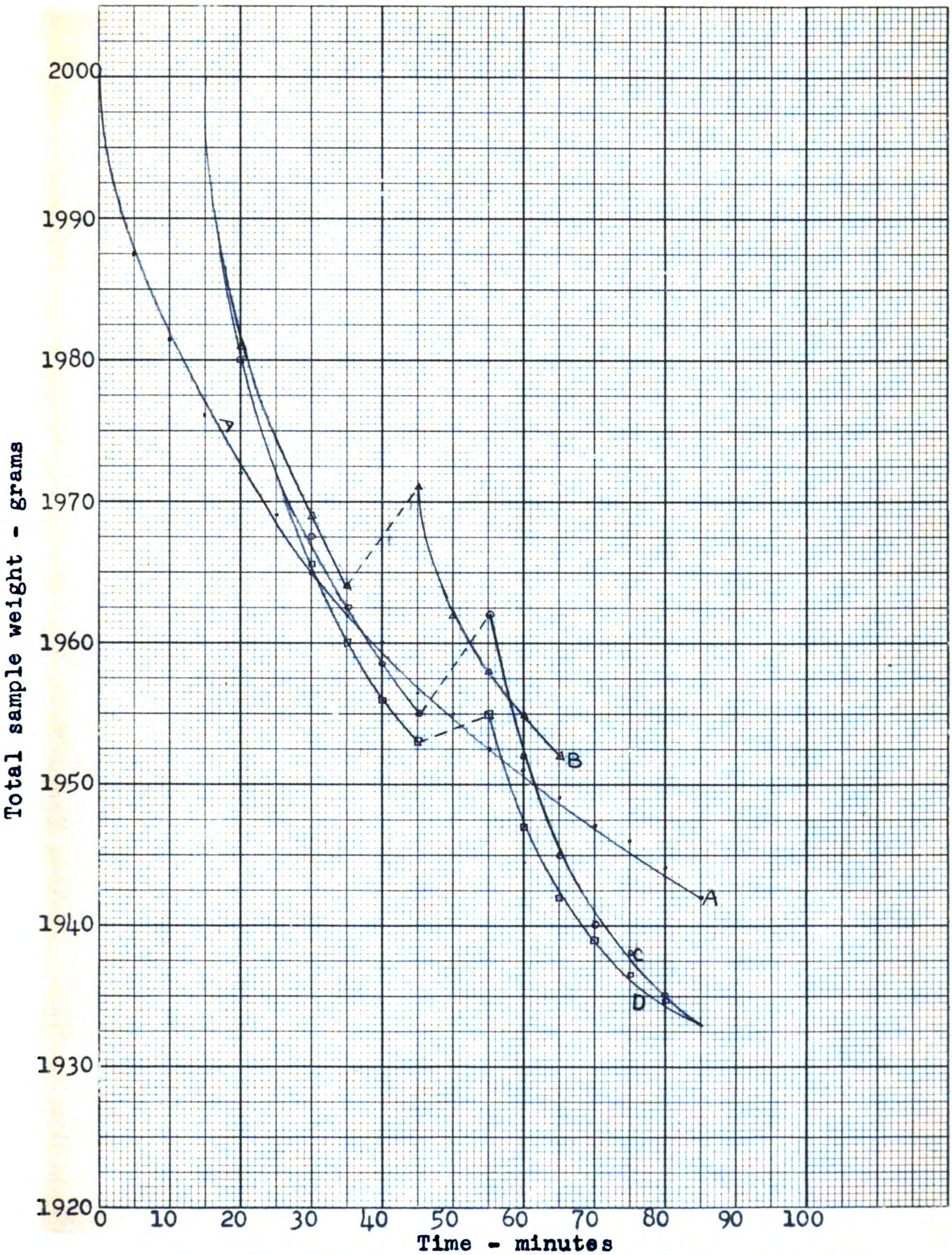
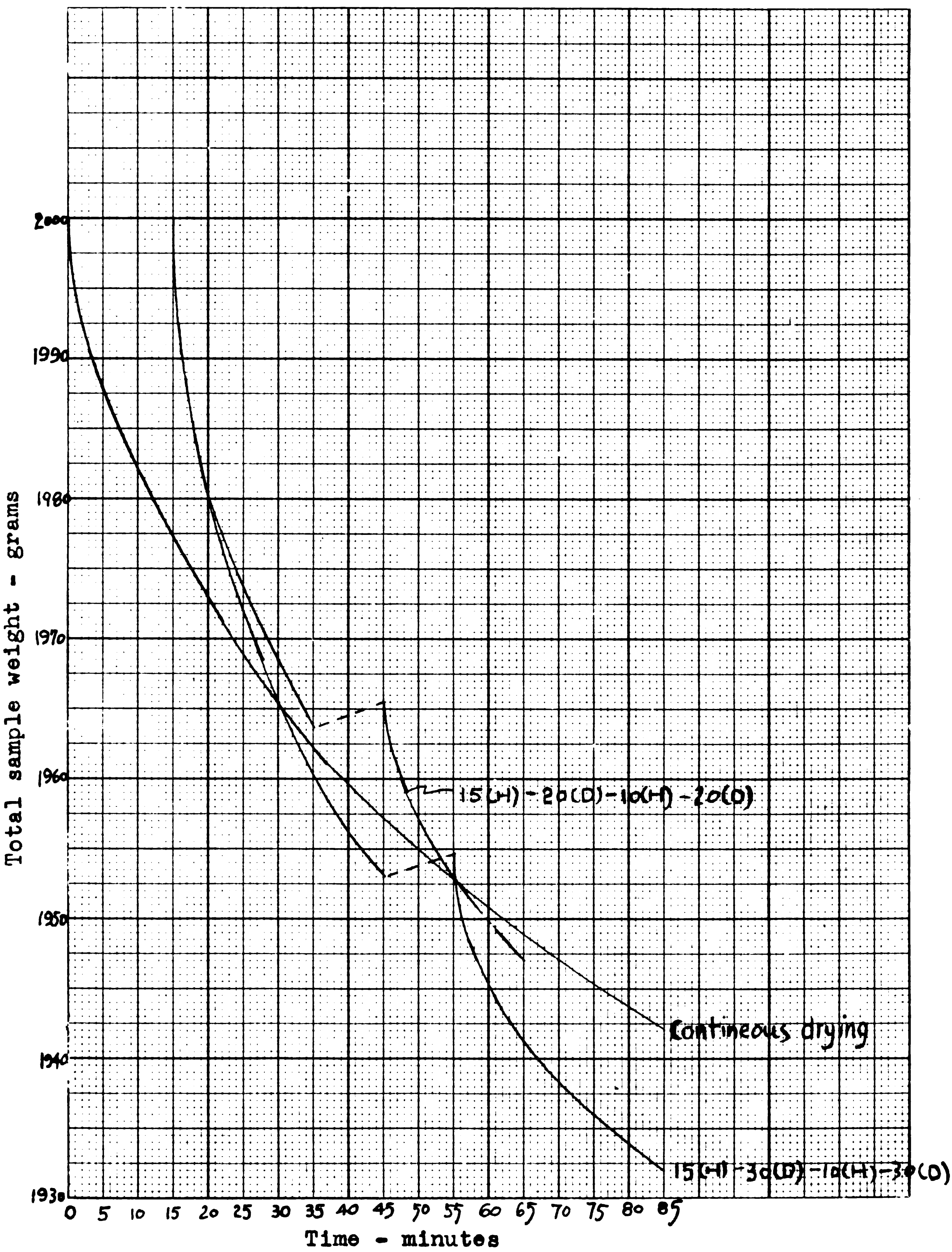


Fig. 12. Different drying processes compared with continuous drying.

Fig. 13. Different drying processes, carefully controlled at the second heating period, compared with continuous drying.



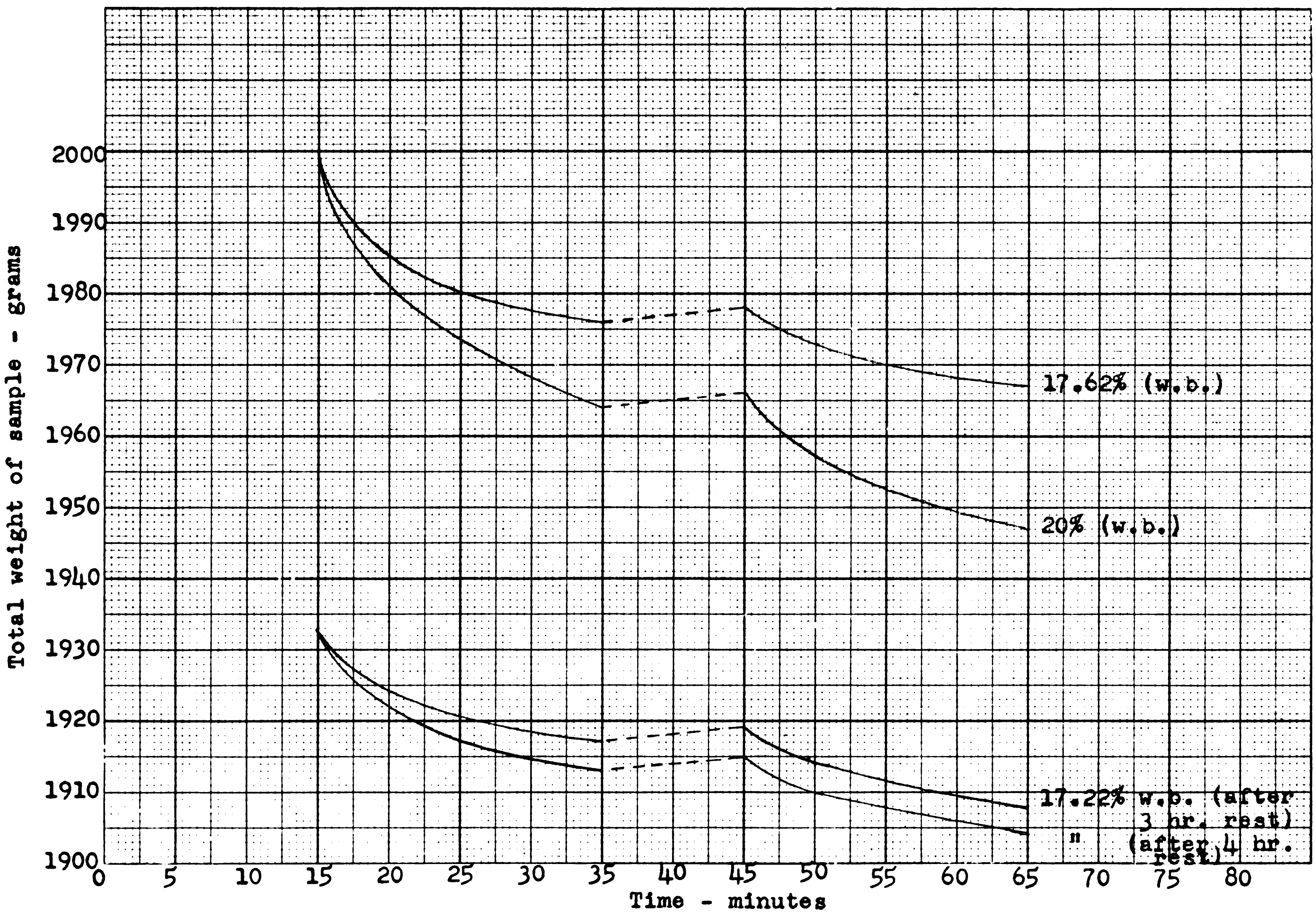


Fig. 14. Comparison between drying curves of the 17.62 percent (w.b.) sample and samples that have a resting period of 4 hours (17.22 percent). Twenty percent (w.b.) curve is for reference.

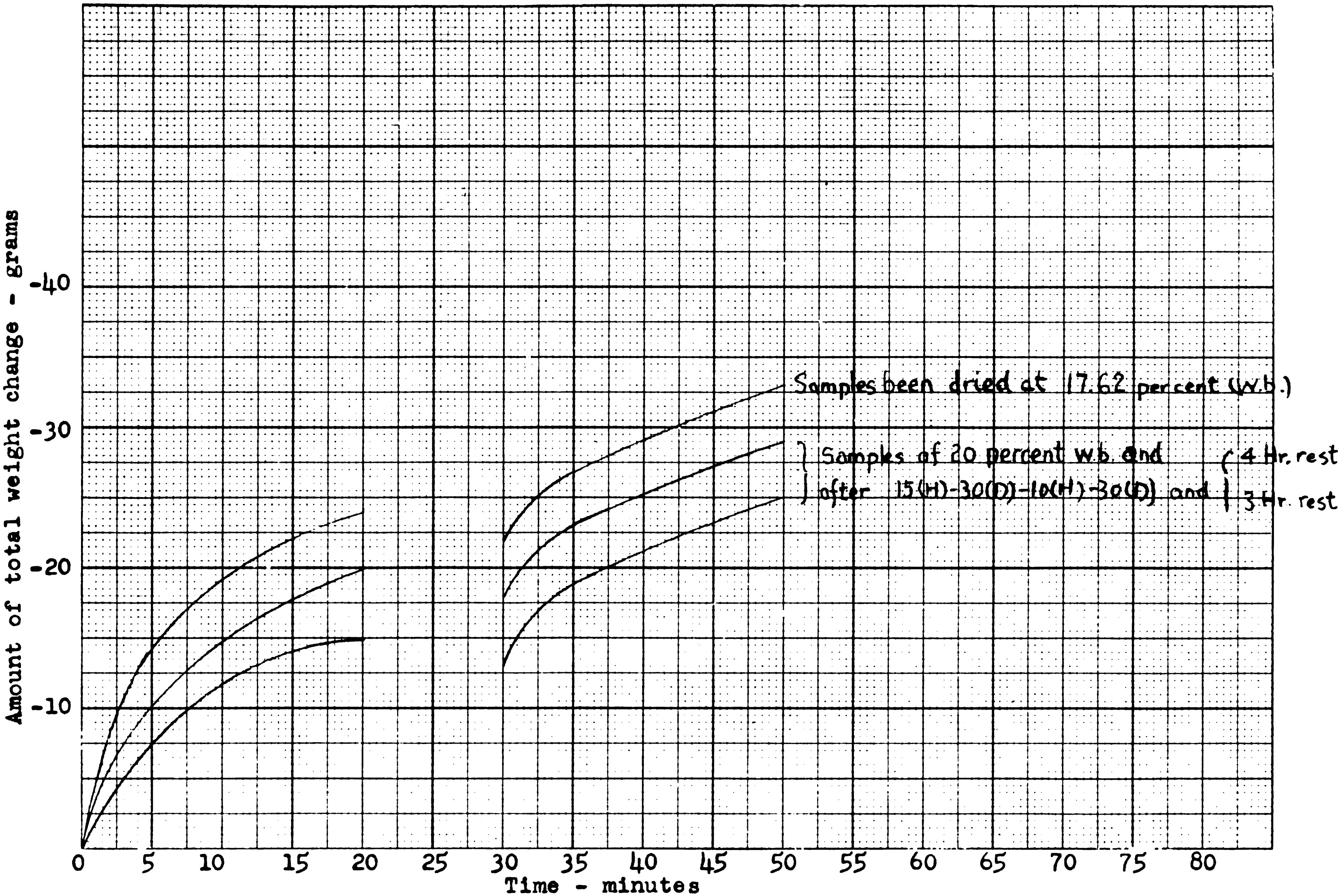


Fig. 15. Total change in weight of a 17.62 percent sample at a 20(D)-10(H)-20(D) drying operation compared to a sample that had a resting period of 3 or 4 hours.

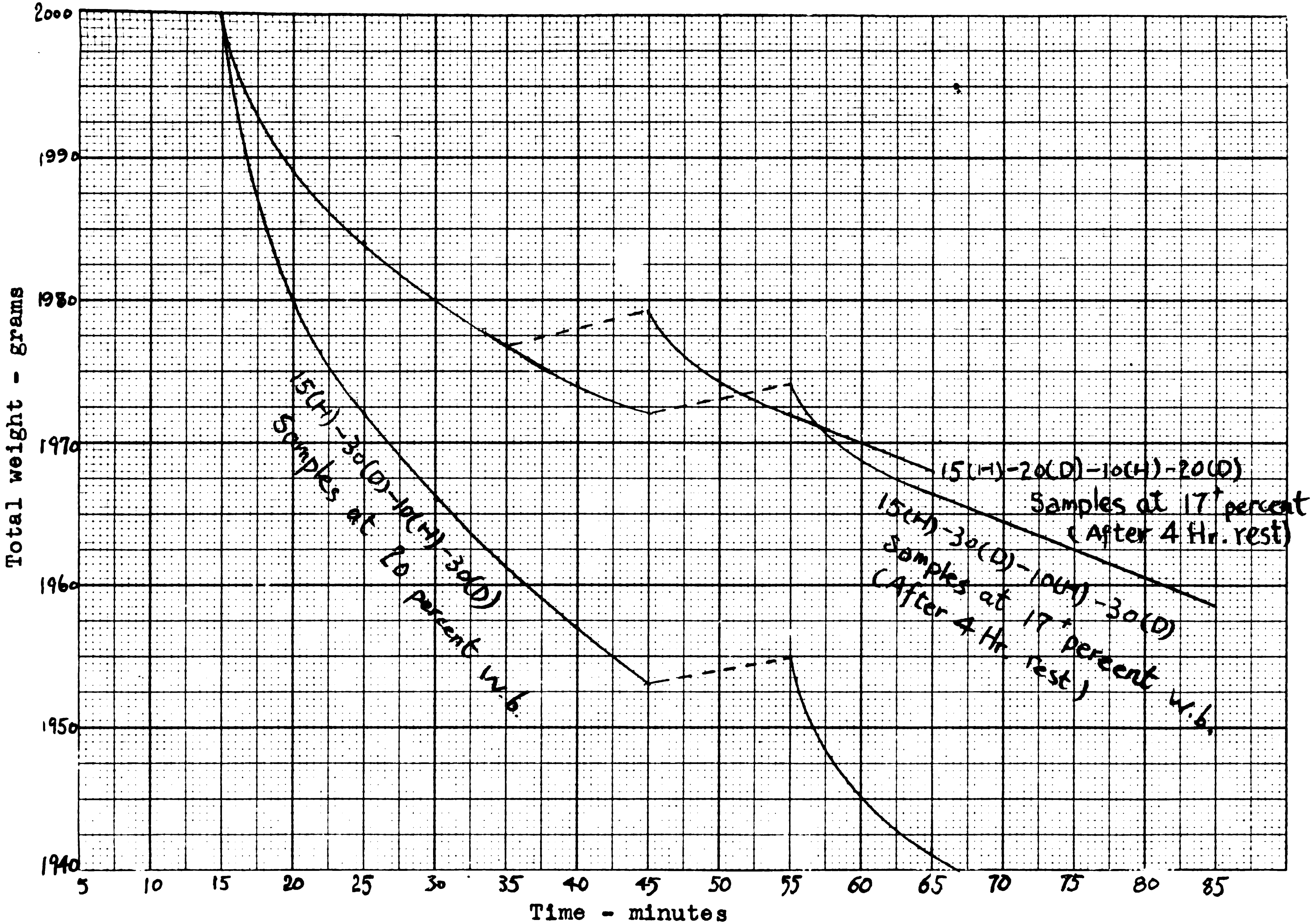


Fig. 16. Comparison between a 15(H)-20(D)-10(H)-20(D) drying operation and a 15(H)-30(D)-10(H)-30(D). Drying started at 17+ percent (w.b.).

SUMMARY AND CONCLUSIONS

Analytic investigation showed that the cracking of pea beans during the drying process is mainly due to unequal shrinkage because of moisture difference between the skin and inner part of the beans. It is the desire of the author to emphasize that although a quick drying rate might result in a moisture difference, a quick drying rate alone does not necessarily cause pea beans to crack.

The above statement is supported by the data from experiments. When heated beans were being dried, the drying rate was high at the beginning, but most cracking occurred at the latter part of the drying process when the drying rate was comparatively low. The vapor pressure is affected mainly by its temperature and less by its moisture content. The fact can be explained simply as follows:

At the beginning of the drying process, the temperature of the inner part was high and the vapor pressure was high, thus when the skin started to lose its moisture the internal vapor pressure caused the moisture to move out and a difference in moisture content resulted. But as the drying proceeded, the evaporation decreased the temperature in the inner part as well as the skin and the rate of moisture transfer lowered. Thus, a comparatively large difference in moisture content between the skin and the inner part occurred.

It has been stated by previous investigation that a "case hardening effect" in the drying process prevented the moisture from moving out and thus reduced the drying rate. Again the author thought this effect could be explained by the heat and temperature relationship in a bean during the drying process.

It has been said previously that the drying process always consumed heat and lowered the temperature of the beans. But as the drying process proceeded further, the increase in temperature difference between the drying air and beans would certainly increase the heat transfer between them. Since the drying rate would be low at this time, the increasing heat transfer rate would cause the temperature of the skin to rise. It is clear, that such a rise in temperature would lower the vapor pressure difference between skin and kernel and therefore lower the moisture transfer rate.

By occasional observations during the experiments it was found that no observable physical changes in various cross-sections of a bean could be detected by the naked eye. Beans were taken from test samples during various drying stages. A razor blade was used to cut those beans into sections, but no physical changes were observed. Maddex[8] has reported the same findings although he used the term "case hardening".

The results of those experiments conducted by the author are summarized into following items:

CONCLUSIONS

1. The heating of pea beans alone does not have a detectable effect on the cracking percentage. (At 1[illegible] deg. F)

2. The heating period was advantageous for increasing the rate of drying without excessive cracking. In the first drying operation the beans were reduced from 20 percent to 17.6 percent with continuous drying and 17.5 percent for drying with the heating period in 25 minutes.

3. A heating period of 1[illegible] to [illegible] minutes was required to heat the beans from room temperature of about 70°F to 1[illegible]°F.

4. A heating period of 4 hours is recommended between the two drying operations. The drying curve for pea beans after a 4-hours heating period is comparable with curves obtained from the wet beans.

5. For drying with an initial moisture content of 20 percent, a maximum of three moisture can be removed at one drying operation without excessive cracking -- 1.5 percent.

SUGGESTIONS FOR FURTHER STUDY

Through the experience gained from previous studies, further studies on this subject are needed. It was also felt that the results from the following recommended investigation would be of great help to illustrate both theoretically and practically the drying of pea beans as well as the drying problem as a whole.

1. A study on the physical properties like heat conductivity, tensile strength under different moisture contents, contraction coefficient due to the change of moisture content, thermal expansion coefficient etc., of the pea beans and other important farm products will be valuable for the understanding of the condition of farm products during the drying process.

2. Experiments should be conducted to obtain drying curves with or without the skin on the pea beans in order to acquire knowledge of the effect that the skin portion has on the drying of the farm products.

3. Future effort should be encouraged on the investigation of a temperature measuring device to measure the temperature distribution within the kernel of the farm product which is to be dried, because of the important part heat has played in the drying problem and since temperature is the best measurement of heat.

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