APPLICATION OF SILICA GEL FOR ON-FARM GRAIN DRYING

AND STORAGE IN DEVELOPING COUNTRIES

by

JUDY YEN-CHEN HSIAO

B. S., National Taiwan University, 1972

A MASTER'S THESIS

sumbitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

Approved by:

Do Sup Chung

Major Professor

THIS BOOK CONTAINS NUMEROUS PAGES WITH THE ORIGINAL PRINTING BEING SKEWED DIFFERENTLY FROM THE TOP OF THE PAGE TO THE BOTTOM.

THIS IS AS RECEIVED FROM THE CUSTOMER.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

INTRODUCTION

Improving the diet of human beings in specific areas of the world, for instance in tropical countries, is almost always considered in terms of increasing food production. This is not the only solution because, unfortunately, between the time a crop is harvested and the time it is consumed by man or by his domestic animals, considerable quantities of food are wasted or eaten by pests, particularly by insects and rodents. Also, loss in quality occurs whenever these pests and microorganisms (fungi and bacteria) grow on produce and also whenever improper and inadequate drying, handling, and storage methods and facilities are used. In some countries losses after harvesting (i.e., during storage, processing, or marketing) may be as high as 50 percent, and in some cases higher, especially in warm, humid areas (Hall, 1970).

The grain losses in developing countries are serious because of the lack of adequate facilities and because of the improper ways of handling, drying, and storing the grains. In developed countries such as the United States, Canada, and England, grain storage, handling, and drying problems have been thoroughly studied. So far, no completely successful technology has been adopted in developing countries, especially at farm and local levels because of the climate, economic conditions, or lack of competent personnel.

Even when they dry the grain to a safe storage condition, the grain regains the moisture in a humid atmosphere, so it must be redried for longer storage. This added procedure requires more labor and money. So this study is to develop a simple drying (or storage) device for the unskilled person.

The approach proposed in this project is to place an adsorbent (silica gel) into the grain mass for the purpose of creating a drier air condition within a storage unit such that the grain quality can be maintained.

THIS BOOK CONTAINS NUMEROUS PAGES WITH ILLEGIBLE PAGE NUMBERS THAT ARE CUT OFF, MISSING OR OF POOR QUALITY TEXT.

THIS IS AS RECEIVED FROM THE CUSTOMER.

LITERATURE REVIEW

Types of Grain Storage and Conditioning

The types of grain storage and conditioning have been studied by Ives (1968), Hall (1970), Christensen & Kaufmann (1968), McBain (1970), Anderson & Alcock (1969). Six types of storage are (1) gas-tight storage, (2) underground storage, (3) temporary storage in piles, (4) bag storage in the open, (5) bag storage within permanent buildings, and (6) bulk storage in containers.

Gas-tight storage involves storage of an agricultural product within a container in such a way that the product is protected from any exchange of gases or liquids with the outside environment. There are several advantages to this type of storage. (a) It causes the destruction of insects and other pests present in the grain at the time of storage. (b) It prevents the admittance of insects and other pests during storage. (c) It prevents mold development and heating in products carrying excess moisture, though without stopping the development of acidity resulting from anerobic fermentation. (d) Products that are dry at the time they are stored remain dry since they cannot take up moisture from the atmosphere.

Underground storage gives complete control of insects by maintaining an oxygen-free atmosphere around the stored grain; the temperature of the grain may also be kept down by cool earth. Protection against ground and surface water is essential.

The success of the practice of piling grain on the ground depends upon the following factors: (a) the weather during the period of exposure, (b) the ground upon which the grain is piled and the drainage at the edges of the piles, (c) the care exercised in piling the grain, and (d) the length

In developing countries produce is commonly stored in jute bags without any form of protection or with only tarpaulin type sheets covering stacks of bags to provide protection from rain. Again, weather factors affect the success of the storage, and protection against moisture and pests is nil.

The design of permanent buildings for bag storage usually is such that there is permanent ventilation, often of such a nature that sheet cladding is fixed permanently at an angle to the vertical at the floor level and midway up the walls to increase normal ventilation. Such design features make rodent proofing virtually impossible and insect control extremely difficult. However, buildings of this type are not only in use in the dry areas of the world but also in the wet or humid areas where produce in storage is exposed to high humidity air. The readsorption of moisture which takes place, especially in the outer layers of bags, accelerates biological activity in the produce. Deterioration inside steel clad buildings fluctuates more than in buildings protected by insulation. In the hot dry areas where surface temperature is extremely high, produce stacked within one metre of the roof or close to the walls becomes hot.

There are three forms of bulk storage in containers: (1) upright storage in concrete or steel structures, (2) flat storage in concrete, steel, or wood structures, and (3) either flat or upright storage in containers made of various indigenous materials such as mud, bamboo, plants, etc. These containers have the advantage of potential use for drying as well as for storing produce.

Certain preventive and control measures have been developed in order to condition grain or remove the cause of a storage difficulty when it is discovered. The particular measure employed depends on the nature of the difficulty. Among conditioning methods, the most commonly used are:

(1) Moving, turning, or cleaning: Cleaning is practiced to prevent the development of heat which is caused by dust and other foreign material mixed with grains. Moving and turning maintain a more uniform temperature distribution in the mass of grain being stored. For large volumes special equipment is necessary for moving grain, so the process is hard to use in developing countries.

(2) Drying: Drying is practiced to prevent germination of seeds, to retain maximum quality of the grain, and to reach a level of moisture which does not allow the growth of bacteria and fungi and which considerably retards the development of mites and insects. It is essential that food grains be dried quickly and yet effectively. There are two types of drying, natural and artificial.

The natural drying utilizes a combination of sun and air but also requires time and some effort by man to spread and later collect the produce. In this method, care must be taken to avoid too rapid drying or overdrying and to minimize excessive movement of the grains, which causes breakage or damage to the seed coat, and to eliminate dust and dirt, which accelerate deterioration by permitting an increase in moisture content and fungal contamination.

The artificial drying involves the use of ambient temperature air and some mechanical means of moving it through the produce, or of air heated

THIS BOOK CONTAINS NUMEROUS PAGES WITH MULTIPLE PENCIL AND/OR PEN MARKS THROUGHOUT THE TEXT.

THIS IS THE BEST IMAGE AVAILABLE.

above ambient temperature with the mechanical means of moving it through the produce. There are three methods for artificial drying:

(1) In-storage or deep layer drying: By this method grain a depth of 9 to 13 feet can be dried. The grain is not moved out of the drier (bin). If drying is being carried out with unheated air, an air flow rate of 5 to 10 cfm/bu. is required. However, if relative humidities are 70 to 80 percent, heater air is required, and the flow rate can be as low as 3 cfm/bu.

(2) Non-mixing driers, of two forms: (a) The column drier is most commonly used because it takes advantage of the gravity flow of grain through the drier to reduce the amount of machinery in the drier itself and utilizes standard elevating and grain handling equipment. (b) The horizontal drier is normally operated as a batch drier.

(3) Mixing driers: (a) Mixing, shallow-layer driers provide slightly more uniformity than non-mixing driers in the drying of grain. (b) Moving-bed, shallow-layer driers have perforated bottoms through which air is forced to dry the grain.

Grain Storage Problem

The storage of grain in farm and similar bins is hampered by (a) insect infestation, (b) moisture migration, and (c) wall and roof leaks, which contribute to the former problems. The remedy of the latter problem is obvious.

Directly responsible for causing loss of stored materials are: insects, mites, rodents, bacteria, and fungi. Among these, rodents, mites, and insects are most commonly found attacking stored foodstuffs, simultaneously distracting attention from bacterial activity which is regarded as a "natural" consequence of storage at normal temperature. Fungi and bacteria are partly caused by unhygienic methods of storage, and by improper conditioning of foodstuffs before storage. The infestation of a commodity where it is first stored will depend entirely on the type and degree of endemic infestation in the locality in which it was produced. The endemic infestation is affected considerably by climatic conditions and their variations.

More than sufficient knowledge is available to eliminate pests in stored products. Heavy losses of stored products, due directly to infestation, are now to be found only in a few developing countries. In highly developed countries the methods which have been used to prevent damage and loss by pests include the following (Rose,G. J.,1963):

(1) Physical control measures

(a) Heat treatment: where a grain or other commodity is raised to a temperature lethal to its known pests and is maintained at this temperature for a given time.

(b) Refrigeration: where a wider range of commodities may be either stored at a temperature at which pest development is arrested, or first subjected to a low temperature for enough time to be lethal to the known pests of that commodity.

(c) Radiation treatment: at present in experimental use only, but of considerable future interest if proved economical and not harmful to materials treated.

(d) Radiasthesia treatment: also in its experimental stages, but economically sound if controllable and without ill-effect on commodities treated.

(e) Trapping: a measure ordinarily used against rodents, and with some value against insects also.

(f) Self-destruction treatment: where infested commodity such as one of the grains is put into airtight storage and the carbon dioxide respired by the insects (and possibly by the grain also) eventually reaches a concentration lethal to the infestation.

(2) Biological control

The use of parasites to reduce populations of moth pests and, in the case of rodents, the use of preparations to reduce the numbers of females in a population, with obvious consequences.

(3) Chemical control measures

(a) fumigants

(b) rodenticides

(c) insecticides and miticides

To prevent the development of fungi and microorganisms, the moisture content of the goods admitted into storage must be 14 percent or less. According to BEHLEN Manufacturing Company (1972) and Sinha (1973), the maximum moisture content (wet basis) of grains for long-term storage is for wheat, 12%; oats, 13%; barley, 13%; grain sorghums, 12%; shelled corn, 13%; soybeans, 11%; rice, 12%. During storage, extremes of temperature and humidity should be avoided, by using forced circulation of dried air if necessary. Reducing the surface area of products (or their containers) to be exposed to air changes is always desirable. Drying can be accomplished using the method discussed above in "Types of Grain Storage and Conditioning."

Since grain foods are seeds, there are three indications of the extent of invasion of seeds by storage fungi: (a) loss of germinating ability, (b) discoloration, and (c) high fat acidity value (Christensen & Kaufmann, 1968). Once any of these signs is observed, the grain can at best be stored for only a short time longer, provided the infestation is in an early stage. If it is more advanced, the grain must be used at once. At worst, the grain might have to be destroyed.

Because dryness is so important to the preservation of grain, it is necessary to understand the behavior of water vapor being adsorbed into and desorbed from grain.

Adsorption and Desorption of Water Vapor in Grains

Although the adsorption and the desorption processes may be classified as physical (van der Waals) or chemical, in grain drying it is the physical process which must be considered. Physical adsorption is caused by intermolecular forces between the molecules of water vapor and the surface of the adsorbent. The lower the water content of the grain, the more tightly the water molecules are bound and, hence, the less free they are to enter the atmosphere. Water which has been adsorbed into grain is no longer ordinary water. In addition to being no longer free to flow, it is of slightly higher density and slightly lower specific heat, and it exerts lower vapor pressure. The net heats of adsorption and desorption of materials approach zero as the amount of adsorbed water increases. This phenomenon indicates that the degree of change that the adsorption makes in the water lessens as more and more water is adsorbed until finally the adsorbed water molecules on the surface of the adsorbent behave like pure water.

Because grains are hygroscopic materials, the researcher needs to know a very important property that hygroscopic materials have, that is, the equilibrium moisture content, related to storage and drying problems. The equilibrium moisture content is reached when the moisture content of a stored farm product approaches a value controlled by the ambient relative humidity and temperature.

Many workers have investigated the relation between the equilibrium moisture content of grain and the atmospheric relative humidity at a constant temperature, and have developed isotherm equations:

$$1-rh = e^{-kTM_e^n} \quad \text{---Henderson (1970)}$$

$$\ln(rh) = -A/RT\, e^{-BM_e} \quad \text{---Chung (1966)}$$

where:

rh: relative humidity of air

T: temperature of air

K, A, B and R: constants

M_e: equilibrium moisture content, d. b.

Most food grains when they adsorb water or desorb water, evince a hysteresis as shown in Fig. 1, which displays the characteristic of the equilibrium moisture content is always being higher for desorption than for adsorption. This is discussed by Babbitt (1945), Breese (1954), Hart (1964), McBain (1935), Chung (1967). They found that the hysteresis effect decreases with increasing of temperature and pressure and also with repeated raising and lowering of moisture content of grain.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

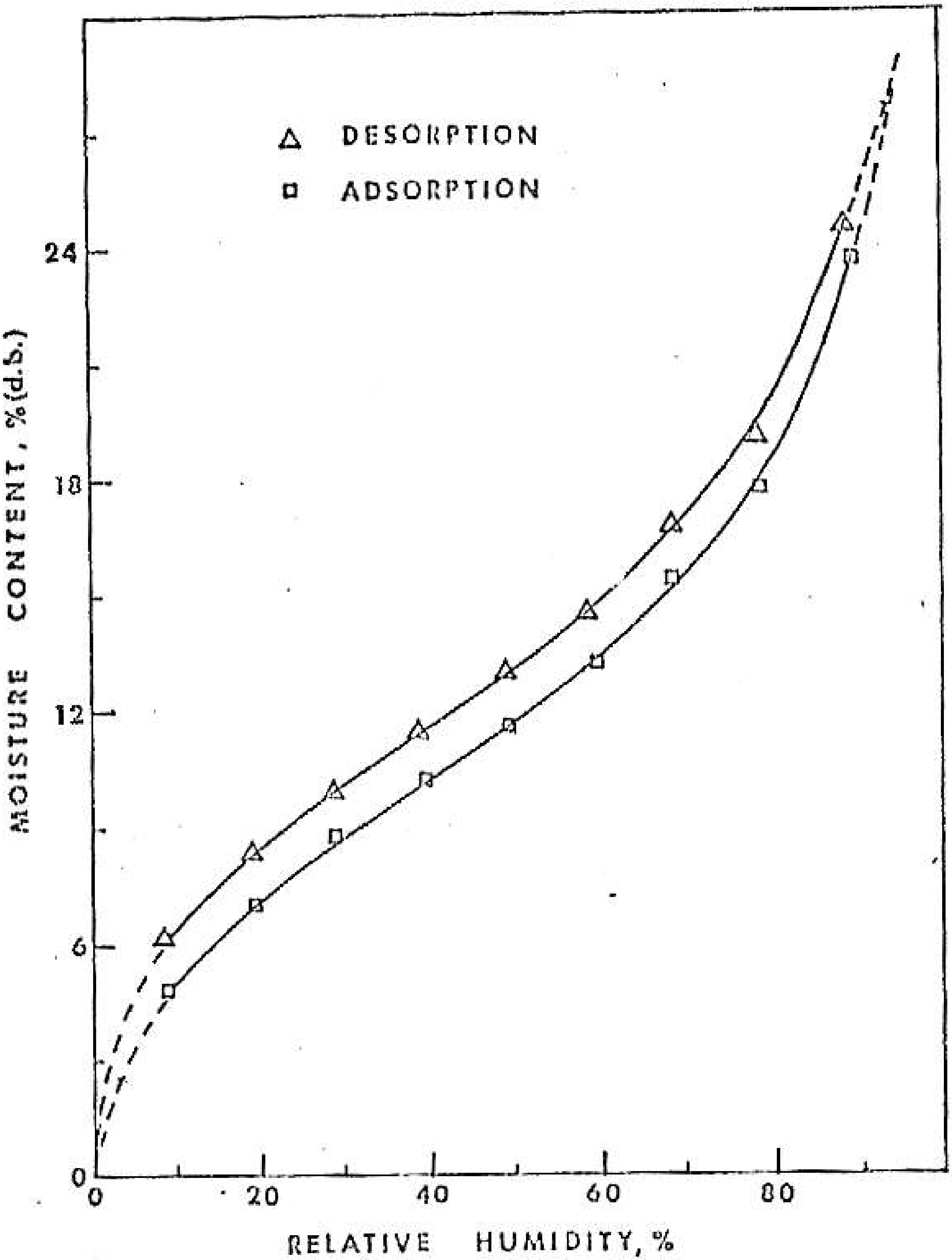


Figure 1. Adsorption-desorption isotherms of corn at 22°C showing hysteresis effect, Chung (1966).

Many studies have been done in efforts to characterize the drying rate predicted, but the diffusion model seems to have a distinct advantage over other models in accurately collating experimental data collected over a long drying period. The close agreement of data suggested by this model indicates that moisture is transferred to the kernel surface by a process of diffusion.

In water-grain relationships, the drying process must be considered. Henderson (1970) and Lebedev (1961) stated that there are two periods in the drying process: (1) the constant-rate period, and (2) the falling-rate period. As the moisture content of the kernel decreases, the intensity of transfer also decreases, and the drying rate drops off. A relationship between moisture content and drying time can be expressed by

$$\frac{\bar{m} - m_e}{m_o - m_e} = Ae^{-kt}$$

where:

A and K: constants

t: time, hr.

$\bar{m}$: average moisture content of grain at time t

m_o: initial moisture content, d. b.

m_e: equilibrium moisture content, d. b.

Crank (1964) presents the equation of diffusion for a homogeneous, isotropic symmetrical sphere with radius R and constant diffusion coefficient D:

$$\frac{\partial m}{\partial t} = D\left(\frac{\partial^2 m}{\partial r^2} + \frac{2}{r}\frac{\partial m}{\partial r}\right)$$

where m is the concentration at radius $r < R$ and time t. He solved this equation for a sphere with uniform initial concentration, m_o, and a constant surface concentration in equilibrium with the environment m_e. His initial and boundary conditions are expressed mathematically as follows:

$$m(r,o) = m_o \ , \ r < R$$

$$m(R,t) = m_e \ , \ t > 0$$

$$\left.\frac{\partial m}{\partial r}\right| r=o \ , \ t > 0$$

The last condition is the result of the sphere's symmetry with respect to the center. Integrating the solution over the volume of the sphere, Crank (1964) obtained the following expression for the average concentration, $\bar{m}$:

$$\frac{\bar{m} - m_e}{m_o - m_e} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} e^{-n^2 Kt} \qquad \text{where:} \quad K = D\ \pi^2/_{R}2$$

Hamdy and H. J. Barre (1969) further assume that the kernel has a uniform initial moisture distribution and is enclosed by a thin, stagnant film of air. If there is no moisture accumulation in the film, its moisture balance can be expressed as follows:

$$D \left.\frac{\partial m}{\partial r}\right|_{r=R} = -\beta(m_s - m_e)$$

where m_s is the surface concentration and β is the film coefficient which will be assumed constant. Using this moisture balance in the boundary conditions, the proposed model can be stated as follows:

$$\frac{1}{D}\frac{\partial M}{\partial t} = \frac{\partial^2 M}{\partial r^2} + \frac{2}{r}\frac{\partial M}{\partial r}$$

where:

$$M(r,o) = 1, \ r < R \qquad M_s = \frac{m_s - m_e}{m_o - m_e}$$

$$\left.\frac{\partial M}{\partial r}\right|_{r=R} = -\frac{\alpha}{D} M_s, \ t > 0$$

$$\left.\frac{\partial M}{\partial r}\right|_{r=o} = 0, \ t > 0$$

where M is the dimensional moisture ratio defined by

$$M(r,t) = \frac{m(r,t) - m_e}{m_o - m_e}$$

By using a computer Hamdy (1969) evaluated the film coefficient in single-kernel drying.

<u>Adsorption and Desorption of Water Vapor on Adsorbents</u>

<u>The Chemical Engineer's Handbook</u> (1950) classifies drying agents into four types: (1) solid adsorbents, which remove water vapor by chemical reaction, (2) deliquescent adsorbents, which remove water vapor by chemical reaction, (3) liquid adsorbents, which remove water vapor by adsorption, and (4) solid adsorbents such as silica gel, which remove water vapor by surface adsorption and capillary condensation.

Solid desiccants retain water by one or more of the following mechanisms: (1) adsorption hydroxides, (2) adsorption in a monomolecular layer on the desiccant surface, and/or (3) adsorption by capillary condensation when the desiccant is highly porous. Fig. 2 shows the isotherms for a few solid adsorbents.

Fleske (1973) tested five solid adsorbents for their effectiveness in grain drying: Lime, $CaCl_2$, NaCl, $CaSO_4$ (drierite), and Silica gel (6-16 mesh). He found that Lime just does not have the adsorptive capacity needed for corn drying; that $CaCl_2$ gives off tremendous amounts of heat when water vapor is adsorbed by it; that NaCl gains moisture at a steady rate, but it becomes a solution after a quantity of water has been accumulated; that $CaSO_4$ also has a steady rate of moisture adsorption, but the rate is too slow to prevent corn spoilage; and that silica gel has an effective capacity for adsorption and maintains grain quality.

Several workers studied the relationship between silica gel and vapor. First, silica gel is chemically inert, non-toxic, non-deliquescent, dimensionally stable, and non-corrosive and is resistant to most acidic streams; second, its adsorption characteristics result from its huge surface and its highly porous nature. Fig. 2 shows that silica gel has a higher adsorption capacity than other desiccants. The equilibrium capacity of silica gel varies little with temperature if the relative saturation is constant.

The amount of vapor that silica gel will adsorb from a given gas mixture depends upon the relative saturation (equivalent to relative humidity) of the vapor in the system. Although many theories have been proposed to account for the adsorption capability of silica gel, none describe it perfectly. The most logical explanation for the behavior of silica gel lies in a combination of theories proposed by Grace Company (1973). In brief, the concept is as follows:

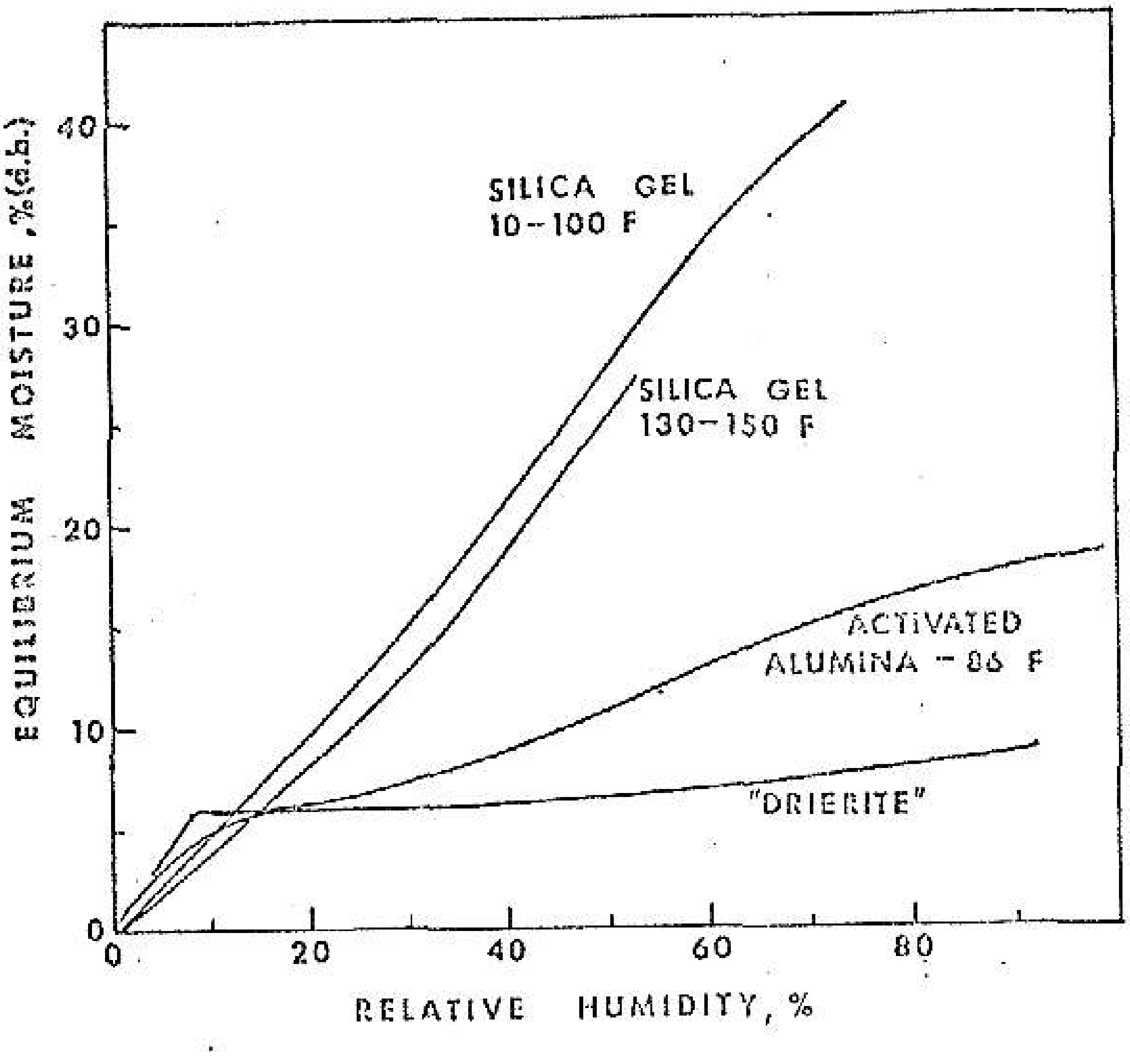


Figure 2. Equilibrium moisture for solid desiccants, Chemical Engineer's Handbook (1950).

1. The pores of silica gel may be regarded as muliple connection channels, or capillaries, of varying widths. The initial vapor condensing in the pores is essentially a monomolecular layer which will form even at very low relative humidities.
2. Further adsorption is in the form of capillary attraction with the condensed liquid in the capillary forming a meniscus, concave to the vapor phase. The vapor pressure over this meniscus is lower than the normal vapor pressure of the liquid by an amount proportional to the degree of curvature. Hence, in small capillaries, such as the narrower sections of the pore channels, *vapors can condense at pressures far below the normal vapor pressure*. Hence, smaller diameter pores give larger lowering of the pressure, resulting in more adsorption at low relative pressures. As the relative pressure increases, adsorption in the larger pores takes place.

For intermediate and high ranges of relative pressure, which apply to most commercial uses of silica gel, the adsorption of vapors is on a volume basis proportional to the relative pressure of the vapor and to the surface tension of the condensed liquid as follows:

$$V = \frac{\sigma K P}{P_o}$$

where:

V = vol. of liquid adsorbed

P = partial pressure

P_o = saturation pressure

σ = surface tension of liquid

K = constant

The pores of regular density silica gel, which have a total volume of about 40 cc/100 gm., will hold approximately 40 cc of any condensed vapor at 100 percent relative saturation (P/P_o). Furthermore, the total volume of adsorbed vapor decreases with decreased relative saturation. Since surface tension is zero at the critical temperature, silica gel will not adsorb vapors of liquids at temperatures approaching the critical point. The heat conductivity of gel material is usually low, hence the transfer of heat from interior capillaries tends to be dependent on gel size.

The rate of adsorption is dependent on the flow rate of the air because of several factors, such as turbulence and consequent contact of the air with the gel (Ahlberg, 1939). At the higher flow rates the air not only causes a greater quantity of adsorbable vapor to come into contact with the adsorbent in a given time, but, owing to the greater heat capacity of the larger volume of air, the heat of adsorption is more rapidly removed from the gel. Miller (1920) found that vapors of liquids of a high boiling point are more strongly adsorbed than vapors from a liquid of a low boiling point. Furthermore, adsorption slightly decreases with increasing temperature, while the greater the partial pressure of vapor being adsorbed, the greater is the extent of the adsorption.

For a given relative humidity the water content and the partial water vapor pressure in air increases with temperature. The adsorption of a given amount of water vapor decreases the relative humidity of the air as it passes over the gel to a greater extent at low than at high temperatures. For a given humidity, the amount of water adsorbed per unit weight of gel at saturation is almost independent of temperature, so Chi & Wasan (1970) developed the isothermal and adiabatic adsorption-desorption models for both an unsupported adsorbent bed and a fixed bed of adsorbents impregnated on a supported bed.

Patrick, Frazer, and Rush (1927) showed that the adsorbing power of silica gel under static conditions is affected by the purity of the gel. They also found that the adsorption does not change until the gel has been heated above 900°C; above this temperature it decreases rapidly, reaching a minimum at 1000°C.

The adsorbed material can be recovered in two ways: (1) by raising the temperature, and (2) by decreasing the partial pressure of the vapor over the gel by evacuation or by displacement with air, steam, or other gas or vapor. Thus, adsorbed water may be driven out by air at 115°C, more rapidly at 125°C, and still more rapidly at 150°C.

OBJECTIVES

The broad objective of this investigation was to develop a simple and inexpensive grain storage unit or method which can be used effectively on the farm or at other local levels in tropical and subtropical areas, in order to preserve the quality of grain.

The specific objectives were as follows:

(1) To re-run the last series of Fleske's tests (1973) to see if they could be successfully repeated;

(2) To study corn samples at a higher initial moisture content (23-24% M.C.) to find an effective ratio of grain quantity to silica gel quantity for preserving grain quality;

(3) To conduct the same experiments with larger sizes of samples to examine whether the methods established in small scale tests could be used for significantly larger storage units;

(4) To test the effectiveness of a drying agent system (silica gel) with air movement within the storage unit for preserving grain quality by using a roof spinner.

MATERIALS AND METHODS

This investigation consisted of two phases of experiments.

Phase I:

Grain used for Phase I was shelled yellow corn at about 10% moisture content (wet basis). Unfortunately, no information on the history of the corn purchased could be obtained: crop year; condition of grain at the time of harvesting, after harvesting, and just before drying; how it was dried, etc. The adsorbent tested was silica gel (6-16 mesh). Small metal cans 7½ inches in diameter and 7½ inches deep, which hold about 10 lbs. of corn, were used as storage containers. Figure 3 shows these cans along with the other elements comprising the storage unit.

For positioning and placing and desiccant in a storage container, a small screen cylinder, of approximately 5/8 inch diameter (for 15% to 20% moisture content), 7/8 inch diameter (for 24% moisture content) was placed at the center of a container. Figure 3 indicates that the position of the cylinder was maintained by wiring it to a frame. Some containers had two, three, or four cylinders which were uniformly positioned in the container (Fig. 4).

In the preparation of a sample for storage tests, several things had to be accomplished. First, the corn at 10% moisture content had to be wetted to the desired initial moisture content for storage tests. The wetted corn was left in cold storage (50°F) overnight, or until the corn reached a desired moisture content. The initial moisture contents of corn selected for storage tests were 15%, 20%, and 24% (w. b.). Next, the cans and cylinders were disinfected with Clorox solution.

THIS BOOK CONTAINS SEVERAL DOCUMENTS THAT ARE OF POOR QUALITY DUE TO BEING A PHOTOCOPY OF A PHOTO.

THIS IS AS RECEIVED FROM CUSTOMER.

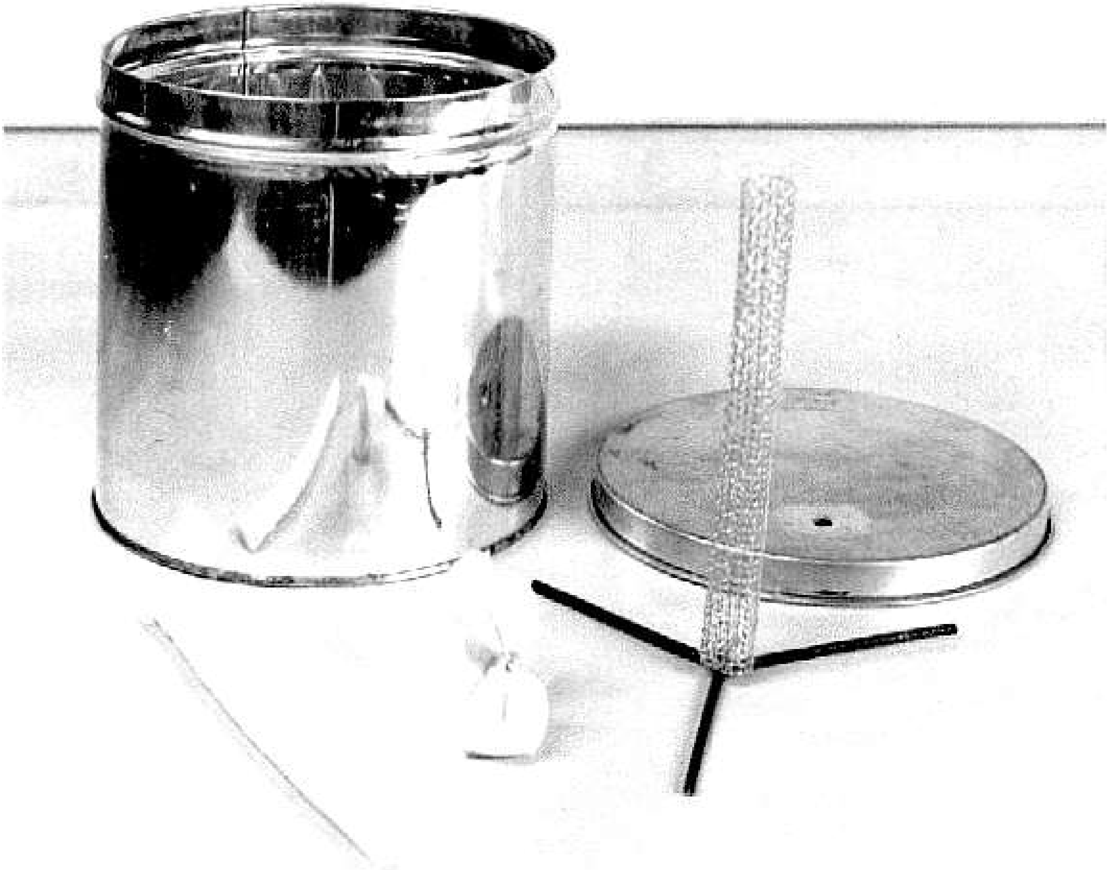


Figure 3. Elements comprising the storage container.

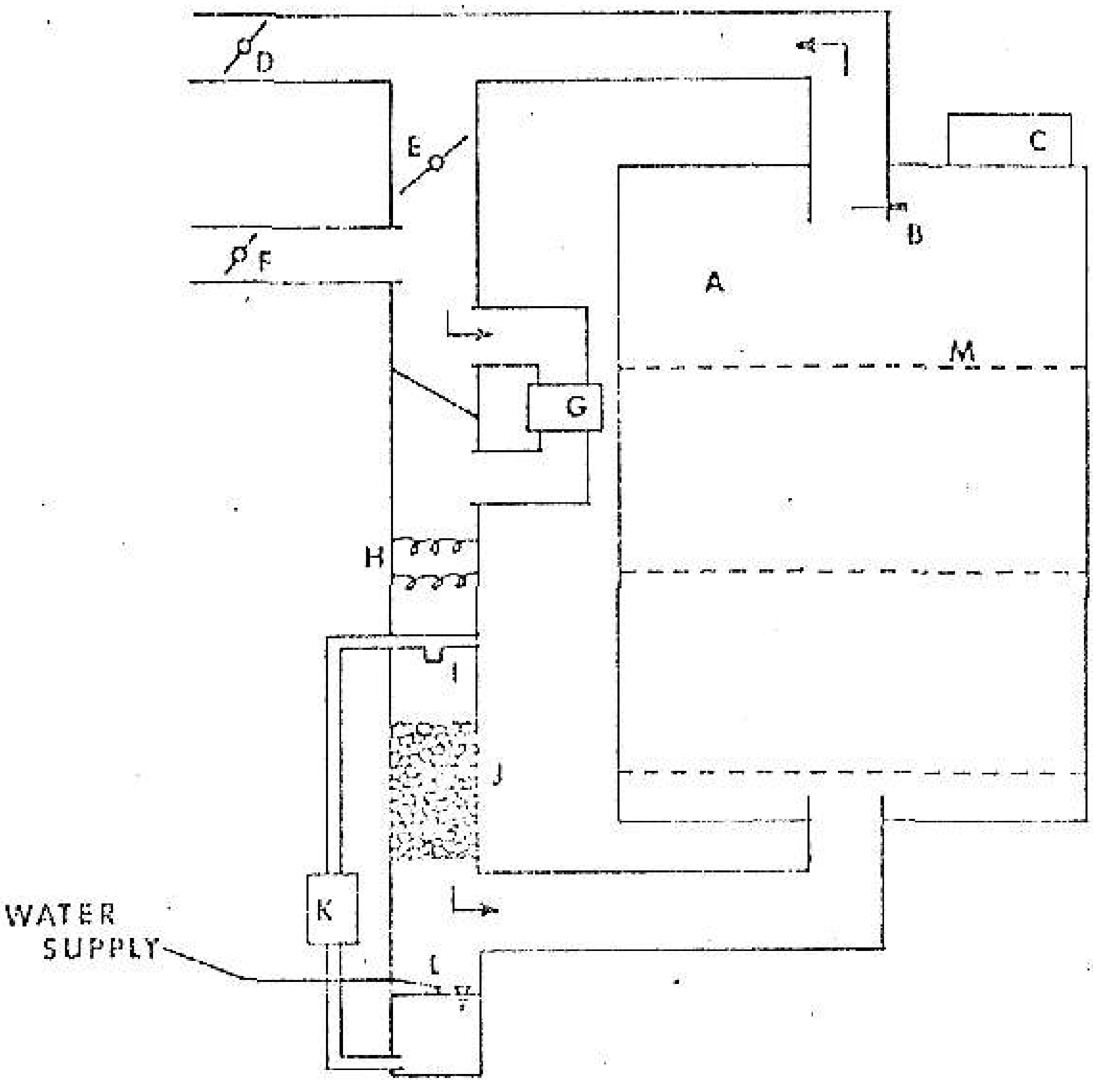
Figure 4. Internal view showing placement of cylinders and sacks.

Before corn samples at a given initial moisture content could be put into the cans, each can was marked with a sample identification code, the correct internal cylinder structure was constructed and placed inside the can, and a hole was punched in the lid for insertion of the thermometer. After these steps had been accomplished, the empty can with accessories was weighed and the weight recorded.

The cylindrical nylon cloth sacks and some small irregularly shaped sacks which were to be laid on top of the corn (Figure 3) was filled with silica gel and weighed. During the can-filling process three moisture content recordings of the corn were made to get an average initial moisture content. The can was then weighed full before the sacks were put into place. With the completion of the weighing, all the sacks were placed in the can. The number of cylinders per can varied, and on top there were either three sacks of silica gel or none. The temperature of the corn sample was recorded before the can was placed in the climate chamber.

The containers with corn and silica gel were then placed in the climate control chamber, which was set to a desired environmental condition for storage testing. Figure 5 shows a schematic diagram of the climate control apparatus used for simulating various environmental conditions. Figure 6 and 7 show the external and the internal views of the apparatus.

The control chamber, A, in Figure 5 was made from an old refrigerator. The outlet valve, D, controlled the flow of air into the system from a refrigerated chamber. This control was mainly for controlling temperature below atmospheric conditions. For this experiment, both D and F were closed, while E was completely open to permit free air flow through the system. The air fan, C, forced the air through the system. The air was



A. Controlled Chamber

B. L7038A Honeywell Thermistor

C. R7187D1019 Honeywell Controller

D. Outlet Control Valve

E. Return Control Valve

F. Inlet Control Valve

G. Air Fan

H. 1000 Watt Resistance Heater

I. Sprinkler Nozzle

J. Rock Column

K. Water Pump

L. Float to Control Water Level

M. Shelves for Cans

Figure 5. Schematic diagram of climatic control apparatus.

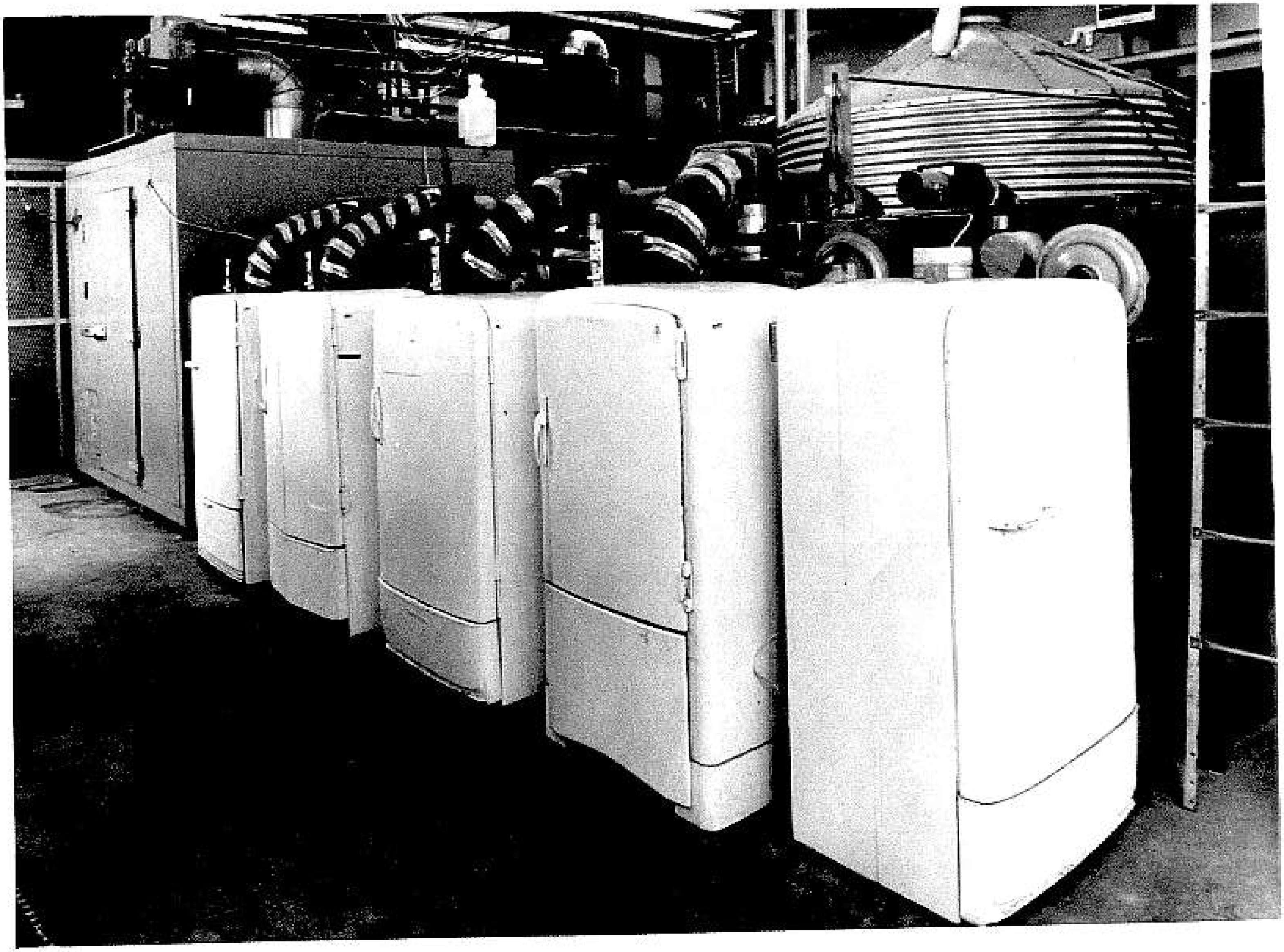


Figure 6. Climate control chamber apparatus.

R7187D1019 Honeywell Controller, C, and the L7038A Honeywell Thermistor, B. This maintained the air temperature at the desired level.

After passing the heater, the air was forced through a rock column being sprayed with an antifreeze-water solution. This was the method used to control the relative humidity. The more antifreeze added, the lower the relative humidity. Once the ratio of antifreeze and water for a desired relative humidity was set, it was kept constant by the float mechanism in the bottom of the duct. After passing through the rocks, the moist heated air was circulated up through the control chamber and then back through the cycle. A plastic sheet was placed over the top of the closed containers in order to prevent the moisture condensing in the chamber from entering the sample containers (The sheet was removed for the photographing of Figure 7).

Environmental conditions set up for storage tests were 90-100% RH (relative humidity) at 90°-95°F air temperature. Figure 7 shows the condition of storage containers tested in an environment chamber. a) lid tightly closed (no air in and out), b) the lid loosely placed (considerable air in), and c) the lid tightly closed but a few small holes in the side of the container which let some air in.

The data which were recorded for each sample included the weight of the storage unit (çorn included) with the adsorbent sack removed, the weight of the adsorbent, the temperature of corn, and the mold growth. The data were recorded twice daily for each sample at twelve-hour intervals. All laboratory materials used (thermometers, bottles, etc.) had been disinfected in alcohol before each use. Only one can was taken at a time from a climate control chamber. The cans were in the laboratory at room temperature for weighing and temperature determination less than five minutes.

Figure 7. Internal view of climate control chamber.

After the silica gel had used 70 percent of its adsorptive capacity, it was dried for 45 minutes at 130 C° by a laboratory oven. The frequency of regeneration also depends on the initial moisture content of corn. This will be discussed in a later section. After this drying, the silica gel was cooled and then placed back in the storage container. During the time the silica gel was drying, the container was placed in the climate control chamber.

In Table 1, the experimental factors examined and the description of a sample identification code used are tabulated.

Phase II:

Grain used for the Phase II tests was shelled yellow corn, which had been newly harvested (September, 1973) at about 24% moisture content, and all tests used that initial moisture content. The corn was cleaned by a Clipper, M-2B, and then the corn was kept in cold storage (35-40°F) until ready for tests. The adsorbent tested was silica gel (6-16 mesh, blue; 3-8 mesh, white).

Three larger cans, which were 36 inches in diameter and 30.5 inches in depth and which could hold about 400 lbs. of corn, were used as storage containers. A perforated plate was on the bottom of each can. CAN No. 1 and CAN No. 2 had rotary roof ventilators four inches in neck diameter (Empire type), which created a vacuum within the turbine. That vacuum was replaced by a strong downward draft of air through the corn mass in CAN No. 1, but by an upward draft of air in CAN No. 2, air from each can becoming wet as it dried the corn. A room fan was used for simulating natural wind at a velocity of 940 fpm or 10.6 miles per hour. The air flow rate created by the spinner was 80 fpm in CAN No. 1 and 50 fpm in CAN No. 2. The third

Table 1. Experimental factors examined and description of sample identification code.

Grain:	Shelled yellow corn at about 10% moisture content (wet basis).
Initial Moisture Content:	24%, 20%, 15%
Environmental Conditions:	90-95°F. 90-100% R.H.
Number of Cylinders: (Grain to Adsorbent Ratio)	Two to five cylinders and three sacks.
Condition of Containers:	Open, closed
Sample Identification Code*:	
15-3S-O	15% initial moisture content, three cylinders with three sacks on top of grain, open can.
15-3S-C	15% initial moisture content, three cylinders with three sacks on top of grain, closed container.

*First two digits indicates initial moisture content: 15, 20, or 24%

The middle number-letter combination indicates number of cylinders (2-5) and the S indicates sacks on top of the grain.

The last symbols (O, C) indicate the condition of the can (i.e. open, closed).

container -- CAN No. 3 -- was used for a *static storage (no air flow)*. Figures 8 and 9 show these cans along with the other elements comprising the storage unit.

Each can was filled with 400 lbs. of corn before the silica gel was put in place. With the completion of the weighing, the needed amount of silica gel was then placed in each can and the temperature of the corn was recorded. CAN No. 1 held about 16 lbs. of 6-16 mesh size blue silica gel; i.e., the ratio of grain to silica gel was 25:1. CAN No. 2 held about 20 lbs. of 3-8 mesh size white silica gel, and CAN No. 3 held about 20 lbs. of 6-16 mesh size blue silica gel; i.e., in these cans the ratio of grain to silica gel was 20:1.

For positioning and placing the desiccant in CAN No. 1 a perforated pan covered with nylon cloth was placed in the top of the can a short distance above the corn. CAN No. 2 and CAN No. 3 each held four screen cylinders uniformly positioned in the container.

The need to regenerate the silica gel was indicated when the blue gel turned to a lighter color. CAN No. 1 and CAN No. 3 used only blue gel, but for CAN No. 2 a small amount of the blue gel was added to the white gel as an indicator.

Two thermometer probes were used for measuring the temperature of corn at different parts of the corn mass. A sampling probe was used for taking samples from different parts of the corn mass to be used for measuring the moisture content (Fig. 10). The moisture content was tested by an oven method and by the Steinlite moisture tester. Plates filled with water and a heater were used for controlling the storage room atmosphere (Fig. 11).

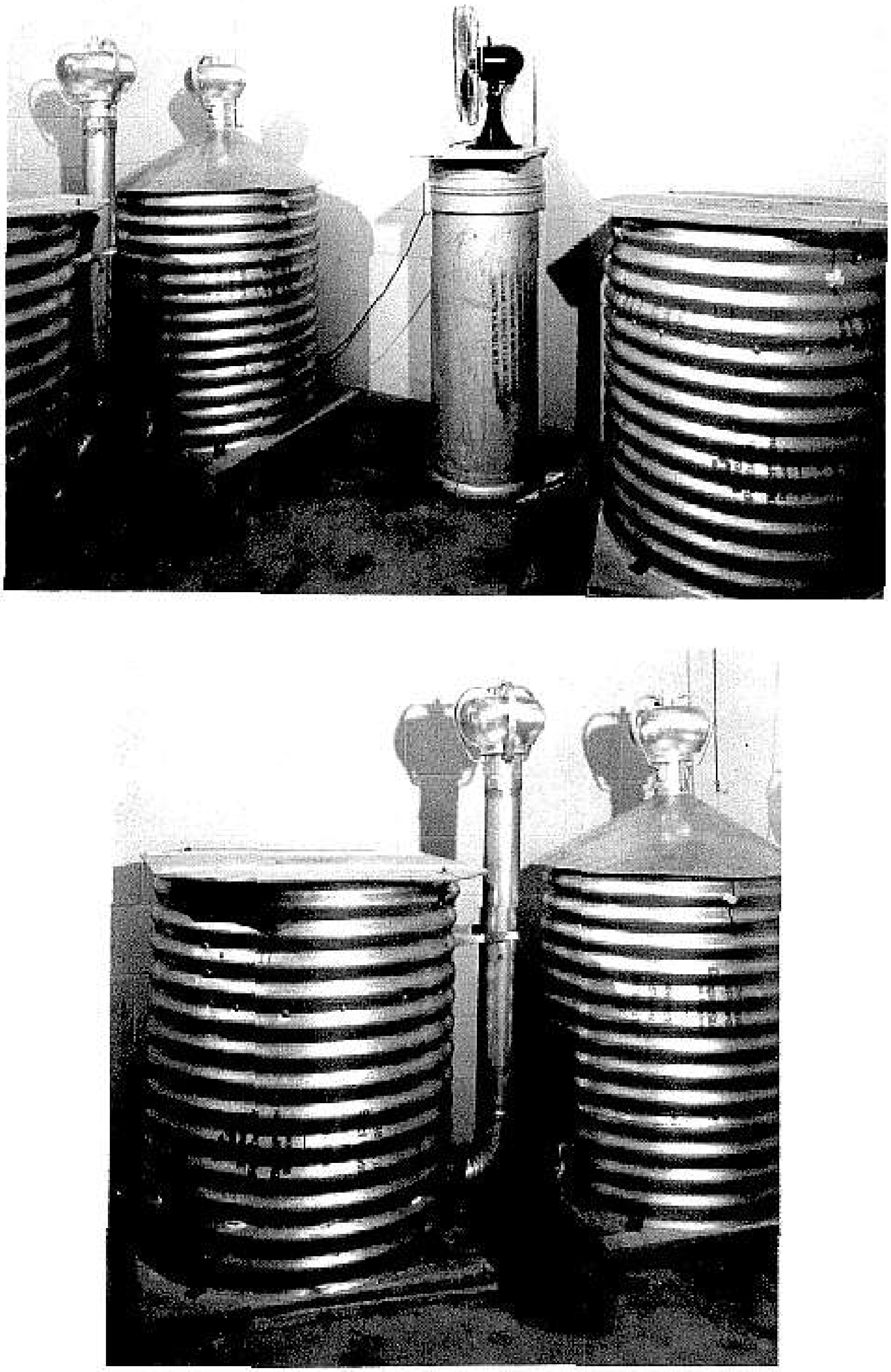


Figure 8. External view of cans in storage room for Phase II tests.
Upper: CAN No. 2 (middle), CAN No. 3 (right)
Lower: CAN No. 1 (left), CAN No. 2 (right)

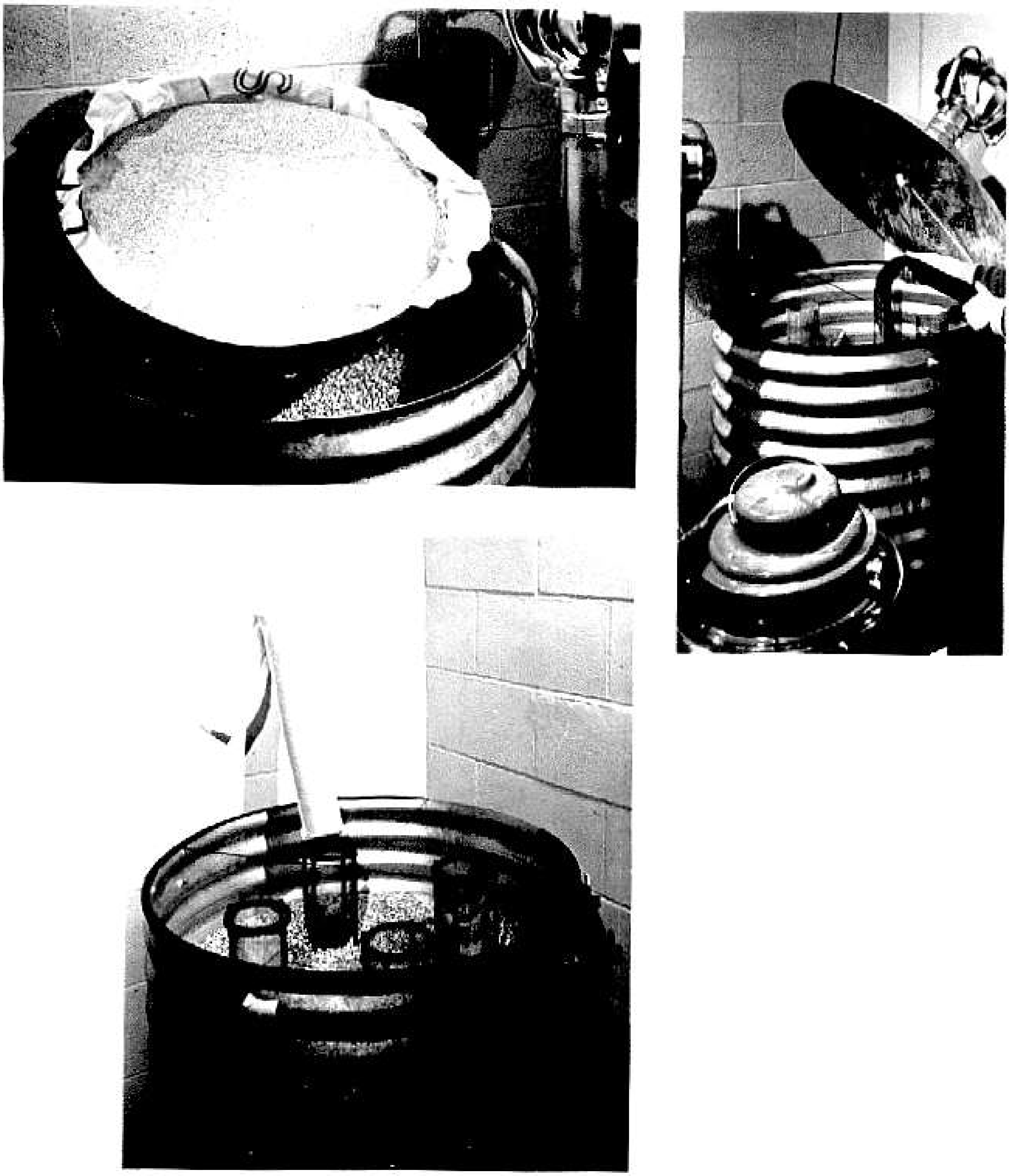


Figure 9. Internal view showing placement of silica gel for Phase II tests.
Upper left: CAN No. 1
Upper right: CAN No. 2
Lower: CAN No. 3

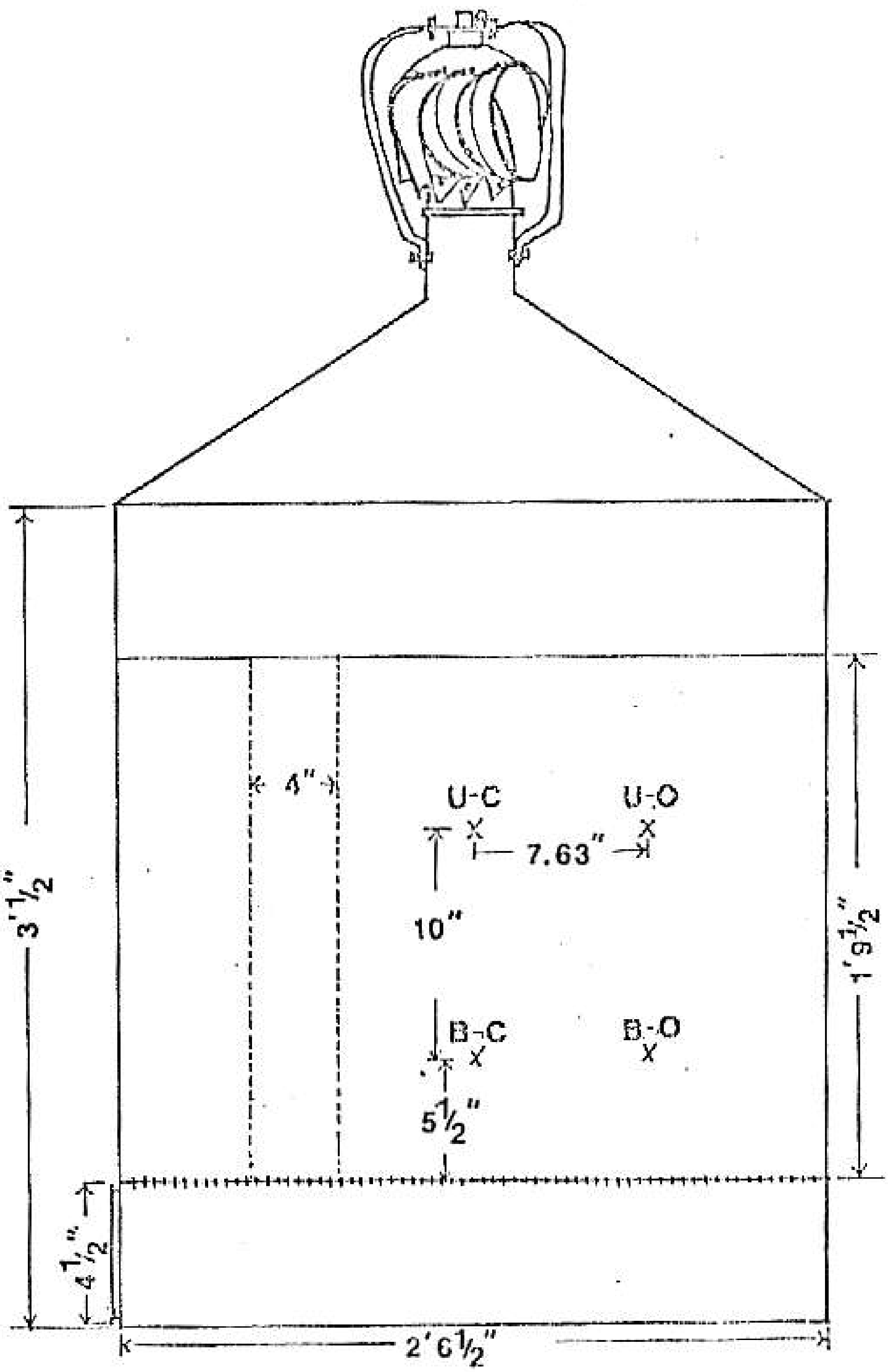


Figure 10. Internal view showing place of sample taken for Phase II tests. (CAN No. 2)

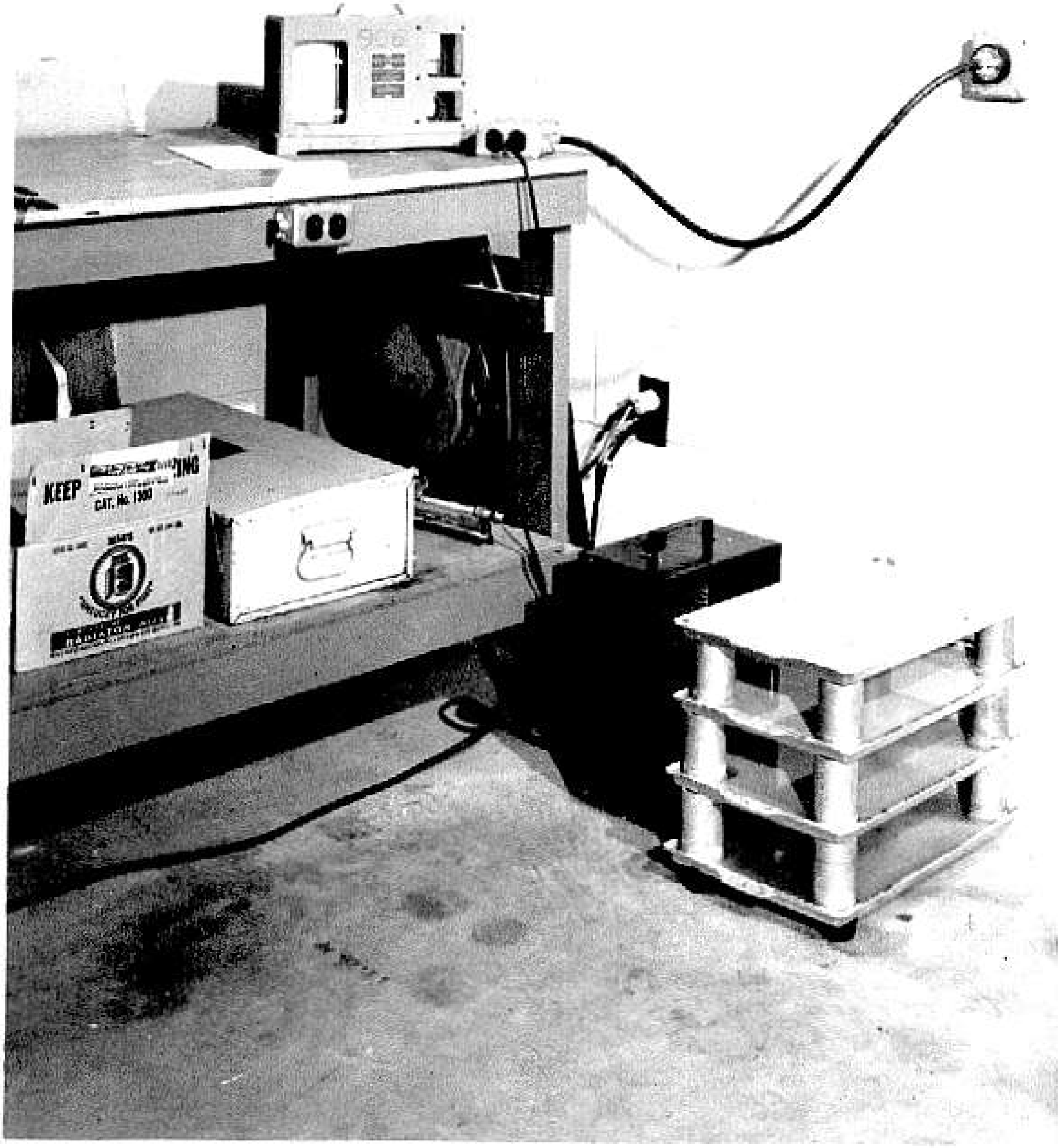


Figure 11. Climate control and measuring apparatus for Phase II tests.

A hygrothermograph was used for recording the room temperature and relative humidity.

The data recorded for each can were the temperature and the moisture content at different parts in the corn mass, the weight gained by the silica gel, and the mold development, The data were recorded once daily for each can.

In Table 2 the experimental factors studied are tabulated.

Table 2. Experimental factors examined and description of sample identification code in Phase II

Grain:	Newly harvested corn of 24% wet base moisture content, purchased at local elevator.
Initial Moisture Content:	24%
Grain to Adsorbent Ratio:	CAN No. 1 -- 25:1 CAN No. 2 -- 20:1 CAN No. 3 -- 20:1
Condition of Containers:	CAN No. 1 & No. 2 with air flowing through corn. CAN No. 3: no air flow (static)
Sample Identification Code:	
U-C	upper center part of corn mass (15½" from the bottom plate, 15¼" from the can wall)
U-O	upper outer part of corn mass (15½" from the bottom plate, 7.62" from the can wall)
B-C	bottom center part of corn mass (15½" from the bottom plate, 15¼" from the can wall)
B-O	bottom outer part of corn mass (5½" from the bottom plate, 7.62" from the can wall)

RESULTS AND DISCUSSION

When this project was first set up, it was hoped that drying and storage of corn could be accomplished by silica gel. If this was not possible, the research was also intended to give a method of storing initially dry corn under humid conditions. Storage of dry corn is not easy in a humid climate because the grain gradually acquires moisture from the air and must be re-dried, or else it soon spoils.

A large number of tests for small amounts of corn have been conducted by Fleske (1973). Because no literature was available for reference to find a workable ratio of corn to adsorbent or a workable drying structure, his study was conducted by trial and error. He tried corn with three different initial moisture contents (12, 15, and 20 percent with various ratios of the grain to silica gel). Those samples were stored in 95°F and 90-100 percent R. H. chambers. If the system functioned at that level, he believed it would succeed under less harsh conditions.

His study showed a definite possibility of using silica gel for drying and conditioning corn under very warm and humid conditions. Therefore, in order to confirm his results, Phase I experiment was conducted by repeating his experiment for corn at initial moisture contents of 15 and 20 percent with the proper ratio of the grain to silica gel as described by Fleske (1973), and also by testing corn with an initial moisture content of 24 percent with various ratios of grain to silica gel.

Figure 12 shows the rate of drying of the 15 percent initial moisture content samples, using for the ratio of corn to silica gel 50 to 1 only within one week the corn had been dried below the maximum moisture content for

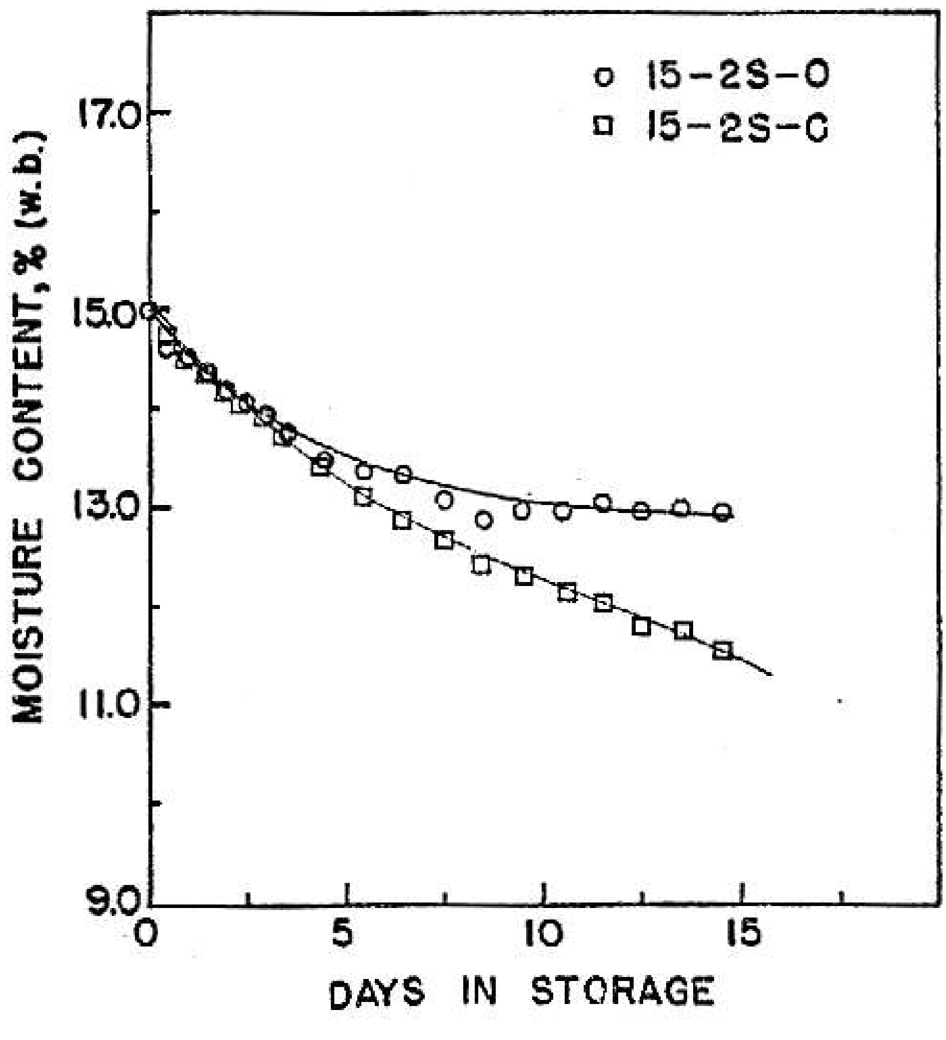


Figure 12. Moisture content versus days in storage for corn samples at 15 percent initial moisture content with silica gel in two cylinders and three sacks in open and in closed containers. (actual ratios of 50:1)

safe storage (13% moisture content). At the end of the experiment the samples did not show any visible mold development.

Figure 13 shows grain temperature changes in 15 percent initial moisture content grain with a grain to silica gel ratio of 50 to 1. Whether the can was open or closed, the temperature of the corn was nearly the same.

The experimental data for moisture changes in corn and silica gel, grain temperature change, and grain quality changes in corn samples initially having 15 percent moisture are tabulated in Tables 3 and 4 in Appendix. Figure 14 shows the drying rate of the 20 percent initial moisture content samples using the 35 to 1 ratio of corn to silica gel. It took about two weeks for the corn to be dried below 14% moisture content. But at the end of two-week's storage, there was a slight mold development on the bottom layers. The mold probably was caused by (1) the corn being kept in the cold storage chamber long enough for the mold growth to begin, before the sample was placed in the storage chamber, or (2) by lack of uniformity in the corn mass as the top layer of corn dried faster than the bottom layers since the weight of the three sacks laid on the top was almost the same as the weight of silica gel in the cylinders.

Figure 15 shows grain temperature changes in the 20 percent initial moisture content sample with the grain to silica gel ratio 35 to 1. Whether the can was open or closed, the temperature of the corn was nearly the same.

The experimental data of moisture changes in the corn and silica gel, the grain temperature change and grain quality change in corn samples initially at 20 percent moisture with about 35:1 ratio of the grain to silica gel are tabulated in Tables 5 and 6 in Appendix.

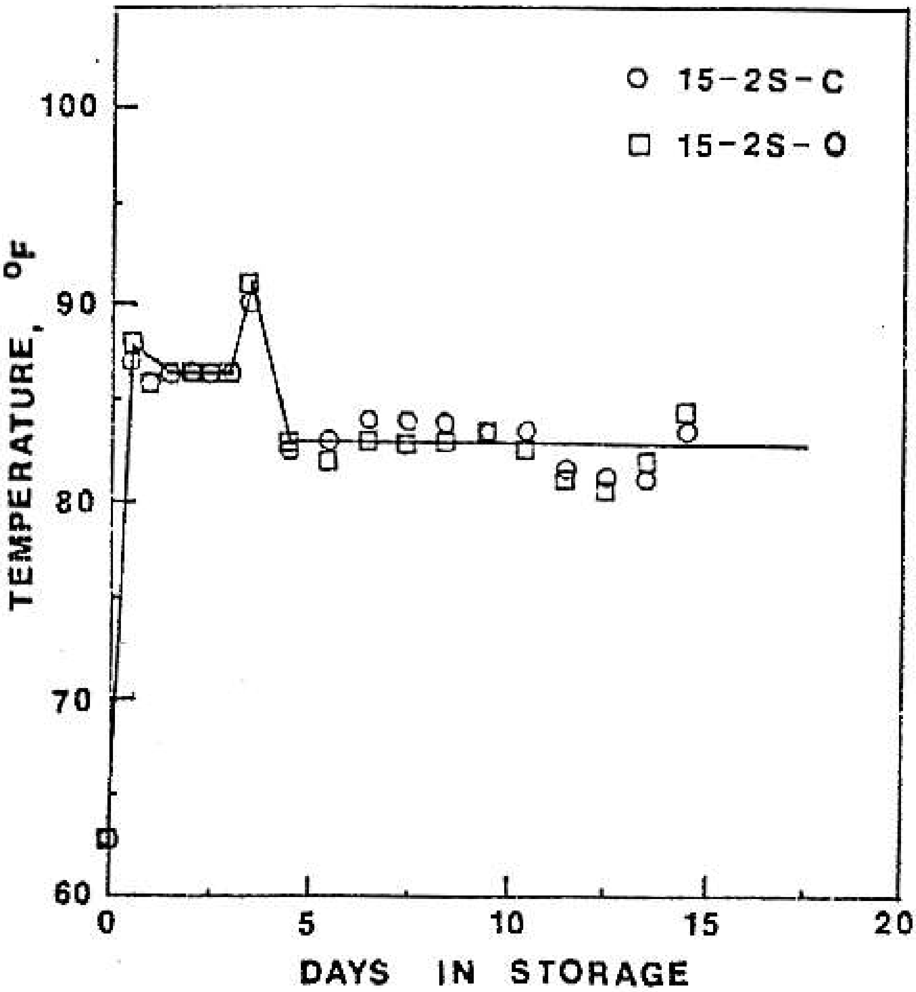


Figure 13. Grain temperature versus days in storage with silica gel for corn samples at 15 percent initial moisture content.

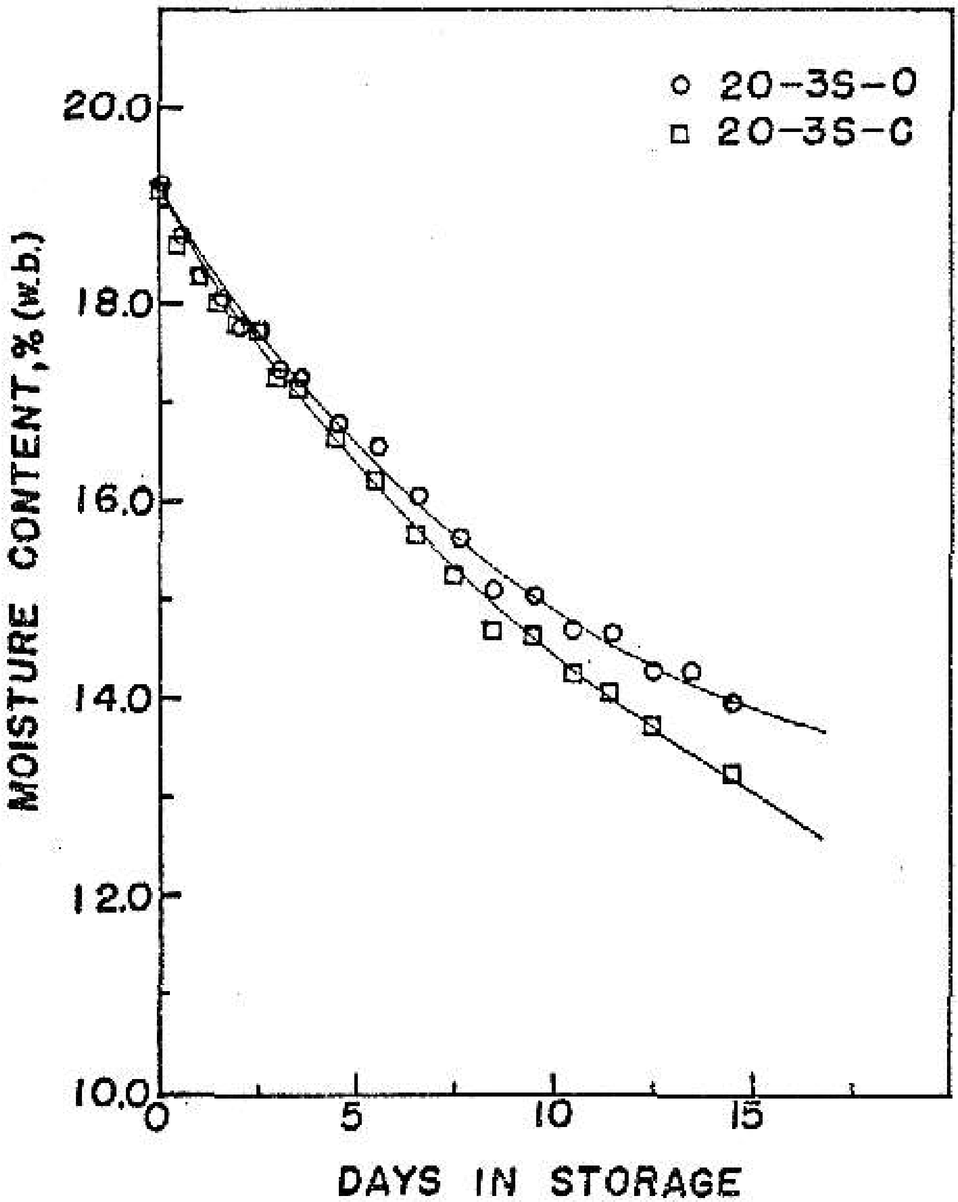


Figure 14. Moisture content versus days in storage for corn samples at 20 percent initial moisture content with silica gel in three cylinders and three sacks in open and in closed containers. (actual ratios of 35:1)

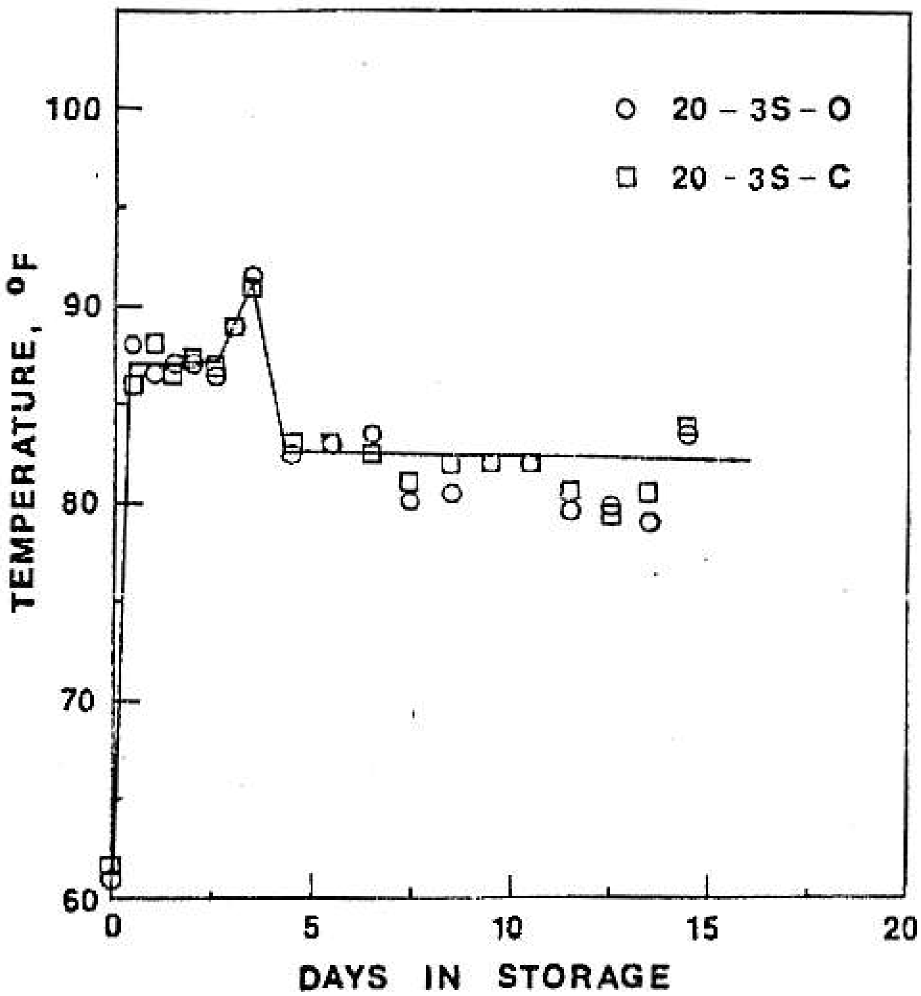


Figure 15. Grain temperature versus days in storage with silica gel for corn samples at 20 percent initial moisture content.

Statistical analysis of the moisture data used to test the *difference* in drying rate between this investigation and Fleske's test for 15% and 20% initial moisture corn is given in Table 7. The analysis showed no significant difference between them, whether the can was open or closed.

Figures 16, 17, and 18 show the rate of drying of the 24 percent initial moisture content samples at 2, 3, and 5 cylinder ratios. Silica gel regeneration was made twice a day for the first three days then once every day for seven days of storage and thereafter every other day for another week. The lower the ratio, the faster the drying rate. It required 20 days for the 28:1 ratio in the can with two cylinders, 12 days for the 20:1 ratio in the can with three cylinders, and 10 days for the 13:1 ratio in the can with five cylinders to dry the corn to the maximum moisture content for safe storage. The experimental data for 24 percent initial moisture content at 2, 3, and 5 cylinder ratios are tabulated in Tables 8 to 13 in Appendix.

Figure 19, 20, and 21 show grain temperature changes in the 24 percent initial moisture content sample with the grain to silica gel ratio 28:1, 20:1, and 13:1. Whether the can was open or closed, the temperature of the corn was nearly the same.

A statistical analysis of the moisture data was made to study the effect of the grain to silica gel ratio on the drying rate. The data used for the statistical analysis and the results are given in Tables 14 and 15 respectively. The results indicated no significant difference in the rate of drying between open and closed samples, but a significant difference between various ratios of grain to silica gel at $\alpha = 0.10$.

By referring to Tables 8 to 13, one can see that the samples with the 28:1 ratio showed signs of mold growth on the top layer in corn after five

Table 7. Analysis of the drying rate difference between Fleske's data (1973) and data of Phase I.

Sample indentification code	$\overline{D}$	$S_{\overline{D}}$	t
15 - 2S - C	0.1233	0.3466	0.3557
15 - 2S - O	0.3240	0.9473	0.3420
20 - 3S - C	0.08900	0.1988	0.4476
20 - 3S - O	0.09133	0.2197	0.4157

$\overline{D}$: the mean difference

$S_{\overline{D}}$: the standard deviation

t : the t-test value

$\alpha = 0.05$

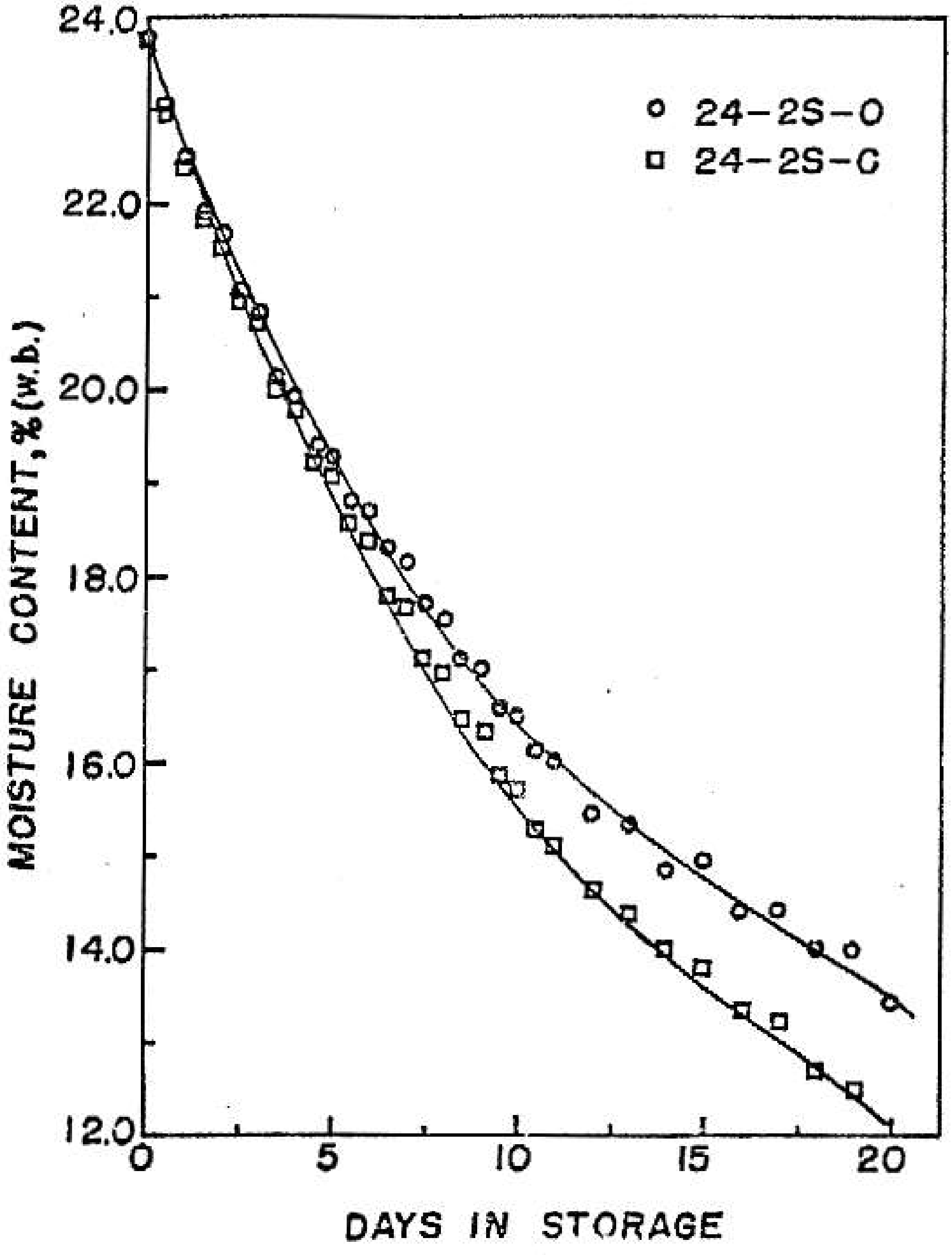


Figure 16. Moisture content versus days in storage for corn samples at 24 percent initial moisture content with silica gel in two cylinders and three sacks in open and in closed containers. (actual ratios of 28:1)

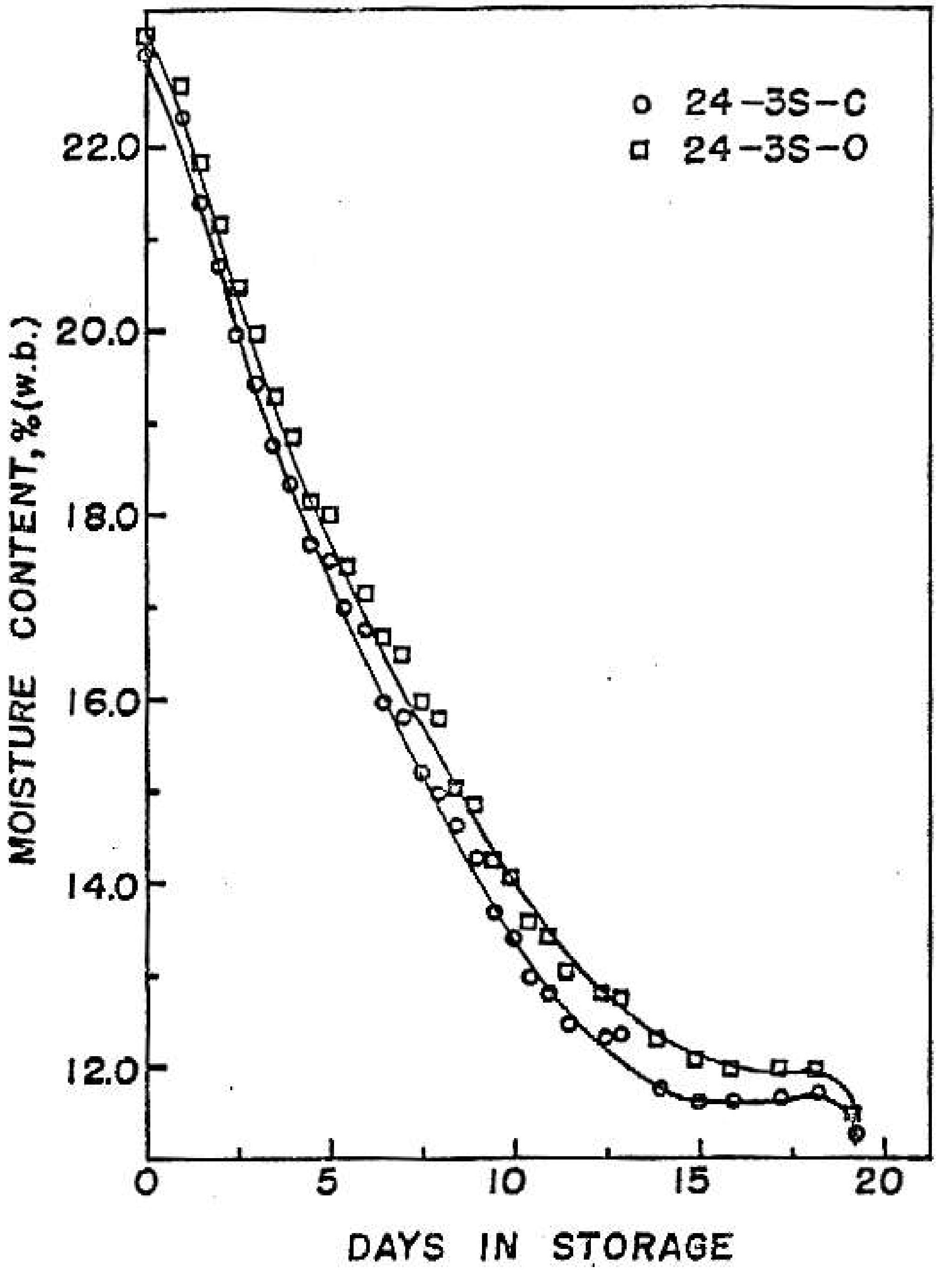


Figure 17. Moisture content versus days in storage for corn samples at 24 percent initial moisture content with silica gel in three cylinders and three sacks in open and in closed containers. (actual ratios of 20:1)

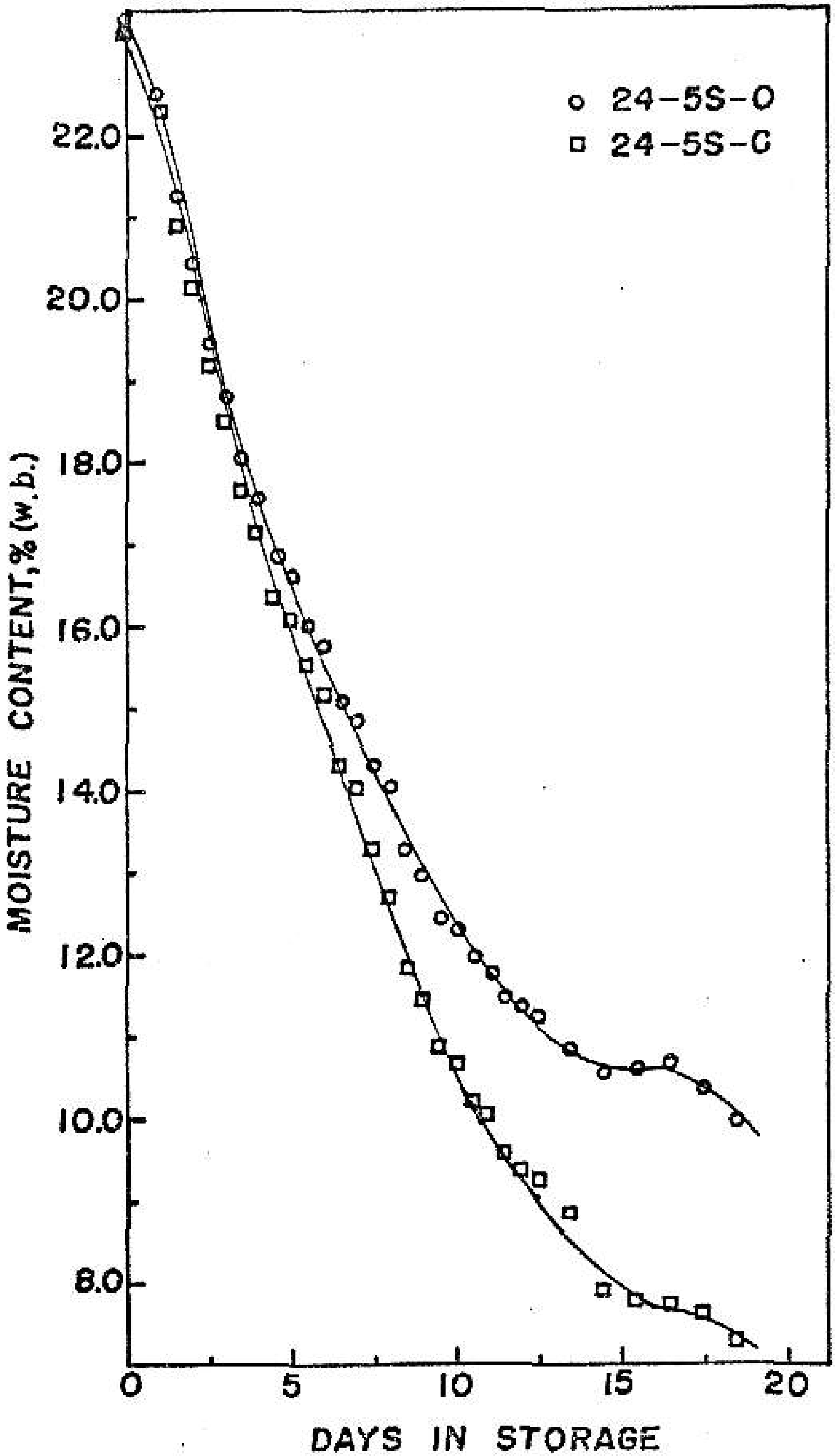


Figure 18. Moisture content versus days in storage for corn samples at 24 percent initial moisture content with silica gel in five cylinders and three sacks in open and in closed containers. (actual ratios of 13:1)

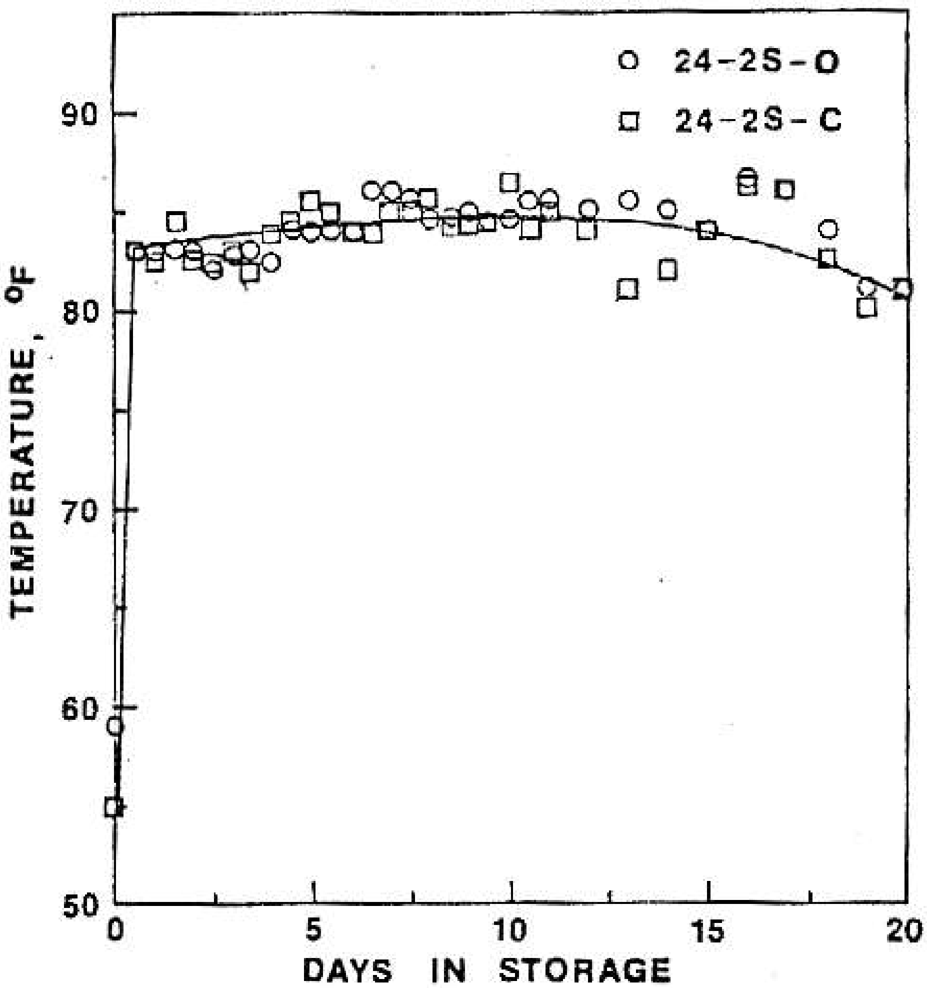


Figure 19. Grain temperature versus days in storage for corn samples at 24 percent initial moisture content with silica gel in two cylinders and three sacks in open and in closed containers.

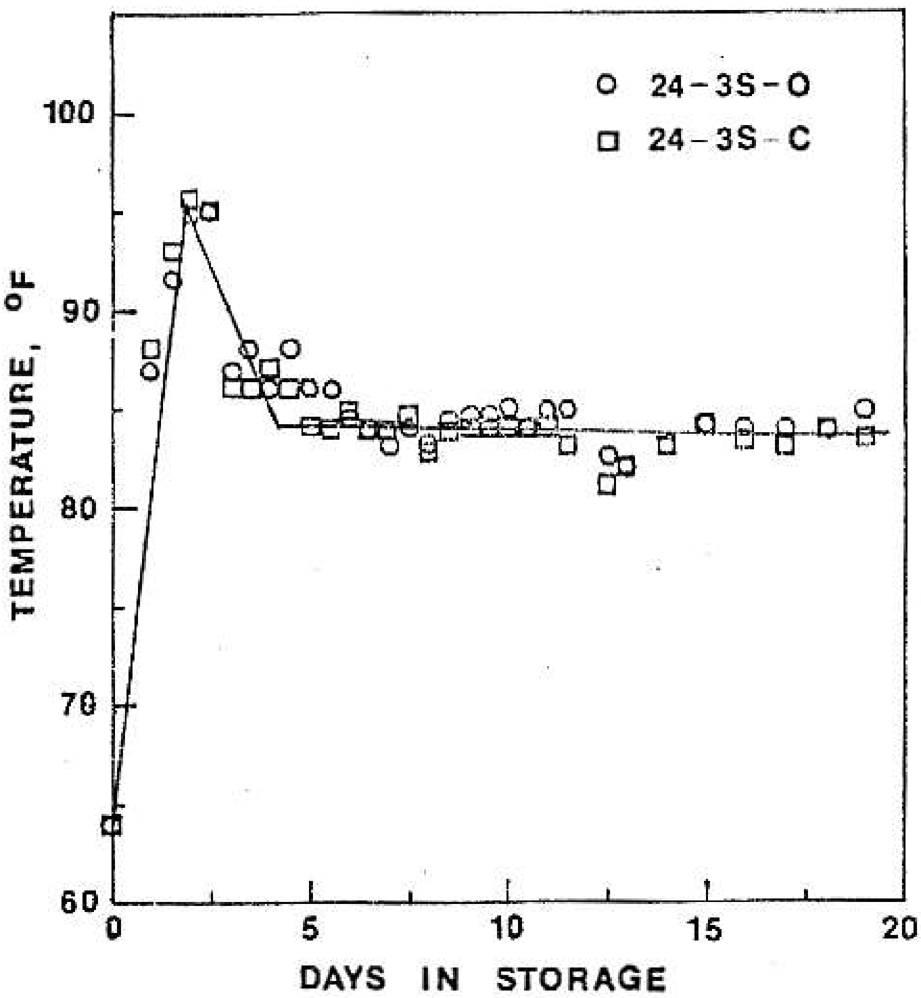


Figure 20. Grain temperature versus days in storage for corn samples at 24 percent initial moisture content with silica gel in three cylinders and three sacks in open and in closed containers.

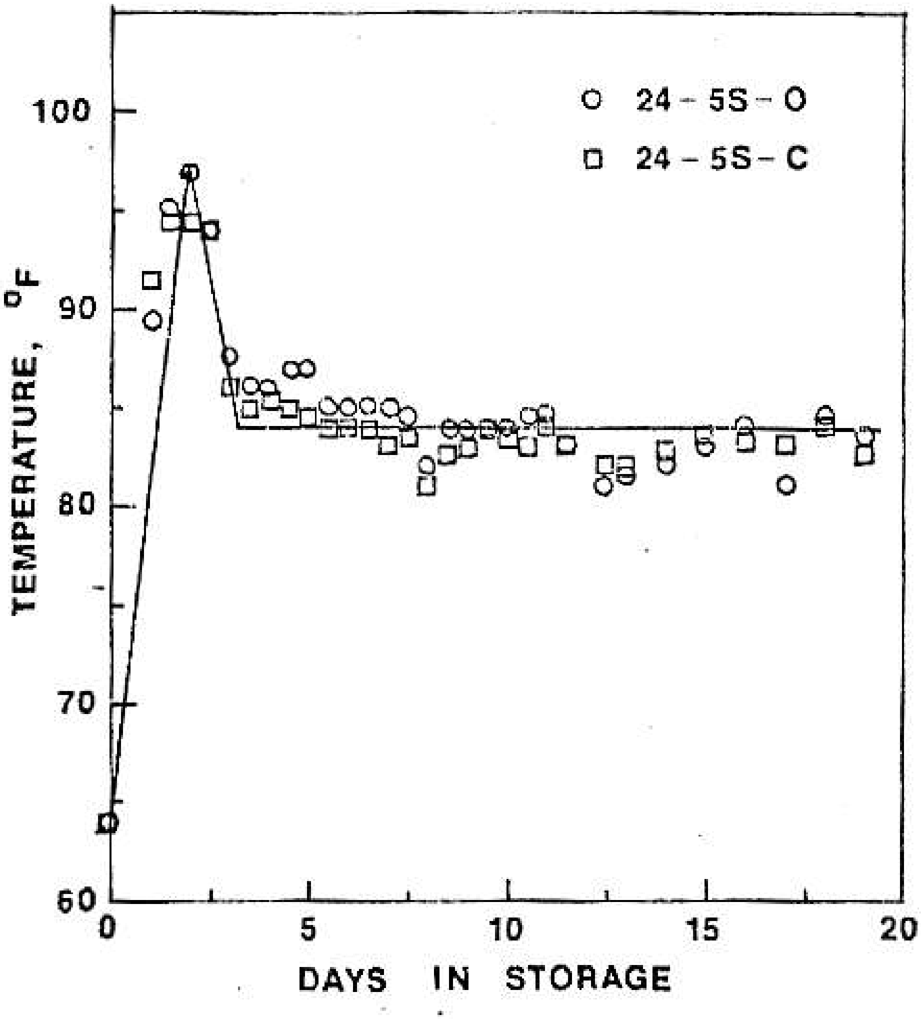


Figure 21. Grain temperature versus days in storage for corn samples at 24 percent initial moisture content with silica gel in five cylinders and three sacks in open and in closed containers.

Table 14. Moisture content of corn (24 percent initial moisture) on seventh day in storage used in analysis of variance for testing the effect of corn to silica gel ratios.

	Treatment		
Condition	28:1	20:1	13:1
Open	18.17	15.82	14.88
Closed	17.67	16.50	14.03

Table 15. Analysis of variance for moisture data on seventh day in storage.

Day	Source	Degrees of freedom	Sum of squares	Mean squares	F (calculated)
7	Treatment	2	12.00725	6.003625	18.68*
	Block	1	0.0748	0.0748	
	Error	2	0.64265	0.321325	
	Total	5	12.7247		

*significant at 0.10 level.

days in storage; the samples at 20:1 ratio showed signs of mold growth on the top layer in corn after six days in storage; the samples at 13:1 ratio showed mold growth on the bottom layer in corn at the end of the experiment. But the mold stopped developing as soon as the grain was dried below the maximum moisture content for storage, so at the end of the experiment, in general, the corn was still marketable. The initial failures in maintaining quality might have resulted from the following facts:

(1) The corn had been kept in the storage chamber long enough for the mold growth to begin even before the sample was placed in the storage chamber.

(2) The drying in the corn mass was not uniform because:

   (a) the weight of the three sacks was almost the same as the weight of silica gel in the cylinders.

   (b) the structure of the wire cylinders and the shape of the ninon tubes, the one to two kernel width prevented fast drying.

   (c) if the experimenter accidently dropped a kernel or more of the corn into the wire cylinder he prevented the silica gel reaching the lowest layer of corn.

In summary, the Phase I experiments showed that

(1) the last series of Fleske's tests (1973) can be successfully repeated;

(2) the effective ratio of grain to silica gel for 24% initial moisture content is about 20:1.

In Phase I experiment, with a small amount of corn, the silica gel to corn ratios needed at different initial moisture contents for preserving corn quality were found under static drying conditions (without air flow). In Phase II experiment, a scale-up study was conducted by using 400 lbs. of corn at initially 24% moisture content, with the silica gel to corn ratio obtained from Phase I, with and without air flow in the corn mass.

When Phase II experiment was set up, high temperature and humidity of the storage room were expected. Because of difficulties in raising the humidity in the room, the relative humidity was about 30-40%, but the room temperature was about 80°-90°F as Tables 16 and 17 show in Appendix. Under these circumstances the air was pretty warm and dry; thus, the experiment should be modified in order to create a humid condition.

In CAN No. 1, using the grain to silica gel ratio of 25 to 1, 16 lbs. of silica gel was put on the perforated pan set above the top layer of corn. A room fan was used for simulating natural wind. When the fan forced the roof spinner to rotate, the wind velocity was about 940 fpm or 10.6 miles per hour. The air flow was created through the hole which was made in the lid and moved downward into the silica gel. After penetrating that silica gel, the air dried to a very low humidity. Then the dried air moved into the corn mass, and the wet air was exhausted by the spinner. The air flow rate was about 80 fpm, and the air volume rate was about 0.96 cfm/bu. In this case the silica gel was used indirectly for the corn; so the corn was dried by air of very low humidity, the moisture of which had been adsorbed by the silica gel.

In CAN No. 2 the grain to silica gel ratio was 20 to 1, so 20 lbs. of silica gel was put in 4 cylinders which were symmetrically distributed in the can, when the fan blew the roof spinner which was on the top of the cone shaped lid to rotate, an air flow was created through the bottom opener and moved upward through the corn and silica gel, the air flow rate was about 50 fpm, the air volume rate was about 0.766 cfm/bu. In this case the corn was dried by 30-40% R.H. air and by the silica gel.

CAN No. 3 had the same structure as CAN No. 2 but without any air flow inside the can, so the drying of the corn mass in CAN No. 3 was static, and the silica gel did the whole drying work.

The experimental data on moisture changes in corn, grain temperature, and quality changes in corn samples initially at 24 percent moisture content for CAN No. 1, CAN No. 2, and CAN No. 3 are tabulated respectively in Tables 18, 19, and 20 in Appendix.

The data shown in these tables are the results of tests made with corn under 80°-90°F and 30-40% R.H. and with silica gel dried or regenerated with 103°C temperature for about 12 hours in a laboratory oven when the condition in the oven was convenient.

The frequency of drying silica gel and the adsorption capacity of silica gel used up in each can were follows:

CAN No. 1

1st time: 1.5 days after storage;

2nd time: 2.5 days after 1st time; 31% capacity used up;

3rd time: 2.5 days after 2nd time; 20.8% capacity used up;

4th time: 3 days after 3rd time; 27.8% capacity used up;

5th time: 3.5 days after 4th time; 21.9% capacity used up;

6th time: 4.5 days after 5th time; 16.8% capacity used up;

7th time: 18.5 days after 6th time; 19.5% capacity used up;

CAN No. 2

1st time: 2 days after storage; 24.8% capacity used up;

2nd time: 3.5 days after 1st time; 14.5% capacity used up;

3rd time: 4 days after 2nd time; 23.5% capacity used up;

4th time: 3.5 days after 3rd time; 13.8% capacity used up;

5th time: 2.5 days after 4th time; 8.25% capacity used up;

6th time: 5 days after 5th time; 40.9% capacity used up;

7th time: 5 days after 6th time; 9.45% capacity used up;

8th time: 7.5 days after 7th time; 23.0% capacity used up;

9th time: 4.5 days after 8th time; 15.1% capacity used up.

CAN No. 3

1st time: 3 days after storage;

2nd time: 2 days after 1st time; 26.0% capacity used up;

3rd time: 2 days after 2nd time; 27.5% capacity used up;

4th time: 5 days after 3rd time; 27.9% capacity used up;

5th time: 5 days after 4th time; 21.9% capacity used up;

6th time: 4.5 days after 5th time; 21.9% capacity used up;

7th time: 7.5 days after 6th time; 34.1% capacity used up;

8th time: 9 days after 7th time; 48.25% capacity used up.

Figure 22 shows the drying rate of 24 percent initial moisture content samples in CAN No. 1 at different parts in the corn mass with corn to silica gel ratio of 25 to 1. It needed 3 days for the upper center part of the corn, 6 days for the upper outer part, 11 days for the bottom center part, and 19 days for the bottom outer part of the corn to be dried below 13 percent moisture content, and 12 days for all the corn to reach the average moisture content of 13%. At the end of this experiment, the samples did not show any

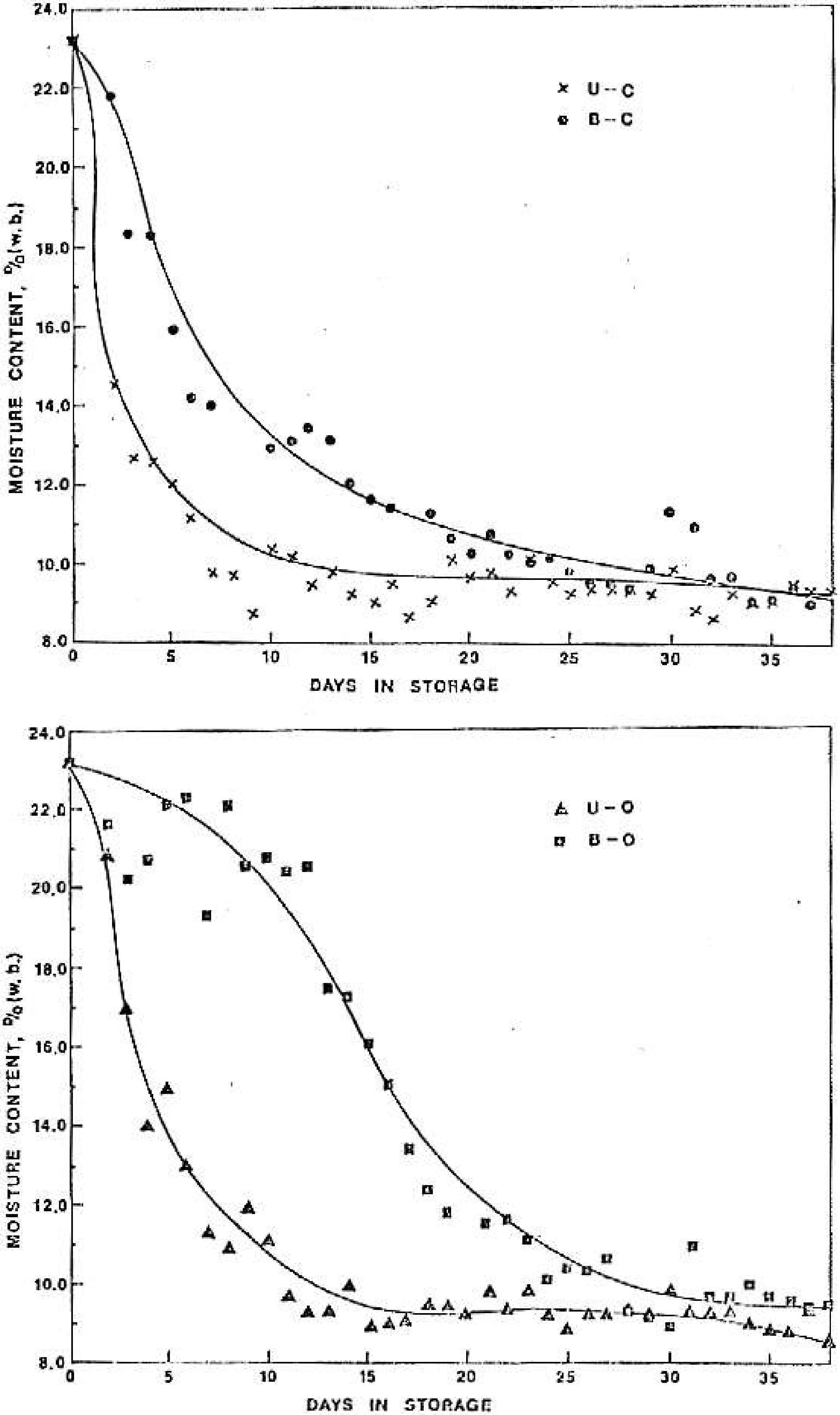


Figure 22. Moisture content versus days in storage for corn samples at 24 percent initial moisture content in CAN No. 1.

mold development. Table 21 shows the mold assay at the beginning and at the end of the experiment, and there is not much difference between them.

Figure 23 shows grain temperature changes of 24 percent initial moisture content samples in CAN No. 1 at different parts in the corn mass. It shows that for all samples the corn temperature was always below the room temperature. Statistical analysis of the temperature data was conducted to test the uniformity of temperature distribution in the corn mass. Results of statistical tests are given in Table 22. In the radial direction there is no significant difference of temperature. In the vertical direction, the temperature of the upper layer is higher than the bottom layer in corn.

Statistical analysis of moisture content data tested the uniformity of the drying rate in the corn mass. The data appears in Table 23. In the radial direction there is no significant difference in drying rate in the upper layer, but there is significant difference in the drying rate in the bottom layer. The center part of the corn dried much faster than the outer part of the corn, probably because the air flow was not uniform after moving through the hole, with much air going through the center part. In the vertical direction the upper layer dried faster than the bottom layer in the corn (that probably caused by depth effect).

Figure 24 shows the drying rate of 24 percent initial moisture content samples in CAN No. 2 at different parts in the corn mass and using the ratio of corn to silica gel 20:1. At the beginning, the drying rate of corn was very fast; then it decreased as the moisture content of the corn decreased. After 20 days of storage the corn was dried to about 15 percent moisture content. It needed 35 days for the upper center part in the corn to dry below 13 percent moisture content, 37 days for the upper outer part, 37½ days for

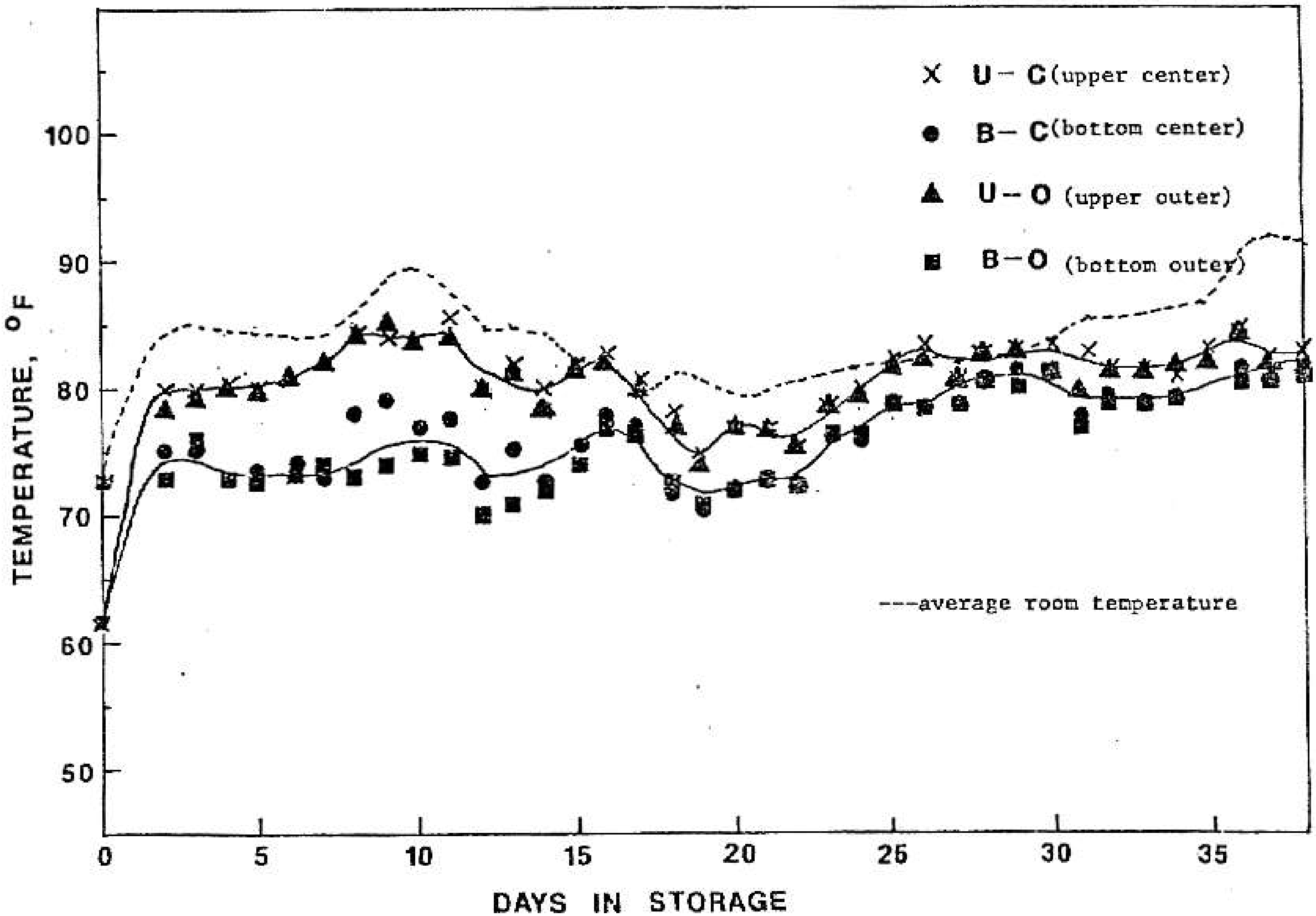


Figure 23. Grain temperature versus days in storage for corn samples at 24 percent initial moisture content in CAN No. 1.

Table 22. Analysis of the corn temperature data within 14 days of storage for testing the temperature gradient in the corn mass.

Can No.	Gradient direction	Code of points	$\bar{D}$	S_D	t
1	radial	U. C. - U. O.	0.5000	0.8010	0.6240
		B. C. - B. O.	1.6429	2.003	0.8202
	vertical	U. C. - B. C.	6.1786	2.058	3.002*
		U. O. - B. O.	7.3214	3.097	2.364*
2	radial	U. C. - U. O.	0.3214	1.5650	0.2054
		B. O. - B. C.	0.1786	0.7466	0.2392
	vertical	U. C. - B. C.	4.5000	2.6250	1.7140*
		U. O. - B. O.	4.0000	1.8898	2.1160*
3	radial	U. C. - U. O.	0.89286	0.9098	0.98138
		B. O. - B. C.	0.46429	1.0932	0.42471
	vertical	B. C. - U. C.	1.0714	2.5340	0.42281
		B. O. - U. O.	2.4286	2.0265	1.1984

*significant at 0.05 level (one-tailed test)

$\bar{D}$: the mean difference

$S_{\bar{D}}$: the standard deviation

t : the t-test value

Table 23. Analysis of the corn moisture content data within 14 days of storage for testing the moisture gradient in the corn mass.

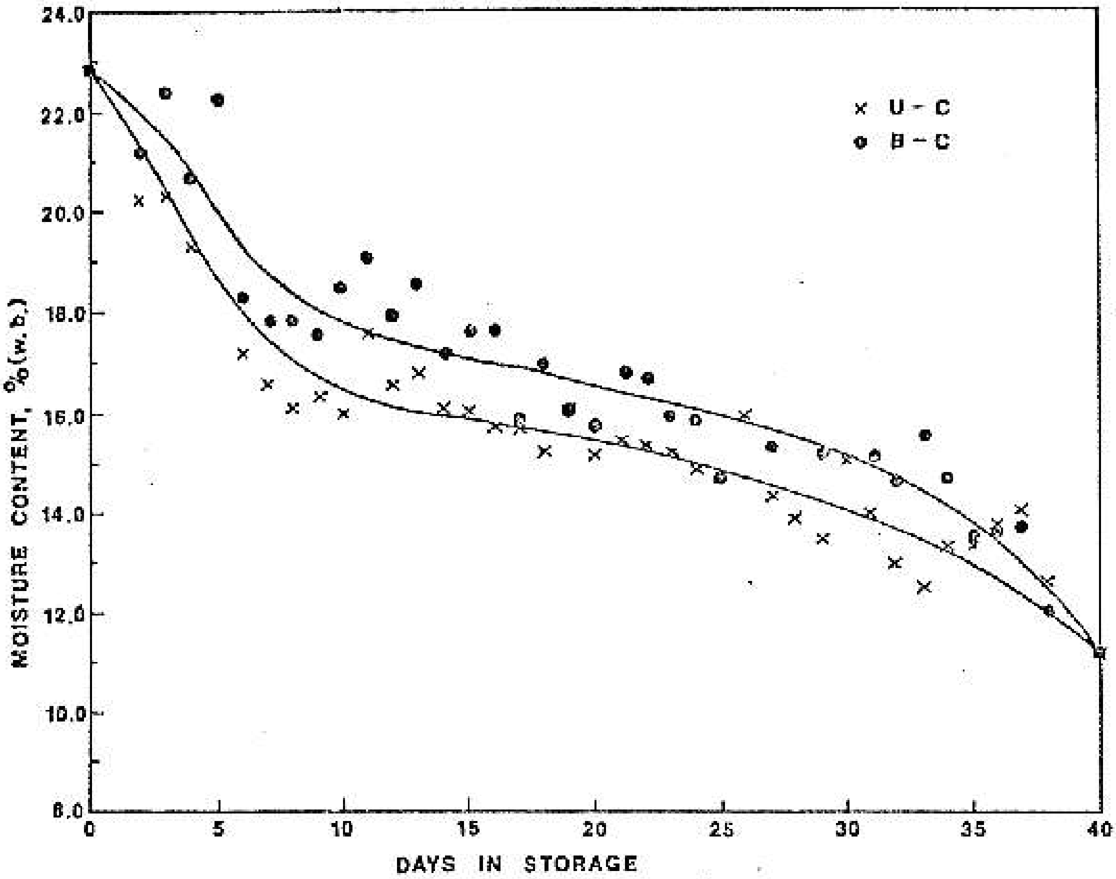
Can No.	Gradient direction	Code of points	$\overline{D}$	S_D	t
1	radial	U. O. - U. C.	1.0280	2.0250	0.5076
		B. O. - B. C.	5.7300	3.1450	1.8220*
	vertical	B. C. - U. C.	3.6279	2.0280	1.7889*
		B. O. - U. O.	8.3300	4.2500	1.9600*
2	radial	U. O. - U. C.	0.3664	0.6480	0.5650
		B. O. - B. C.	0.3707	0.9340	0.3969
	vertical	B. C. - U. C.	1.4021	0.5710	2.4555*
		B. O. - U. O.	1.5136	0.9300	1.6275*
3	radial	U. O. - U. C.	0.9514	0.8214	1.1583
		B. O. - B. C.	1.3907	1.3130	1.0592
	vertical	B. C. - U. C.	0.7207	0.8893	0.8104
		B. O. - U. O.	1.3971	1.5390	0.9078

* significant at 0.05 level (one-tailed test)

$\overline{D}$: the mean difference

$S_{\overline{D}}$: the standard deviation

t : t-test value



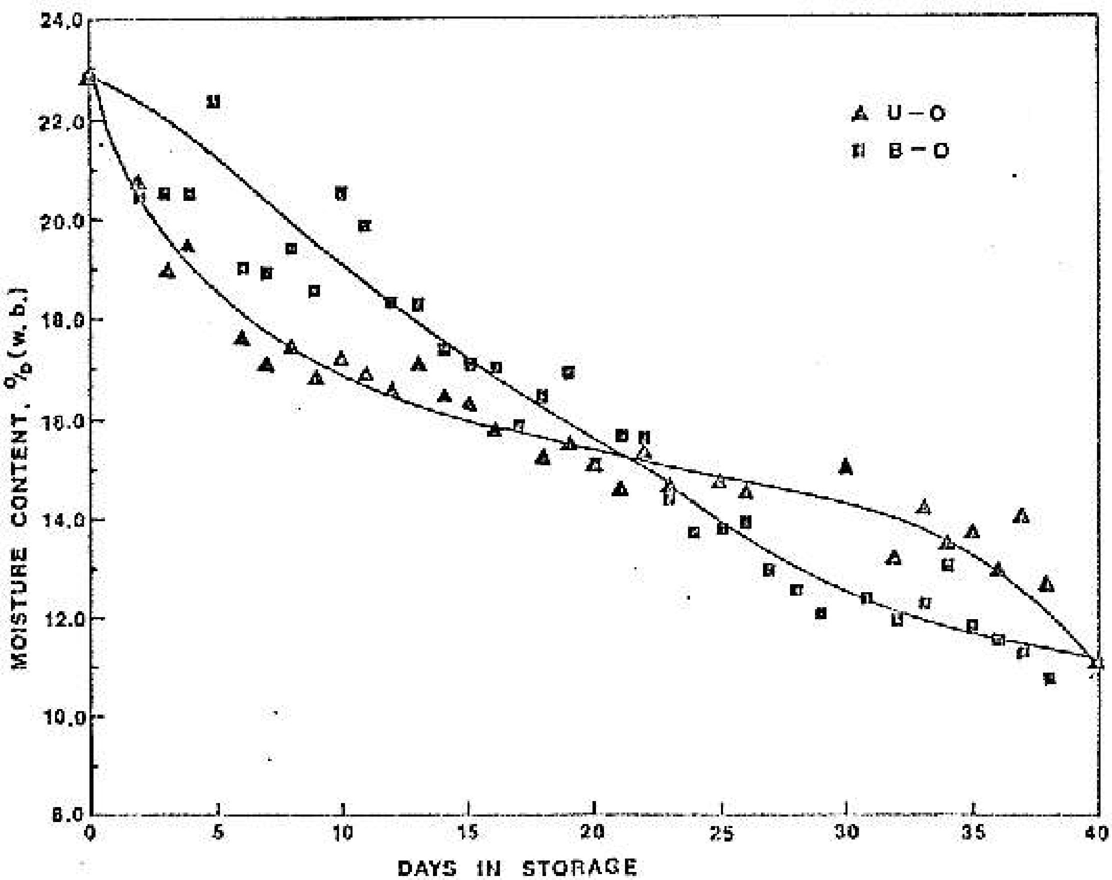


Figure 24. Moisture content versus days in storage for corn samples

the bottom center part, 36 days for the bottom outer part of the corn, and 37 days for all the corn to reach the average moisture content of 13 percent. At the end of the experiment the samples did not show any mold development. Table 21 shows the result of mold tests at different parts of the corn. One can see that there is not much difference between the beginning of the experiment and its end. The mold test indicated that the corn's general appearance was good.

Figure 25 shows grain temperature changes of 24 percent initial moisture content among samples in CAN No. 2 at different parts in the corn mass. The temperature of the corn was always below the average room temperature.

Statistical analyses of the temperature data and the moisture content data, to test the uniformity of temperature distribution and drying rate, were performed. Results of statistical tests are given in Tables 22 and 23. In the radial direction there is no significant difference for temperature or drying rate. In the vertical direction there is no significant difference of temperature in the center part, but there is significant difference of temperature in the outer part, and the temperature of the upper layer in the corn mass is higher than that of the bottom layer. There is also significant difference in the drying rate in the vertical direction. The upper layer dried faster than the bottom layer in the corn mass.

Figure 26 shows the drying rate of 24 percent initial moisture content samples in CAN No. 3 at different parts in the corn mass and using the ratio of corn to silica gel, 20:1. At the beginning the drying rate was fast; then it gradually decreased. At the beginning the bottom center part dried faster than the bottom outer part. After 20 days of storage the upper layer of corn had dried to 16 percent moisture content, and the bottom layer of

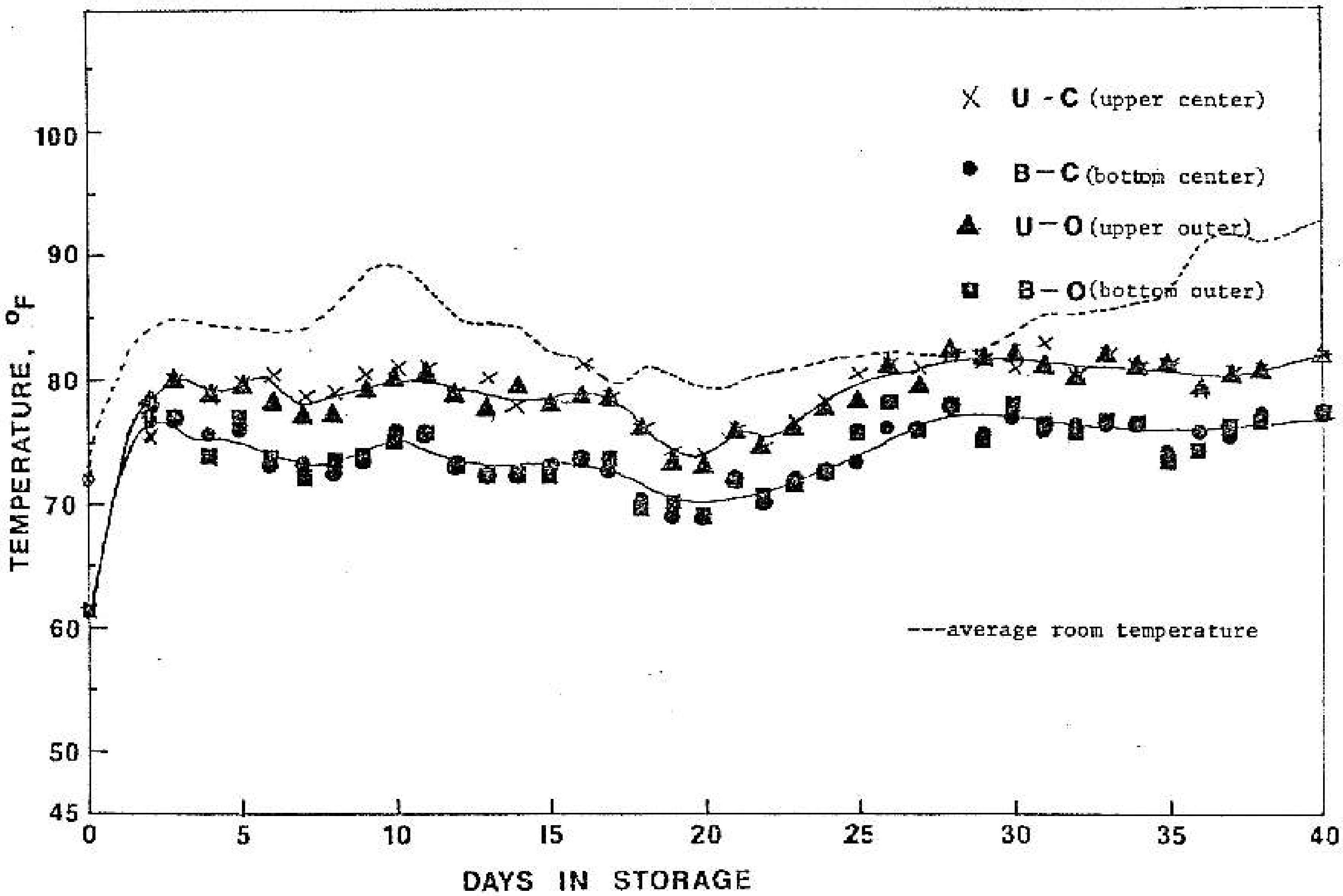
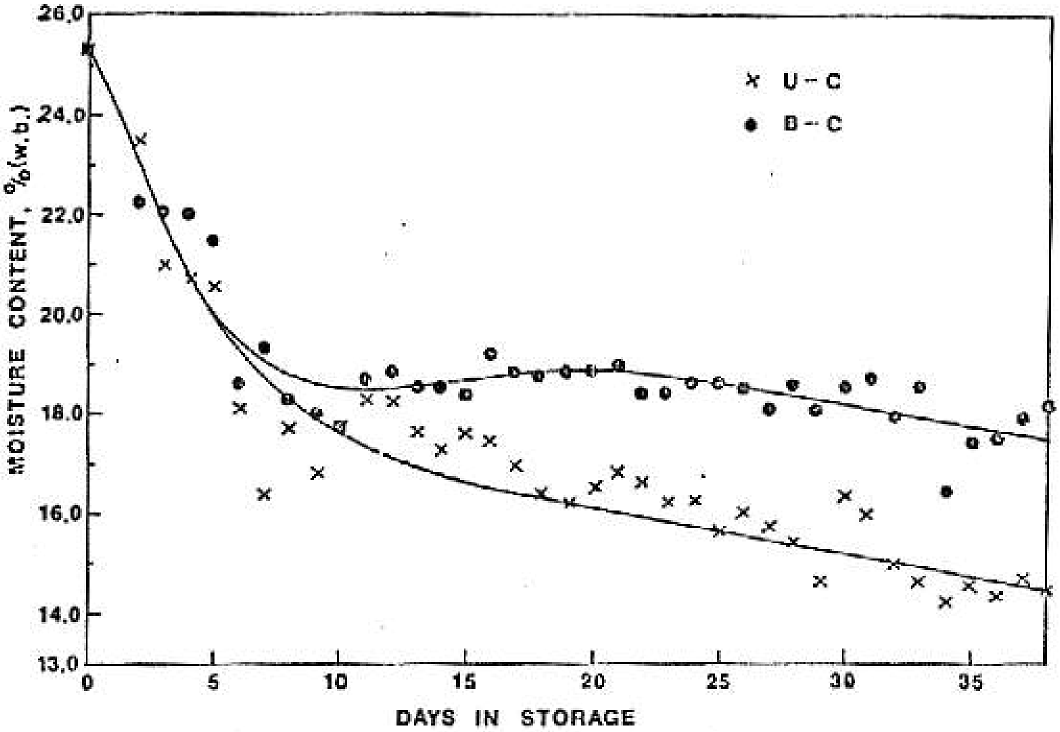


Figure 25. Grain temperature versus days in storage with silica gel for corn samples at 24 percent initial moisture content in CAN No. 2.



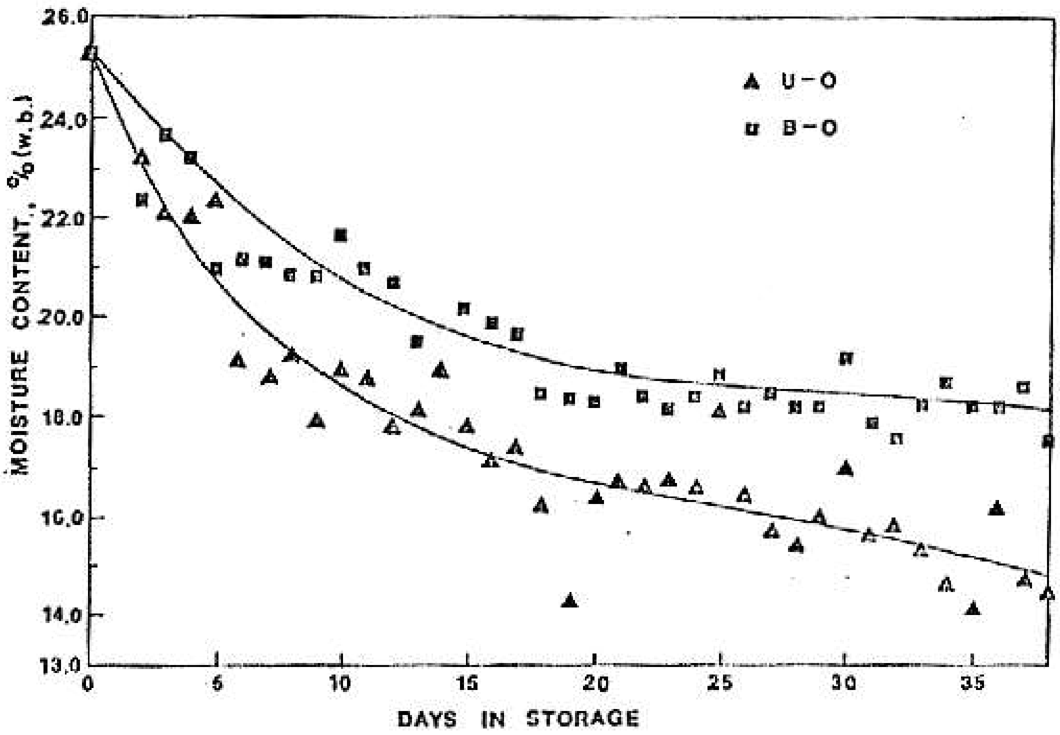


Figure 26. Moisture content versus days in storage for corn samples at 24 percent initial moisture content in CAN No. 3. (U-C : upper center, U-O : upper outer, B-C : bottom center,

38 days of storage, the upper layer in the corn was still above 14 percent moisture content and the bottom layer in the corn was still *about* 18 percent moisture content. At the end of the experiment the corn around the can was moldy and in a bad condition. Thus, the drying rate was too slow to prevent the mold development. Table 21 shows the results of the mold test at different parts of the corn. One can see that the mold development in CAN No. 3 was much worse than in CAN No. 1 and in CAN No. 2, and that the bottom layer was worse than the upper layer.

Statistical analyses of the temperature data and moisture content data to test the uniformity of temperature distribution and drying rate were performed. Results of statistical tests are given in Tables 22 and 23. Tables show no significant difference either in the temperature or in the drying rate. Figure 27 also shows that after 10 days of storage the temperature of the bottom layer was higher than the average room temperature, and after 15 days of storage the temperature of the upper layer was higher than the average room temperature, this extra temperature gain was caused by the respiration of the corn and mold development. From Table 20 in Appendix, one can see that after 13 days of storage the mold was visible in the bottom layer of corn, and after 15 days of storage the mold was visible in the upper layer of corn.

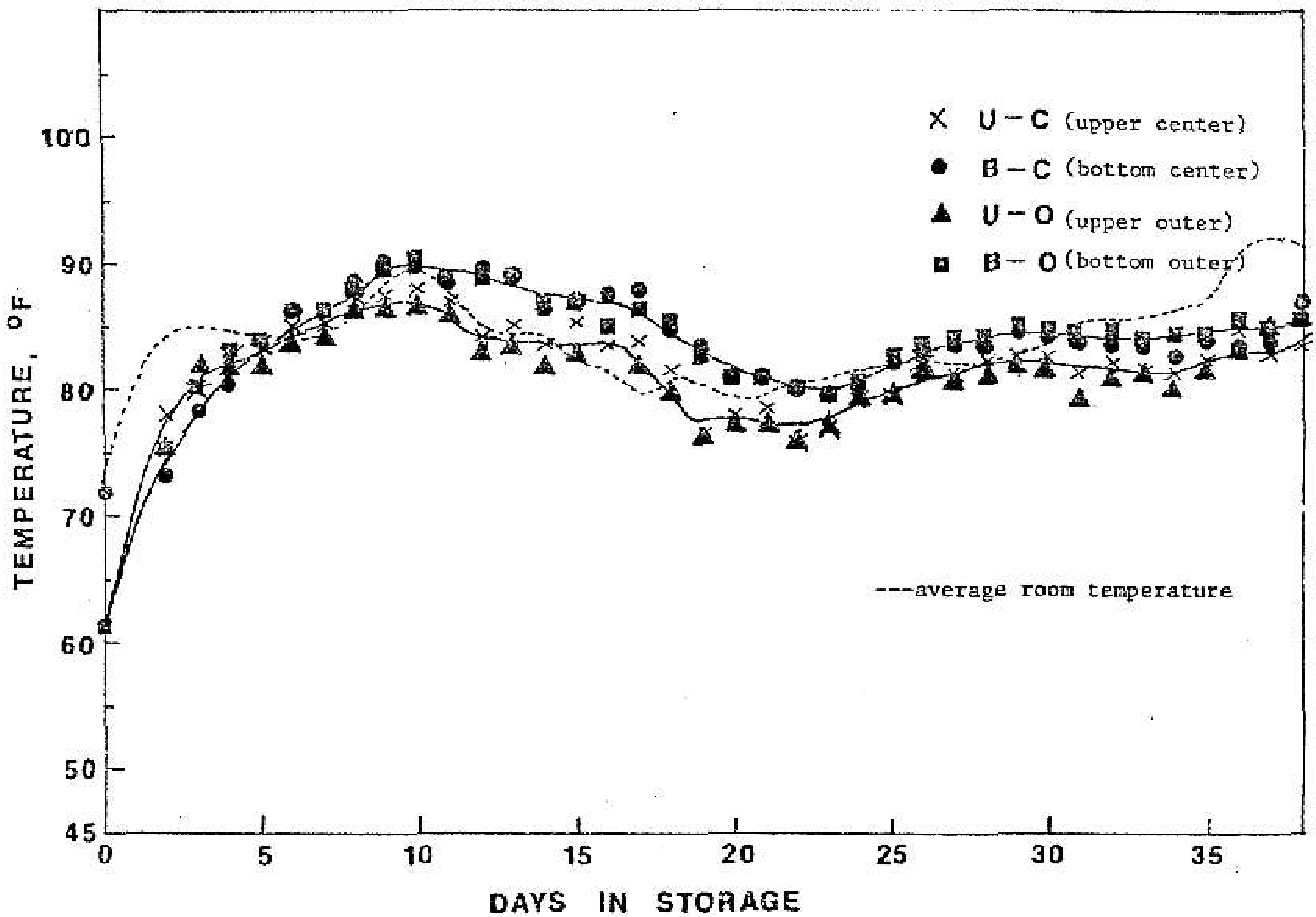


Figure 27. Grain temperature versus days in storage for corn samples at 24 percent initial moisture content in CAN No. 3.

CONCLUSIONS

From the results of this study the following conclusions were drawn:

I. For Phase I

1. Results showed that there was no significant difference between Fleske's work and the Phase I work. The experiments were successfully replicated.

2. Adequate drying and storage of clean grain in small amounts at the initial moisture content below 24% under extremely humid conditions can be accomplished by the proper use of silica gel as follows:

Initial moisture content of 15%:

1) Where ratio of grain to silica gel is 50:1 (in two cylinders and three sacks).

2) Regenerating (drying) silica gel once every day for the first seven days of storage, at approximately 130°C for 45 minutes and thereafter every other day for another week. At this point the grain is at safe moisture content for storage.

Initial moisture content of 20%

1) Where the ratio of grain to silica gel is 35:1 (in three cylinders and three sacks).

2) Regenerating silica gel as in the procedure for corn of 15% initial moisture content.

Initial moisture content of 24%

1) Where the ratio of grain to silica gel is 20:1 (in three

2) Regenerating silica gel twice a day for the first three days then following the procedure for grain of 15% initial moisture content.

The general conclusion for the Phase II experiment is:

1) For static storage conditions, the drying rate was too slow to prevent mold development, especially in the bottom layer and the outer parts of corn. The corn temperature was above the average room temperature when mold developed.

2) For the drying and conditioning method in which the incoming air was pre-dried with silica gel, then passed through a grain bed, using a roof spinner (CAN No. 1), the drying rate was very fast. Only 12 days after storage the corn was dried to the average safe moisture content of 13%, and at the end of the experiment no mold was visible. The corn temperature was always below the average room temperature. The incoming air distribution was not uniform. The drying rate of the bottom outer part was much slower than that of the other parts.

3) For the drying and conditioning method in which the incoming air was pulled upward by a roof spinner through a grain bed in which silica gel placed in four cylinders was uniformly distributed (CAN No. 2), the drying rate of the corn was much slower than in CAN No. 1. It required 37 days after storage to dry the corn to the average safe moisture content of 13%, and at the end of the experiment no mold was visible. The corn temperature was always below

the average room temperature. The moisture distribution was more uniform than in CAN No. 1, because the incoming air was more uniformly distributed.

4) From the statements listed above, it is obvious that the best method was that used in CAN No. 1, which was to use silica gel to dry the incoming air to a very low level of humidity and then use this dried air for drying and storing the grain. However, this method needs to be improved so that incoming air is more uniformly distributed.

5) The silica gel need not be regenerated frequently; if its maximum capacity for adsorption is 40% of the silica gel, the researcher may start redrying the gel when 70% of the maximum adsorption capacity has been used.

SUGGESTIONS FOR FUTURE WORK

The following suggestions are recommended for future work:

1. Repeat experiment under humid conditions with less regeneration of adsorbent.
2. Study effective and efficient silica gel regeneration.
3. Search for cheaper adsorbents which can be used for grain drying and storage.
4. Develop an effective and inexpensive storage unit by testing several shapes of storage units constructed with different construction materials.
5. Conduct field tests with a recommended storage unit and method at selected humid areas in developing countries.

ACKNOWLEDGEMENTS

The author wishes to express her sincere gratitude to the members of her graduate committee for their support and guidance in the completion of her work. Special thanks go to Dr. Do Sup Chung, the author's major professor, and Dr. T. O. Hodges for their esteemed guidance and encouragement in the preparation of her master's thesis and through her graduate studies.

The author wishes to give special recognition and thanks to Dr. David Sauer and Mrs. Rosemary Burroughs, U. S. Grain Marketing Center, USDA, Manhattan, Kansas, for special efforts in checking the samples for mold growth.

The author wishes to recognize the Food and Food Grain Institute, Kansas State University, for financial assistance provided for this project.

The author wishes to give special thanks to Prof. Helen P. Hostetter, KSU Emeritus Professor of Journalism, who checked the English of this thesis.

REFERENCES

Ahlberg, J. Elston. 1939. Rates of water adsorption from air by silica gel. Industrial and Engineering Chemistry 31(8): 988-992.

Anderson, J. A. and A. W. Alcock. 1969. Storage of cereal grains and their products. *American Association of Cereal Chemists. St. Paul, Minnesota.* Sec. ed.

Babbitt, J. D. 1945. Hysteresis in the adsorption of water vapor by wheat. Nature 156: 265-266.

BEHLEN Manufacturing Company. 1972. Modern grain condition. BEHLEN Manufacturing Company. Columbus, Nebr.

Breese, M. H. 1954. Hysteresis in the hygroscopic equilibria of rough rice at 25°C. Cereal Chem. 32: 481-485.

Chemical Engineer's Handbook. 1950. Mcapraw-Hill Book Company, Inc. New York.

Chi, C. W. and D. T. Wasan. 1970. Fixed bed adsorption drying. AECHE Journal 16(1): 23-31.

Christensen, Clyde M. and H. Kaufman. 1968. Grain storage. Minneapolis, University of Minnesota Press.

Chung, D. S. and H. B. Pfost. 1967. Adsorption and desorption of water vapor by cereal grains and their products. Part II: Development of the general isotherm equation. Part III: An hypothesis for explaining the hysteresis effect. Trans. of ASAE 10(4): 553-556.

Crank, J. 1964. The mathematics of diffusion. Oxford University Press, New York.

Fleske, L. F. 1973. Application of drying agents for small scale on-farm drying and storage in humid regions of developing countries. M.S. thesis. Kansas State University.

Grace & Company. 1973. Silica gels. Grace & Company.

Hall, D. W. 1970. Handling and storage of food grains in tropical and subtropical areas. FAO Paper No. 90.

Hamdy, M. Y. and H. J. Barre. 1969. Evaluating film coefficient in single-kernel drying. American Society of Agricultural Engineers Transactions 12: 205-208.

Hart, J. R. 1964. Hysteresis effects in mixture of wheats taken from the same sample but having different moisture contents. Cereal Chem. 41: 340-350.

Henderson, S. M. and R. L. Perry. 1970. Agricultural process engineering. Sed. ed.

Ives, Norton C. 1968. Grain drying and storage for warm, humid climates. Inter-American Institute of Agricultural Sciences.

Lebedev, P. D. 1961. Heat and mass transfer during the drying of moist materials. International Journal of Heat and Mass Transfer 1: 294-301.

McBain, J. W. 1935. An explanation of hysteresis in the hydration and dehydration of gels. Journal of the American Society of Chemistry 57: 699-700.

McFarlane, J. A. 1970. Insect control by airtight storage in small containers. Tropical Stored Products Information. (19): 10-14.

Miller, E. B. Adsorption by silica gel I. Chemical and Metallurgical Engineering. 23(24): 1155-1520.

Oxley, T. A. 1948. The scientific principles of grain storage.

Patrick, W. A., J. C. W. Frazer, and R. I. Rush. 1927. A study of the structural changes in amorphous materials -silica gel. Journal of Physical Chemistry 31: 1511-1520.

Rose, G. J. 1963. Crop protection. Chemical Publishing Co. New York.

Sinha, R. M. 1973. Grain storage: part of a system. Westport, Conn. Avi. Pub. Co.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical methods. The Iowa State University Press. Ames, Iowa. Sixth ed.

APPENDIX

Table 3. Grain weight, temperature, and moisture changes during storage period for 15 percent M. C. corn stored in a closed container with silica gel in 2 cylinders and 3 sacks (15-2S-C) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3451.11	0	63.0	.15		Initial adsorbent wt.-69.52 g.
.5	3439.61	15.61	88.0	.1472		Desiccant dried every day at 130 C
1.0	3431.61	6.11	86.0	.1452		
1.5	3424.61	6.43	87.0	.1435		
2.0	3417.61	7.17	86.5	.1417		
2.5	3415.11	4.68	86.8	.1408		
3.0	3407.11	6.81	86.5	.1388	.1304	60.67 g. sample taken for analyses.
3.5	3340.61	4.89	91.0	.1373		
4.5	3330.11	10.86	83.0	.1346		R. H. : 56 for 12 hrs.
5.5	3317.11	10.18	83.0	.1312	.1273	62.22 g. sample taken for analyses.
6.5	3247.11	10.40	83.0	.1291		
7.5	3238.61	9.59	82.5	.1268	.1189	65.49 g. sample taken for analyses,
8.5	3162.11	9.92	83.0	.1238		desiccant dried every 2 days after
9.5	3159.11	3.03	83.5	.1230		this day.
10.5	3152.11	8.97	82.5	.1211	.1156	69.21 g. sample taken for analyses.
11.5	3079.61	2.84	81.0	.1202		
12.5	3071.11	7.24	80.5	.1178		
13.5	3070.61	2.31	82.0	.1177		
14.5	3063.11	8.07	84.5	.1155	.120	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:49.64. Corn harvested 6 months previously.

Table 4. Grain weight, temperature, and moisture changes during storage period for 15 percent M. C. corn stored in an open container with silica gel in 2 cylinders and 3 sacks (15-2S-0) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3541.88	0	60.0	.15		Initial adsorbent wt.-71.73 g.
.5	3500.38	16.50	87.0	.1465		Desiccant dried every day at 130 C
1.0	3493.38	7.07	86.0	.1448		
1.5	3489.38	7.80	86.5	.1438		
2.0	3480.38	8.01	86.5	.1416		
2.5	3476.88	5.10	86.5	.1407		
3.0	3471.38	8.14	86.5	.1393	.1291	61.29 g. sample taken for analyses.
3.5	3402.88	5.33	90.0	.1375		
4.5	3393.38	12.52	82.5	.1351		R. H. : 56 for 12 hrs.
5.5	3388.38	12.59	82.0	.1338	.1288	65.64 g. sample taken for analyses.
6.5	3320.88	14.02	84.0	.1333		
7.5	3310.88	12.51	84.0	.1307	.1315	64.34 g. sample taken for analyses, desiccant dried every 2 days after this day.
8.5	3239.38	13.03	84.0	.1288		
9.5	3241.88	3.37	83.5	.1295		
10.5	3241.38	14.21	83.5	.1294	.1253	66.26 g. sample taken for analyses.
11.5	3178.88	1.90	81.5	.1304		
12.5	3176.88	13.92	81.0	.1299		
13.5	3176.38	1.40	81.0	.1298		
14.5	3176.38	13.95	83.0	.1298	.1280	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:49. Corn harvested 6 months previously.

Table 5. Grain weight, temperature, and moisture changes during storage period for 20 percent M. C. corn stored in a closed container with silica gel in 3 cylinders and 3 sacks (20-3S-C) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3472.88	0	61.5	.192		Initial adsorbent wt.-95.66 g. Desiccant dried every day at 130 C
.5	3447.38	25.61	86.0	.186		
1.0	3434.88	13.09	88.0	.183		
1.5	3427.88	7.33	86.5	.1813		
2.0	3412.88	14.60	87.5	.1777		
2.5	3410.88	3.29	87.0	.1772		
3.0	3392.88	16.02	89.0	.1728	.1744	58.25 g. sample taken for analyses.
3.5	3328.38	5.32	91.0	.1712		
4.5	3311.38	17.86	83.0	.1669		R. H. : 56 for 12 hrs.
5.5	3292.88	18.46	83.0	.1622	.1717	57.60 g. sample taken for analyses.
6.5	3214.88	20.79	82.5	.1569		
7.5	3197.38	18.74	81.0	.1523	.1545	67.63 g. sample taken for analyses, desiccant dried every 2 days after this day.
8.5	3110.38	17.30	82.0	.1470		
9.5	3108.38	2.79	82.0	.1465		
10.5	3092.88	16.05	82.0	.1422	.1522	63.75 g. sample taken for analyses.
11.5	3023.88	3.34	80.5	.1407		
12.5	3011.88	13.90	79.5	.1373		
13.5	3009.38	2.39	80.5	.1366		
14.5	2995.38	14.54	83.5	.1326	.1375	Sample taken. Mold on the bottom layers.

[1]Initial silica gel to corn ratio of 1:36.30. *Corn harvested 6 months previously.*

Table 6. Grain weight, temperature, and moisture changes during storage period for 20 percent M. C. corn stored in an open container with silica gel in 3 cylinders and 3 sacks (20-3S-0) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3503.42	0	61.0	.192		Initial adsorbent wt.-101.02 g. Desiccant dried every day at 130 C
.5	3481.42	26.61	88.0	.1869		
1.0	3465.42	14.59	86.5	.1831		
1.5	3458.42	8.19	87.0	.1814		
2.0	3443.92	16.75	87.0	.1780		
2.5	3440.92	2.81	86.8	.1773		
3.0	3424.42	16.65	89.0	.1733	.1862	56.5 g sample taken for analyses.
3.5	3365.92	3.26	91.5	.1728		
4.5	3346.42	20.50	82.5	.1680		R. H. : 56 for 12 hrs.
5.5	3337.42	19.47	83.0	.1658	.1727	66.9 g. sample taken for analyses.
6.5	3250.42	23.39	83.5	.1606		
7.5	3234.42	20.94	80.0	.1564	.1670	72.63 g. sample taken for analyses, desiccant dried every 2 days after this day.
8.5	3142.42	20.18	80.5	.1512		
9.5	3140.92	2.99	82.0	.1508		
10.5	3126.92	21.50	82.0	.1470	.1717	69.44 g. sample taken for analyses.
11.5	3055.92	2.20	79.5	.1466		
12.5	3042.42	18.68	80.0	.1428		
13.5	3041.92	1.43	79.0	.1427		
14.5	3031.42	16.79	84.0	.1397	.1450	Sample taken. Mold on the bottom layers.

[1]Initial silica gel to corn ratio of 1:34.68. Corn harvested 6 months previously.

Table 8. Grain weight, temperature, and moisture changes during storage period for 24 percent M. C. corn stored in a closed container with silica gel in 2 cylinders and 3 sacks (24-2S-C) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3061.12	0	55.2	.2375		Initial adsorbent wt.-109.01 g.
.5	3032.62	28.80	83.2	.2303		Desiccant dried every 12 hrs. at 130 C.
1.0	3009.62	21.70	82.5	.2244	.2395	67.84 g. sample taken for analyses.
1.5	2920.12	21.51	84.5	.2186		
2.0	2910.62	9.30	82.5	.2160	.2372	67.51 g. sample taken for analyses.
2.5	2822.12	20.15	82.8	.2102		
3.0	2810.62	11.19	83.0	.2070	.2328	58.58 g. sample taken for analyses.
3.5	2732.62	19.11	82.2	.2014		
4.0	2721.12	11.30	84.0	.1980	.2195	61.52 g. sample taken for analyses, desiccant dried every day from this day.
4.5	2640.62	17.20	84.5	.1922		
5.0	2635.62	5.74	85.5	.1907		
5.5	2619.12	16.60	85.0	.1856		Mold developed on the bottom layers.
6.0	2612.62	4.81	84.0	.1836		
6.5	2594.12	16.96	84.0	.1778		
7.0	2590.62	5.04	85.0	.1767	.1854	61.25 g. sample taken for analyses.
7.5	2512.62	15.24	84.8	.1717		
8.0	2508.62	4.34	85.5	.1699		
8.5	2493.12	15.66	84.0	.1647		
9.0	2488.12	3.94	84.5	.1630	.2251	66.62 g. sample taken for analyses.
9.5	2409.12	13.85	84.5	.1587		
10.0	2404.62	3.39	86.5	.1571		
10.5	2392.62	12.37	84.0	.1529	.1701	64.19 g sample taken for analyses, desiccant dried every 2 days after this day.

Table 8 (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
11.0	2324.12	3.98	84.8	.1513		
12.0	2310.12	14.65	84.0	.1462		
13.0	2304.12	4.70	81.0	.1440		
14.0	2293.12	11.84	82.0	.1399	.1698	65.13 g. sample taken from analyses.
15.0	2222.62	4.45	84.0	.1378		
16.0	2211.12	13.23	86.0	.1333		
17.0	2208.12	4.88	86.0	.1321		
18.0	2195.62	11.77	82.5	.1271		
19.0	2190.62	3.95	80.0	.1251	.1310	Samples taken. Mold stopped to develop.

[1]Initial silica gel to corn ration of 1:28.8. Corn harvested 6 months previously.

Table 9. Grain weight, temperature, and moisture changes during storage period for 24 percent M. C. corn stored in an open container with silica gel in 2 cylinders and 3 sacks (24-2S-0) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3001.05	0	57.8	.2375		Initial adsorbent wt.-105.71 g.
.5	2974.55	28.62	83.0	.2307		Desiccant dried every 12 hrs. at 130 C.
1.0	2951.55	21.64	83.0	.2247	.2392	69.1 g. sample taken for analyses.
1.5	2861.05	20.97	83.0	.2189		
2.0	2853.55	9.48	83.0	.2168	.2283	67.1 g. sample taken for analyses.
2.5	2765.05	21.87	82.0	.2107		
3.0	2754.05	11.97	82.5	.2082	.2360	58.75 g. sample taken for analyses.
3.5	2677.55	20.65	82.8	.2030		
4.0	2665.55	10.87	82.5	.1994	.2296	62.81 g. sample taken for analyses, desiccant dried every day from this day.
4.5	2585.55	18.95	84.0	.1941		
5.0	2582.55	5.61	84.0	.1932		Mold developed on the bottom layers.
5.5	2567.05	18.98	84.0	.1883		
6.0	2563.55	3.71	84.0	.1872		
6.5	2550.55	17.67	86.0	.1831		
7.0	2546.05	4.37	86.0	.1817	.1920	63.2 g. sample taken for analyses.
7.5	2468.55	16.92	85.5	.1770		
8.0	2450.55	17.57	84.5	.1755		
8.5	2447.55	2.92	84.5	.1710		
9.0	2367.55	13.76	85.0	.1700	.1722	67.81 g. sample taken for analyses.
9.5	2365.55	8.98	84.5	.1657		
10.0	2355.05	18.91	84.5	.1650		
10.5	2289.55	2.90	85.5	.1613	.1586	63.17 g. sample taken for analyses, desiccant dried every 2 days after this day.

Table 9. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
11.0	2289.55	2.90	85.5	.1604		
12.0	2273.55	17.49	85.0	.1545		
13.0	2271.05	2.92	85.5	.1536		
14.0	2257.55	19.19	85.0	.1485	.1840	64.14 g. sample taken for analyses.
15.0	2196.05	2.19	84.0	.1497		
16.0	2181.55	19.26	86.5	.1440		
17.0	2181.05	4.39	86.0	.1438		
18.0	2170.55	19.45	84.0	.1397		
19.0	2171.05	3.06	81.0	.1399		
20.0	2157.05	15.25	81.0	.1345	.1370	Sample taken. Mold stopped to develop.

[1]Initial silica gel to corn ratio of 1:28.4. Corn harvested 6 months previously.

Table 10. Grain weight, temperature, and moisture changes during storage period for 24 percent M. C. corn stored in a closed container with silica gel in 3 cylinders and 3 sacks (24 3S-C) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3187.50	0	64.0	.2320		Initial adsorbent wt.-153.83 g. Desiccant dried every 12 hrs. at 130 C.
1.0	3165.22	23.4	88.0	.2268	.2183	64.93 g. sample taken for analyses.
1.5	3065.72	32.88	92.8	.2181		
2.0	3040.72	24.12	95.4	.2116	.1985	66.95 g. sample taken for analyses.
2.5	2948.72	23.54	94.8	.2049		
3.0	2929.22	18.38	86.2	.1996	.1752	64.22 g. sample taken for analyses.
3.5	2841.22	23.21	86.2	.1929		
4.0	2825.72	16.59	87.2	.1885	.1396	68.23 g. sample taken for analyses, desiccant dried every day from this day.
4.5	2735.22	21.47	86.0	.1819		
5.0	2729.22	6.35	83.8	.1801	.1497	65.31 g. sample taken for analyses.
5.5	2645.22	16.91	84.2	.1743		
6.0	2637.22	7.64	85.2	.1718	.1582	67.13 g. sample taken for analyses, mold developed on the bottom layers.
6.5	2551.72	18.39	84.4	.1658		
7.0	2549.22	2.36	83.8	.1650	.1811	67.33 g. sample taken for analyses.
7.5	2465.22	15.32	84.5	.1594		
8.0	2461.22	3.29	82.5	.1580		
8.5	2439.72	19.58	83.5	.1506		
9.0	2434.22	5.50	84.0	.1487	.1584	68.02 g. sample taken for analyses.
9.5	2348.22	17.02	84.0	.1422		
10.0	2343.22	4.46	84.0	.1404		
10.5	2330.22	13.76	84.0	.1356		

Table 10. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
11.0	2326.22	3.78	84.0	.1341		Desiccant dried.
11.5	2316.22	10.49	83.0	.1304		
12.5	2308.72	6.82	81.0	.1276		
13.0	2307.22	0.75	81.8	.1270		Desiccant dried.
14.0	2295.72	17.75	83.0	.1226	.1292	66.29 g. sample taken for analyses.
15.0	2224.72	6.25	84.0	.1207		
16.0	2221.72	1.84	83.5	.1195		
17.0	2222.22	0.60	83.0	.1197		
18.0	2221.72	0.32	84.0	.1195		Desiccant dried.
19.0	2209.72	12.21	83.5	.1147	.1230	Sample taken. Mold stopped to develop.

[1]Initial silica gel to corn ratio of 1:20.72. Corn harvested 6 months previously.

Table 11. Grain weight, temperature, and moisture changes during storage period for 24 percent M. C. corn stored in an open container with silica gel in 3 cylinders and 3 sacks (24-3S-0) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3184.6	0	64.0	.229		Initial adsorbent wt.-161.02 g. Desiccant dried every 12 hrs. at 130 C.
1.0	3160.74	22.52	87.2	.2232	.2243	65.64 g. sample taken for analyses.
1.5	3059.10	35.96	91.5	.2141		
2.0	3032.10	26.75	94.8	.2071	.2000	64.69 g. sample taken for analyses.
2.5	2939.60	26.95	95.0	.1996		
3.0	2920.60	19.58	87.0	.1944	.1692	65.46 g. sample taken for analyses.
3.5	2831.60	24.20	87.8	.1877		
4.0	2816.60	16.08	86.3	.1834	.1572	65.04 g. sample taken for analyses, desiccant dried every day from this day.
4.5	2729.60	23.61	88.0	.1768		
5.0	2724.10	7.00	85.6	.1751	.1443	66.03 g. sample taken for analyses, mold developed on the bottom layers.
5.5	2640.60	16.74	85.8	.1696		
6.0	2636.60	8.00	84.5	.1677	.1678	66.20 g. sample taken for analyses.
6.5	2544.60	26.69	83.8	.1599		
7.0	2539.60	6.00	83.0	.1582	.1686	66.26 g. sample taken for analyses.
7.5	2454.60	18.73	84.0	.1521		
8.0	2450.55	4.05	83.4	.1507		
8.5	2438.10	20.42	84.5	.1464		
9.0	2427.10	10.54	84.5	.1425	.1514	67.67 g. sample taken for analyses.
9.5	2344.10	16.49	84.4	.1369		
10.0	2336.10	7.01	85.2	.1339		
10.5	2323.60	15.93	83.8	.1292		

Table 11. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
11.0	2320.10	4.78	85.0	.1279		Desiccant dried.
11.5	2310.60	15.09	85.0	.1243		
12.5	2307.60	5.65	82.5	.1232		
13.0	2307.60	1.00	82.0	.1232		Desiccant dried.
14.0	2293.10	17.15	83.0	.1177	.1348	69.04 g. sample taken for analyses.
15.0	2220.10	7.57	83.8	.1161		
16.0	2220.10	2.83	84.0	.1161		
17.0	2222.10	0.54	84.0	.1169		
18.0	2223.10	0.23	84.0	.1173		Desiccant dried.
19.0	2211.10	17.08	84.8	.1125	.0820	Samples taken. Mold stopped to develop.

[1]Initial silica gel to corn ration of 1:19.79. Corn harvested 6 months previously.

Table 12. Grain weight, temperature, and moisture changes during storage period for 24 percent M. C. corn stored in a closed container with silica gel in 5 cylinders and 3 sacks (24-5S-C) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3030.81	0	64.0	.2320		Initial adsorbent wt.-223.05 g. Desiccant dried every 12 hrs. at 130 C.
1.0	2994.81	37.27	91.5	.2228	.2460	67.18 g. sample taken for analyses.
1.5	2875.81	48.17	94.5	.2088		
2.0	2849.31	25.85	94.5	.2014	.1786	66.51 g. sample taken for analyses.
2.5	2749.31	33.23	94.0	.1917		
3.0	2726.31	23.53	85.8	.1849	.1635	66.24 g. sample taken for analyses.
3.5	2633.31	26.00	85.0	.1766		
4.0	2616.81	17.05	85.5	.1714	.1532	66.21 g. sample taken for analyses, desiccant dried every day from this day.
4.5	2526.81	23.10	84.8	.1636		
5.0	2518.81	8.13	84.6	.1609	.1230	65.49 g. sample taken for analyses.
5.5	2436.81	17.62	84.0	.1552		
6.0	2427.31	8.22	84.4	.1519	.1661	69.12 g. sample taken for analyses.
6.5	2333.31	24.97	84.0	.1429		
7.0	2326.31	7.07	83.0	.1403	.1643	67.28 g. sample taken for analyses.
7.5	2239.31	21.10	83.5	.1327		
8.0	2224.81	12.91	81.3	.1270		
8.5	2202.31	20.94	82.5	.1181		
9.0	2193.31	8.46	83.0	.1145	.1202	66.77 g. sample taken for analyses.
9.5	2112.31	14.35	83.8	.1085		
10.0	2107.31	5.11	83.5	.1064		
10.5	2096.81	11.01	83.2	.1019		

Table 12. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
11.0	2093.31	3.94	84.0	.1004		Desiccant dried.
11.5	2082.31	10.71	83.0	.0956		
12.5	2077.31	7.07	82.0	.0934		
13.0	2074.81	2.49	82.0	.0923		Desiccant dried.
14.0	2065.31	9.70	82.5	.0881	.953	65.39 g. sample taken for analyses.
15.0	1995.31	5.85	83.5	.0789		
16.0	1992.81	3.59	83.3	.0777		
17.0	1991.31	2.15	82.8	.0770		
18.0	1989.81	1.38	83.8	.0763		Desiccant dried.
19.0	1982.31	18.41	82.5	.0728		Sample taken. Mold on the bottom layers.

[1]Initial silica gel to corn ratio of 1:13.588. Corn harvested 6 months previously.

Table 13. Grain weight, temperature, and moisture changes during storage period for 24 percent M. C. corn stored in an open container with silica gel in 5 cylinders and 3 sacks (24-5S-0) at 95 F and 90-100 percent R. H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3193.24	0	64.0	.2340		Initial adsorbent wt.-236.5 g. Desiccant dried every 12 hrs. at 130 C.
1.0	3156.24	37.57	89.6	.2250	.2076	64.24 g. sample taken for analyses.
1.5	3042.24	51.39	95.0	.2123		
2.0	3011.74	34.63	97.0	.2043	.1625	66.25 g. sample taken for analyses.
2.5	2909.74	35.85	94.0	.1945		
3.0	2887.24	29.98	87.6	.1882	.1400	65.92 g. sample taken for analyses.
3.5	2795.24	31.00	86.0	.1806		
4.0	2778.74	20.21	86.2	.1757	.1431	65.17 g. sample taken for analyses, desiccant dried every day from this day.
4.5	2688.74	26.95	87.0	.1681		
5.0	2682.74	7.44	87.0	.1662	.1248	65.03 g. sample taken for analyses.
5.5	2598.24	20.82	85.3	.1600		
6.0	2590.74	9.85	85.4	.1576	.1752	67.17 g. sample taken for analyses.
6.5	2523.57	21.00	85.4	.1508		
7.0	2497.24	5.80	84.6	.1488	.1687	68.12 g. sample taken for analyses.
7.5	2412.74	25.34	84.5	.1430		
8.0	2406.24	5.36	82.0	.1407		
8.5	2384.24	27.52	83.8	.1328		
9.0	2375.24	12.60	84.0	.1295	.1510	66.57 g. sample taken for analyses.
9.5	2295.24	14.81	83.8	.1244		
10.0	2291.74	5.40	84.0	.1231		
10.5	2281.24	21.71	84.5	.1191		

Table 13. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
11.0	2277.24	4.54	84.5	.1178		Desiccant dried.
11.5	2269.24	13.96	82.8	.1147		
12.5	2265.74	2.72	81.0	.1133		
13.0	2264.74	7.73	81.5	.1129		Desiccant dried.
14.0	2253.24	15.86	82.0	.1084	.1282	71.76 g. sample taken for analyses .
15.0	2174.74	7.69		.1056		
16.0	2176.24	9.73		.1062		
17.0	2177.74	0.85		.1068		
18.0	2180.74	1.96		.1037		Desiccant dried.
19.0	2170.24	12.76		.0994	.0980	Sample taken. Mold on the bottom layers.

[1]Initial silica gel to corn ratio of 1:13.499. Corn harvested 6 months previously.

Table 16. Room temperature during storage for phase II experiment

Days in storage	4 a.m.	8 a.m.	12 a.m.	4 p.m.	8 p.m.	12 p.m.	Max.	Min.	Average
0				72.0					
2					85.0	85.0	85.0	83.0	84.0
3	85.0	85.0	86.0	86.0	84.0	84.0	86.0	84.0	85.0
4	84.0	84.0	84.0	83.0	82.0	86.0	86.0	82.0	84.0
5	86.0	86.0	86.0	86.0	83.0	84.0	86.0	82.0	85.0
6	84.0	84.0	82.0	88.0	86.0	84.0	88.0	80.0	84.5
7	84.0	84.0	84.0	84.0	82.0	84.0	85.0	81.0	83.5
8	85.0	85.0	85.0	86.0	81.0	86.0	86.0	80.0	84.5
9	86.0	86.0	89.0	90.0	92.0	93.0	93.0	86.0	89.3
10	88.0	88.0	88.0	91.0	92.0	92.0	92.0	87.0	89.8
11	92.0	89.0	88.0	86.0	84.0	84.0	92.0	84.0	87.1
12	84.0	83.0	82.0	82.0	87.0	88.0	88.0	82.0	84.3
13	88.0	84.0	84.0	84.0	86.0	86.0	88.0	84.0	85.3
14	85.0	84.0	84.0	84.0	85.0	84.0	85.0	84.0	84.3
15	82.0	82.0	81.0	81.0	80.0	78.0	82.0	78.0	80.7
16	77.0	76.0	75.0	74.0	78.0	81.0	81.0	74.0	77.0
17	82.0	82.0	82.0	82.0	83.0	82.0	84.0	82.0	82.1
18	82.0	82.0	81.0	81.0	79.0	81.0	82.0	79.0	81.0
19	81.0	80.0	80.0	80.0	80.0	80.0	82.0	80.0	80.1
20	81.0	81.0	80.0	80.0	80.0	80.0	81.0	80.0	80.3
21	81.0	81.0	82.0	82.0	82.0	82.0	82.0	80.0	81.7
22	82.0	82.0	82.0	83.0	83.0	82.0	84.0	82.0	82.3
23	82.0	82.0	82.0	84.0	82.0	83.0	84.0	82.0	82.5
24	82.0	83.0	82.0	82.0	82.0	82.0	83.0	82.0	82.1
25	84.0	82.0	83.0	82.0	82.0	83.0	84.0	82.0	82.7
26	82.0	83.0	83.0	82.0	84.0	82.0	84.0	82.0	82.7

Table 16. (Cont'd)

Days in storage	4 a.m.	8 a.m.	12 a.m.	4 p.m.	8 p.m.	12 p.m.	Max.	Min.	Average
27	82.0	82.0	84.0	82.0	83.0	82.0	84.0	82.0	82.5
28	82.0	82.0	83.0	84.0	83.0	82.0	84.0	82.0	82.7
29	82.0	84.0	82.0	83.0	82.0	85.0	85.0	82.0	83.0
30	85.0	86.0	86.0	85.0	84.0	84.0	86.0	84.0	85.0
31	84.0	84.0	85.0	85.0	86.0	86.0	86.0	84.0	85.0
32	85.0	85.0	85.0	85.0	86.0	86.0	87.0	85.0	85.3
33	85.0	85.0	86.0	87.0	87.0	86.0	87.0	85.0	86.0
34	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0
35	86.0	86.0	86.0	86.0	87.0	87.0	87.0	86.0	86.3
36	88.0	88.0	88.0	90.0	93.0	93.0	93.0	88.0	90.0
37	93.0	93.0	92.0	90.0	90.0	90.0	93.0	90.0	91.3
38	90.0	90.0	90.0	90.0	90.0	90.0	90.0	89.0	90.0
39	91.0	91.0	90.0	91.0	92.0	92.0	92.0	90.0	91.1
40	92.0	92.0	92.0	92.0	92.0	92.0	93.0	90.0	92.0

Table 17. Room relative humidity.

Days in storage	4 a.m.	8 a.m.	12 a.m.	4 p.m.	8 p.m.	12 p.m.	Max.	Min.	Average
0				30.0					
2				28.0	30.0	30.0	30.0	24.0	29.0
3	30.0	30.0	30.0	32.0	34.0	30.0	34.0	30.0	31.0
4	30.0	31.0	34.0	34.0	32.0	30.0	34.0	30.0	31.8
5	28.0	26.0	24.0	28.0	26.0	30.0	30.0	26.0	27.0
6	30.0	29.0	22.0	30.0	24.0	32.0	31.0	22.0	28.0
7	32.0	30.0	26.0	30.0	30.0	37.0	37.0	26.0	30.8
8	36.0	36.0	36.0	40.0	36.0	41.0	42.0	35.0	37.5
9	30.0	30.0	38.0	40.0	40.0	40.0	40.0	36.0	37.3
10	44.0	42.0	34.0	38.0	38.0	38.0	44.0	34.0	39.0
11	40.0	38.0	36.0	40.0	38.0	34.0	41.0	36.0	37.7
12	38.0	34.0	34.0	34.0	32.0	29.0	38.0	30.0	33.5
13	36.0	38.0	44.0	46.0	48.0	46.0	48.0	34.0	43.0
14	46.0	38.0	40.0	38.0	38.0	30.0	46.0	30.0	38.3
15	29.0	29.0	34.0	34.0	31.0	34.0	36.0	29.0	31.8
16	36.0	35.0	38.0	38.0	36.0	36.0	38.0	34.0	36.5
17	36.0	35.0	36.0	38.0	39.0	39.0	40.0	34.0	37.1
18	34.0	32.0	36.0	36.0	36.0	38.0	39.0	32.0	35.3
19	36.0	36.0	34.0	38.0	36.0	40.0	38.0	34.0	36.7
20	39.0	40.0	40.0	40.0	38.0	38.0	40.0	36.0	39.1
21	36.0	38.0	40.0	38.0	36.0	36.0	40.0	36.0	37.3
22	38.0	38.0	38.0	36.0	40.0	36.0	40.0	36.0	37.7
23	40.0	40.0	36.0	38.0	38.0	36.0	40.0	36.0	38.0
24	38.0	38.0	34.0	36.0	36.0	38.0	40.0	34.0	36.7
25	38.0	39.0	40.0	38.0	36.0	38.0	40.0	36.0	38.1

Table 17. (Cont'd)

Days in storage	4 a.m.	8 a.m.	12 a.m.	4 p.m.	8 p.m.	12 p.m.	Max.	Min.	Average
26	38.0	36.0	38.0	38.0	40.0	36.0	40.0	34.0	37.7
27	40.0	40.0	38.0	38.0	36.0	34.0	40.0	34.0	37.7
28	38.0	38.0	36.0	40.0	42.0	42.0	42.0	36.0	39.3
29	42.0	42.0	45.0	44.0	42.0	40.0	45.0	40.0	43.5
30	38.0	35.0	37.0	36.0	36.0	34.0	38.0	29.0	36.0
31	34.0	34.0	34.0	34.0	33.0	34.0	36.0	29.0	33.8
32	34.0	33.0	36.0	36.0	36.0	32.0	38.0	32.0	34.5
33	30.0	28.0	35.0	32.0	36.0	34.0	36.0	29.0	32.5
34	34.0	34.0	34.0	36.0	35.0	35.0	36.0	34.0	34.7
35	38.0	36.0	42.0	30.0	30.0	30.0	42.0	30.0	34.3
36	29.0	24.0	30.0	30.0	32.0	30.0	30.0	24.0	29.1
37	30.0	29.0	30.0	28.0	30.0	28.0	30.0	27.0	29.0
38	28.0	28.0	32.0	26.0	26.0	31.0	32.0	26.0	28.5
39	30.0	30.0	32.0	31.0	30.0	30.0	32.0	30.0	30.5
40	26.0	24.0	28.0	27.0	29.0	24.0	30.0	22.0	26.3

Table 18. Grain temperature and moisture changes during storage period for 24 percent M. C. corn stored in CAN No. 1 with silica gel on top of perforated pan at 80-90 F and 30-40 percent R.H.[1]

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-O	B-O[2]	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	
0	62.0	62.0	62.0	62.0	23.3	23.3	23.3	23.3					Initial adsorbent wt.- 16 lbs. Desiccant dried at 130 C.
2	80.0	75.0	78.0	73.0	14.6	21.8	20.9	21.6					Dry desiccant (1.5 days).
3	80.0	75.0	79.0	76.5	12.7	18.4	16.9	20.2					Samples taken for analyses.
4	80.5	73.0	80.0	73.0	12.6	18.3	14.0	20.8					
5	80.0	74.0	79.5	73.0	12.1	15.9	14.9	22.1					Dry desiccant (2.5 days), it gained 1.98 lbs.
6	80.5	74.5	81.0	74.0	11.1	14.2	13.0	22.3	9.1	16.1	11.3	26.3	
7	82.0	73.0	82.0	74.0	11.9	14.0	11.3	20.6	9.8	12.2	9.7	19.4	Samples taken for analyses.
8	84.5	78.0	84.0	73.0			10.9	23.6	9.7	10.8	9.5	22.1	Dry desiccant (2.5 days), it gained 1.33 lbs.
9	84.0	79.0	85.0	74.0			11.9	23.2	8.8	11.4	8.9	20.6	
10	84.0	77.0	84.0	75.0			11.1	23.3	10.4	13.0	9.9	20.8	
11	85.5	77.5	84.0	74.5			12.8	21.1	10.2	13.2	9.7	20.5	Dry desiccant (3 days), it gained 1.778 lbs.
12	80.0	72.5	80.0	70.0			12.0	20.4	9.5	13.4	9.3	20.6	Samples taken for analyses.
13	82.0	75.0	81.0	71.0			12.5	20.3	9.9	13.0	9.3	17.4	
14	80.0	73.0	78.5	72.5			11.7	19.0	9.2	12.0	8.9	17.2	Dry desiccant (3.5 days), it gained 1.778 lbs.

Table 18. (Cont'd)

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-0	B-0^2	U-C	B-C	U-0	B-0	U-C	B-C	U-0	B-0	
15	82.0	75.5	81.5	74.0			11.6	18.4	9.1	11.7	8.9	16.1	
16	83.0	78.0	82.0	77.0			11.2	16.3	9.5	11.4	9.0	15.1	
17	81.0	77.0	80.0	76.5			11.7	16.3	8.7	10.4	8.9	13.4	Samples taken for analyses.
18	78.5	72.0	77.0	73.0			11.7	15.6	9.1	11.2	9.4	12.4	
19	75.0	70.5	74.0	71.0			11.4	14.6	10.1	10.7	9.4	11.8	
20	77.0	72.0	77.0	72.0			12.0	16.3	9.6	10.2	9.1	11.0	Dry desiccant (6 days), it gained 1.071 lbs.
21	76.5	73.0	76.5	73.0			11.1	15.3	9.7	10.7	9.8	11.6	Samples taken for analyses.
22	75.5	72.5	75.0	73.0			11.6	14.6	9.3	10.0	9.3	11.6	
23	79.0	76.5	78.5	77.0			11.5	13.8	10.2	10.0	9.8	11.2	
24	80.0	76.0	79.5	76.5					9.6	10.2	9.1	10.1	Samples taken for analyses.
25	82.5	79.0	81.5	78.5					9.2	9.7	8.8	10.4	
26	83.5	78.5	82.0	78.5					9.3	9.4	9.1	10.3	
27	81.0	78.5	80.5	78.5					9.3	9.4	9.0	10.7	Samples taken for analyses.
28	83.0	81.0	83.0	80.5					9.3	9.2	9.3	9.3	
29	83.0	81.5	83.0	80.0					9.1	9.9	9.1	8.8	
30	83.5	81.0	81.5	81.5					9.8	12.3	9.8	10.9	
31	82.0	77.5	80.0	77.0					8.8	9.7	9.2	9.6	
32	81.5	79.0	81.5	78.5					8.5	8.9	9.2	9.6	
33	81.0	78.5	81.5	78.0					9.2	9.6	9.3	9.9	
34	81.0	79.0	82.0	79.0					9.0	9.1	9.0	9.6	
35	83.0	78.5	82.0	78.0					8.9	9.2	8.7	9.5	

Table 18. (Cont'd)

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-0	B-0	U-C	B-C	U-0	B-0	U-C	B-C	U-0	B-0	
36	84.5	81.5	83.5	80.5					9.4	9.3	8.7	10.1	
37	82.0	80.5	82.0	80.5					9.2	8.8	9.3	9.4	
38	83.0	80.5	82.0	81.5					8.7	9.2	8.5	9.4	Desiccant gained 1.25 lbs. (18.5 days). Samples taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:25.

[2]U-C : upper center part, B-C : bottom center part, U-0 : upper outer part, B-0 : bottom outer part.

Table 19. Grain temperature and moisture changes during storage period for 24 percent M. C. corn stored in CAN No. 2 with silica gel in 4 cylinders at 80-90 F and 30-40 percent R. H.[1]

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-0	B-0[2]	U-C	B-C	U-0	B-0	U-C	B-C	U-0	B-0	
0	62.0	62.0	62.0	62.0	22.9	22.9	22.9	22.9					Initial adsorbent wt.- 20 lbs. Desiccant dried at 130 C.
2	75.0	77.0	79.0	78.0	20.3	21.2	20.7	20.5					Dry desiccant (2 days), it gained 1.98 lbs.
3	80.0	77.0	80.0	77.0	20.3	22.4	18.9	20.6					Samples taken for
4	79.0	75.0	79.0	73.5	19.4	20.8	19.5	20.6					analyses.
5	79.5	76.0	79.0	77.0	20.3	22.3	21.5	22.4					
6	80.0	73.0	78.0	73.5	18.9	20.5	21.7	22.2	17.2	18.3	17.7	19.0	Dry desiccant (3.5 days)
7	78.0	73.0	77.0	72.0	18.3	22.0	20.4	23.4	16.6	18.0	17.1	19.0	Samples taken for
8	79.0	72.5	77.0	73.5	18.8	19.7	19.7	22.2	16.2	17.9	17.4	19.5	analyses.
9	80.0	73.5	79.0	74.0	20.6	21.5	20.5	21.5	16.4	17.6	16.8	18.5	Samples taken for analyses.
10	81.0	75.0	80.0	76.0			19.1	20.2	16.1	18.5	17.2	20.5	Dry desiccant (4 days),
11	80.0	76.0	80.0	76.0			20.0	22.3	17.6	19.0	16.8	19.9	it gained 1.828 lbs.
12	79.0	73.0	79.0	73.0			20.5	20.5	16.6	17.9	16.6	18.4	Samples taken for analyses.
13	80.0	72.5	77.5	72.0			18.3	20.3	16.8	18.5	17.1	18.3	Dry desiccant (3.5 days)
14	78.0	72.0	79.5	72.5			18.7	20.8	16.1	17.1	16.0	17.4	it gained 1.1 lbs.
15	78.0	73.0	78.0	71.5			17.9	20.5	16.1	17.6	16.3	17.1	Samples taken for analyses.
16	81.5	73.5	78.5	73.5			17.8	20.2	15.7	17.7	15.8	17.0	Dry desiccant (2.5 days)
17	78.5	73.0	78.0	73.5			16.7	18.6	15.7	15.8	17.7	15.7	it gained 0.66 lbs.
18	76.0	70.0	76.0	69.0			17.4	19.4	15.2	17.0	15.3	16.4	Samples taken for
19	74.0	68.5	73.0	70.0			17.0	18.5	15.9	16.0	15.4	16.9	analyses.
20	74.0	69.0	73.0	69.0			16.6	18.5	15.7	15.7	15.1	15.0	

Table 19. (Cont'd)

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	
21	76.0	71.5	75.5	72.0			16.7	18.0	15.4	16.8	14.6	15.7	Dry desiccant (5 days), it gained 3.27 lbs.
22	74.5	70.0	73.5	70.5			16.2	18.1	15.3	16.6	15.2	15.5	
23	77.0	72.0	76.5	71.0			14.2	15.5	15.1	15.9	14.6	14.5	
24	78.0	72.5	77.5	72.5					14.8	15.8	13.6	13.7	Samples taken for analyses.
25	80.5	73.5	78.5	75.5					14.7	14.8	14.8	13.8	
26	81.5	76.0	81.0	77.0					16.0	13.9	14.5	14.0	
27	81.0	75.5	79.5	76.0					14.1	15.3	13.4	12.9	Dry desiccant (5.5 days), it gained 0.756 lbs, samples taken for analyses.
28	82.0	77.5	82.5	77.5					13.8	14.1	12.9	12.5	
29	82.0	75.5	81.0	75.0					13.4	15.1	13.3	12.1	
30	81.0	77.0	82.0	78.0					15.1	17.3	15.2	14.2	Samples taken for analyses.
31	83.0	75.0	81.0	76.0					13.9	15.2	12.3	12.4	
32	80.0	76.0	80.0	75.5					12.9	14.5	13.2	11.9	
33	82.0	76.0	80.5	76.5					12.4	15.6	14.2	12.2	Samples taken for analyses.
34	81.0	76.0	81.0	76.0					13.2	14.6	13.4	13.0	
35	81.0	74.0	81.0	73.5					13.3	13.5	13.7	11.7	Dry desiccant (7.5 days), it gained 1.84 lbs.
36	79.0	75.5	79.5	74.5					13.6	13.5	13.0	11.4	Samples taken for analyses.
37	80.5	75.5	80.0	76.0					13.9	13.6	14.0	11.3	

Table 19. (Cont'd)

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	
38	80.5	77.0	81.0	76.5					12.6	12.1	12.6	10.7	
40	82.0	77.0	82.0	77.0					11.1	11.2	11.1	8.6	Desiccant gained 1.23 lbs. (4.5 days). Samples taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:20.

[2]U-C : upper center part, B-C : bottom center part, U-O : upper outer part, B-O : bottom outer part.

Table 20. Grain temperature and moisture changes during storage period for 24 percent M. C. corn stored in CAN No. 3 with silica gel in 4 cylinders at 80-90 F and 30-40 percent R. H.[1]

Days in storage	Temperature (F) at				Moisture content (%) by Stelinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-O	B-O[2]	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	
0	62.0	62.0	62.0	62.0	25.3	25.3	25.3	25.3					Initial adsorbent wt.- 20 lbs. Desiccant dried at 130 C.
2	78.0	73.0	75.5	75.5	23.5	22.2	23.2	22.4					
3	80.5	78.5	82.0	80.0	21.0	22.1	22.1	23.7					Dry desiccant (3 days).
4	83.0	81.0	81.5	83.5	20.8	22.0	22.0	23.3					Samples taken for analyses.
5	83.0	84.0	82.0	84.0	20.6	21.5	22.3	21.1					Dry desiccant (2 days), it gained 2.08 lbs., samples taken for
6	85.0	86.5	85.0	86.0	20.3	21.1	21.4	20.8	18.2	18.7	19.0	21.2	analyses.
7	85.0	86.0	84.0	86.5	20.1	20.6	20.2	22.7	16.4	19.3	18.7	21.1	Dry desiccant (2 days), it gained 2.2 lbs., samples taken for
8	87.0	89.0	86.5	88.0	19.1	19.4	20.6	23.3	17.8	18.4	19.2	20.9	analyses.
9	87.5	90.0	86.5	89.5	22.3	22.6	18.9	23.6	16.8	18.1	18.0	20.9	
10	87.5	90.0	86.5	90.5	21.1	21.9	20.9	22.8	17.8	17.8	19.0	21.7	
11	87.0	88.5	86.0	89.5			19.4	21.9	18.4	18.7	18.8	21.0	
12	84.5	89.5	83.0	88.5			20.5	20.5	18.3	18.8	17.9	20.7	Dry desiccant (5 days), it gained 2.23 lbs., samples taken for analyses.
13	85.0	89.0	83.5	89.0			22.1	21.8	17.6	18.6	18.2	19.5	Mold developed at B-C,
14	83.5	86.5	82.0	87.5			20.1	20.5	17.3	18.6	19.6	17.6	B-O.

Table 20. (Cont'd)

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture content (%) by oven at				Remarks
	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	
15	85.0	87.0	83.0	87.0			20.4	21.2	17.6	18.4	17.8	20.0	Samples taken for analyses. Mold developed at B-C, B-O.
16	83.5	87.5	83.0	85.0			20.7	20.7	17.4	19.2	17.1	19.9	
17	84.0	88.0	82.0	86.5			19.3	20.9	17.0	18.8	17.3	19.7	Dry desiccant (5 days), it gained 1.75 lbs.
18	81.5	85.0	79.5	85.5			19.2	19.8	16.3	18.7	16.2	18.5	
19	76.5	83.5	75.5	82.5			19.8	20.5	16.2	18.8	14.4	18.4	
20	78.0	81.0	77.0	81.0			19.6	21.4	16.5	18.8	16.3	18.4	
21	78.5	81.0	77.0	81.0			17.6	18.4	16.8	19.0	16.6	19.0	Dry desiccant (4.5 day), it gained 1.75 lbs.
22	76.0	80.0	75.5	80.0			18.5	20.2	16.6	18.4	16.5	18.5	
23	77.0	79.5	77.0	79.0			17.3	19.0	16.2	18.4	16.7	18.2	
24	79.5	80.5	79.0	80.5					16.3	18.6	16.5	18.3	Samples taken for analyses.
25	80.0	82.0	80.0	82.5					15.7	18.6	18.1	18.9	
26	82.5	83.0	81.5	83.5					16.1	18.5	16.4	18.2	
27	81.5	83.5	81.0	84.0					15.8	18.1	15.8	18.5	Samples taken for analyses.
28	82.5	83.5	81.0	84.5					15.5	18.7	15.5	18.1	
29	82.5	84.5	82.0	85.0					14.7	18.0	15.9	18.1	Dry desiccant (7.5 days), it gained 2.173 lbs.
30	82.5	84.5	82.0	85.5					16.3	18.5	16.9	19.1	Samples taken for analyses.
31	81.0	83.5	79.5	84.5					16.0	18.7	15.5	17.9	
32	82.0	83.0	80.5	84.5					15.0	17.9	15.8	17.6	
33	81.5	83.5	81.0	84.0					14.6	18.6	15.3	18.2	Samples taken for analyses.
34	81.0	82.5	80.0	84.5					14.3	16.2	14.5	18.7	

Table 20. (Cont'd)

Days in storage	Temperature (F) at				Moisture content (%) by Steinlite Machine at				Moisture contetn (%) by oven at				Remarks
	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	U-C	B-C	U-O	B-O	
35	82.5	84.0	81.5	84.0					14.5	17.4	14.1	18.2	
36	84.0	84.0	83.0	85.5					14.4	17.5	16.2	18.2	Samples taken for analyses.
37	82.5	84.0	82.0	85.0					14.8	17.9	14.7	18.5	
38	83.0	87.0	84.0	86.0					14.5	18.1	14.5	17.6	Desiccant gained 3.86 lbs. Samples taken. Mold developed in the bottom layers and around the can.

[1] Initial silica gel to corn ratio of 1:20.

[2] U-C : upper center part, B-C : bottom center part, U-O : upper outer part, B-O : bottom outer part.

Table 21. Percentages of kernels invaded by indicated storage furgi at the end of the experiment for the 24 percentage moisture content samples.[1]

Sample	Days	Fus.	Ceph	Pen.	Negro.	Alt.	Clado.	Grodelty.	A. Gl.
CAN No. 1									
U. C.	38	72	16	14	28	10	18	4	
U. O.	38	78	10	16	44	6	14	8	
B. C.	38	72	10	6	26	4	10	2	
B. O.	38	86	10	14	24	10	6	6	
CAN No. 2									
U. C.	40	74	10	28	20	6	6	2	2
U. O.	40	74	10	26	30	4	8	4	4
B. C.	40	64	12	18	22	2	8		
B. O.	40	70	14	16	34	2	16	4	2
CAN No. 3									
U. C.	38	74	4	42	30	16	14		2
U. O.	38	74	8	50	24	4	22		
B. C.	38	72	6	40	12	6	10		4
B. O.	38	80	6	52	16	8	20		
24 Initial	0	81	9	15	27	4	1		

[1]For mold tests: 50 surface disinfected kernels per sample; plated on malt agar with 4% NaCl and 20 p.p.m. ergotol.

APPLICATION OF SILICA GEL FOR ON-FARM GRAIN DRYING AND STORAGE IN DEVELOPING COUNTRIES

by

JUDY YEN-CHEN HSIAO

B. S., National Taiwan University, 1972

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1974

The broad objective of this study was to develop a simple and inexpensive grain drying and storage method which can be effectively used at farm and local levels in humid areas of developing countries. The approach taken was a use of desiccant, silica gel, to dry the grain, with and without aeration. Roof ventilators powered by wind were used for the aeration study.

Fleske (1973) had performed experiments by using ten-pound samples of corn to find the proper ratio of silica gel to corn and the frequency of desiccant regeneration needed for static drying and for maintaining the quality of corn with initial moisture content levels of 12, 15, and 20 percent. In Phase I tests, Fleske's last series of tests for 15 and 20 percent initial moisture content were repeated. The same procedure was used to find the proper ratio of silica gel to corn and the frequency of desiccant regeneration for the 24 percent initial moisture content of corn.

Results revealed no significant difference between Fleske's work and this investigation. The experiments were successfully replicated. So the ratios of grain to adsorbent needed to preserve the grain quality for 15, 20, and 24 percent initial moisture content corn were 50:1, 35:1, and 20:1, respectively. The necessary frequency of silica gel regeneration for 15 and 20 percent initial moisture content corn was once every day for a week, and thereafter every other day for another week; for 24 percent initial moisture content, the regeneration of silica gel was needed twice a day for the first three days, then once every day for seven days and thereafter every other day for another week.

In Phase II experiment, a scale-up study was conducted by using 400 pounds of corn initially at 24 percent moisture content with the silica gel to corn ratio obtained from Phase I, with and without air flow in the corn mass under

In CAN No. 1 the air flow rate created by a rotation of roof spinner was 80 fpm and the air volume rate was about 0.96 cfm/bu; in CAN No. 2 it was 50 fpm and the air volume rate was about 0.766 cfm/bu. A fan for simulating natural wind with a velocity of 940 fpm or 10.6 miles per hour forced the ventilators to rotate. CAN No. 3 was used for static storage (no air flow).

In CAN No. 1 the silica gel was put on the top perforated pan with a grain to silica gel ratio of 25:1, and the air was entering through a 4" hole in the lid. In CAN No. 2 and CAN No. 3 the silica gel was put into 4 cylinders with a grain to silica gel ratio of 20:1.

Results showed that for static drying (CAN No. 3) the rate was too slow to prevent the mold development. As for drying with natural air flow inside the corn mass, the results showed that the drying and conditioning method, air pre-dried by silica gel, using a roof spinner (CAN No. 1) was the best. To dry the 24 percent initial moisture content of the corn to the average safe moisture content of 13 percent, it took only 12 days for this method but 37 days in CAN No. 2, in which silica gel in four cylinders was uniformily distributed in a bin and aerated by a roof spinner. *No mold was visible.*

This investigation showed a definite potential for drying and storing grain in developing countries, with pre-dried air, using silica gel, and use of a roof spinner.