This morning we are concerned with the topic "Seed Drying and Conditioning." Dr. Matthes and I will be discussing this topic in its relationship to those seed which will be used for planting purposes only. I emphasize this because we often overlook our main objectives when we try to dry large volumes of seeds through inadequately designed drying facilities. We should design and operate our systems in a manner that seed quality can be preserved.

As we return to the basic concepts and practices used in seed drying and conditioning, we find that certain principles remain relatively constant, but the needs of our farmers and processors have to change as competition and increased production and production handling demand it. So let us first turn our attention to the basic principles of seed drying as they are related in all drying systems—no matter how simple or highly sophisticated the system may be.

I will cover the following points:

I. Why is it necessary to dry and pre-condition seed for storage?

II. What does "Seed" drying involve?
   a. The Seed (chemically and physically)
   b. The Air (temperature and relative humidity)

Dr. Matthes will discuss (1) fundamentals of drying, (2) designing for drying and (3) operational management of drying.

When we investigate the reasons for harvesting crops at high moisture levels, we find that the list is extremely long. Keeping in mind our objective, to maintain high quality seed, we need to have a better understanding of the physiological events occurring within the seed at maturity. When a seed matures on a plant, the moisture content is in the range of 25-35%, depending on the crop. At this point the seed is physiologically mature. It is at this time many crops are harvested and then dried so that the quality can be preserved. However, some crops cannot be harvested because of the mechanical problems involved. When the crop is permitted to remain in the field for an excessive

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period, several events may occur to drastically lower the quality and may result in partial or total seed crop failure. In Table I, we have listed some of the effects of extended field exposures.

**TABLE I. Effects of Extended Pre-harvest Field Exposure After Physiological Maturity.**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Yield losses of 10-20% or more may occur</td>
</tr>
<tr>
<td>B.</td>
<td>Loss in vigor and viability</td>
</tr>
<tr>
<td></td>
<td>1. High rates of respiration</td>
</tr>
<tr>
<td></td>
<td>2. Decrease in maximum dry weight</td>
</tr>
<tr>
<td></td>
<td>a. Test weight drop of 1 pound per bushel can occur every 4 days after wheat reaches 24% moisture and declines in field</td>
</tr>
<tr>
<td>C.</td>
<td>Increase in diseases</td>
</tr>
<tr>
<td>D.</td>
<td>Increase in storage insect infestations</td>
</tr>
<tr>
<td>E.</td>
<td>Total Loss</td>
</tr>
<tr>
<td></td>
<td>1. High winds and beating rains</td>
</tr>
<tr>
<td></td>
<td>2. Excessive lodging</td>
</tr>
<tr>
<td></td>
<td>3. Shattering</td>
</tr>
</tbody>
</table>

Immediately after harvest, the farmer and seed processor are confronted with the problems in handling a product which is too high in moisture for safe storage. As indicated in Table II, if the moisture content is too high, seed deterioration can be quite rapid.

**TABLE II. Effect of Moisture Content on Seeds During Storage.**

<table>
<thead>
<tr>
<th>Moisture Content</th>
<th>Deterioration Effects that Can Occur During Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-60%</td>
<td>Germination begins</td>
</tr>
<tr>
<td>↑ 16%</td>
<td>Heating begins, due to increased rate of respiration and micro-organism activity</td>
</tr>
<tr>
<td>↑ 12-14%</td>
<td>Mold growth may begin</td>
</tr>
<tr>
<td>↑ 8%</td>
<td>Insect activity begins</td>
</tr>
</tbody>
</table>

As mentioned in an earlier presentation, a given seed type may vary greatly from another type both chemically and physically. All seeds are living and as hygroscopic organic materials, they are characterized by a very complex and heterogeneous structure with water as a fundamental and ubiqui-
tous part of this structure. Internally the water content may vary greatly from one region to another region where the chemical constituents are different. Table III illustrates how seed from different crops may vary in their chemical composition. In addition, when we consider the many kinds of organ structure occurring in seeds, we find that moisture transfer in the drying process may vary between seed kinds. The physical properties of size, shape, and accessory parts also influence the rate that drying may occur.

"Drying," as we have referred to it, actually involves more than the mere removal of external and internal moisture or volatile constituents. The process used must conform to the physical and often the chemical characteristics of the given type seed. As an example, at 63 percent relative humidity the water absorption varies directly with the carbohydrate content. At 90 percent relative humidity, the relationship is reversed.

**TABLE III. Chemical Composition of the Five Crop Seeds.**

<table>
<thead>
<tr>
<th>Name of Crop</th>
<th>Carbohydrates</th>
<th>Crude Protein</th>
<th>Crude Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fat %</td>
<td>Protein %</td>
<td>Fiber %</td>
</tr>
<tr>
<td>Austrian W. P.</td>
<td>0.98</td>
<td>22.31</td>
<td>6.34</td>
</tr>
<tr>
<td>Corn</td>
<td>4.29</td>
<td>8.00</td>
<td>2.35</td>
</tr>
<tr>
<td>Cotton</td>
<td>21.17</td>
<td>26.25</td>
<td>15.21</td>
</tr>
<tr>
<td>Rape</td>
<td>49.47</td>
<td>16.81</td>
<td>7.71</td>
</tr>
<tr>
<td>Soybean</td>
<td>19.70</td>
<td>37.94</td>
<td>5.74</td>
</tr>
</tbody>
</table>

Since we have briefly covered the properties of the seed, we will turn our attention to the properties of the drying agent, which is air. Air has the capacity of holding water in a gaseous form and this capacity is proportional to the temperature. Thus, as we raise the temperature of air we raise its capacity for holding moisture. The relative humidity is defined as the ratio of the actual quantity of moisture in the air compared to what it can hold at saturation at the same temperature. Thus, as we increase the temperature of the air we decrease the relative humidity since we increase the capacity to hold moisture at saturation without changing the actual moisture content. Since seed are hygroscopic, the moisture content of the seed is influenced by the relative humidity and temperature of the air. The occurrence of this relationship is based on the phenomena involving vapor pressure. Whenever a liquid changes to a gaseous form the volume of that liquid will expand. Inside the seed, the tendency to further expand increases in intensity as the temperature increases and sets up a definite, uniform pressure upon the cellular walls of the seed. Whenever the vapor pressure within the seed is greater than that of the surrounding atmosphere, molecular action will be such that vapor will move from the seed. If the vapor pressure are reversed, the movement of vapor will also reverse and moisture will move into the seed. When the vapor pressures
are equal there is no movement of vapor in either direction and at this point the 
moisture content of the seed is in a state of equilibrium with the surrounding 
atmosphere. When a seed is exposed to a constant temperature but different 
relative humidities the equilibrium moisture content of the seed will adjust 
itself to the relative humidity because of the differences in vapor pressures 
existing between the seed and the surrounding atmosphere as indicated in Figure 
1.

Fundamentals of Drying

When drying takes place from seeds there is a transformation from 
liquid moisture absorbed hygroscopically in the seed to water vapor in the 
surrounding air, thus, evaporation of moisture takes place during drying. 
From our study of Physics we remember that in order to evaporate moisture 
it takes heat. Specifically it takes 970 BTU's of heat energy to evaporate one 
pound of water. The same phenomena take place in evaporating moisture in 
seed; however, it takes some additional energy to remove a pound of moisture 
from seed because it is more tightly bound due to absorption in the seed. It 
takes approximately 1100 BTU's of heat energy to remove one pound of mois­
ture from seed.

The drying air basically has two functions: (1) To provide heat in order 
to evaporate moisture, heat transfer from the air to the water vapor is 
evidenced by a drop in the temperature from the entering air to that of the 
exhausting air from a moist seedbed; (2) To provide a medium in which the 
water vapor surrounding the seed can be removed and allow more moisture to be eva­
porated from the seed. This is evident from the fact that the exhaust air has a 
higher relative humidity than the incoming air. This increase in the moisture 
in the air comes from the seeds.

The rate at which a seed dries is a function of how fast the moisture 
evaporates from the surface of the seed which depends upon the relative humidity 
and the temperature of the drying air, and the rate at which moisture moves 
from the inside of the seed to the surface of the seed as related to the 
permeability of the seed to the moisture movement. For most seed drying an 
air flow greater than 10 CFM/Bu will not result in increased drying because 
the limiting factor is not the air flow but the rate at which the moisture moves 
from inside of the seed to the surface of the seed. In some cases the permea­
ibility of the seed to moisture movement is low. Rice seed is very impermeable 
to moisture movement. This is evident from the fact that in most cases rice 
must be dried slowly and in some cases, particularly when a tower drier is 
used, the rice is run for one pass and is allowed to go through an equilibrium 
period called a "sweating" period for 12 hours to allow the moisture from the 
interior to equilibrate with that of the surface. In these cases if the drying is 
speeded up by increasing the temperature sufficiently high to increase moisture 
movement from the surface, a stress is set up due to a difference of moisture 
within the seed and mechanical checking or cracking takes place, which is detri­
mental to the viability of the seed.
Figure 1. Moisture equilibrium percentages of 5 seed kinds stored at 20°C and 4 different levels of relative humidity. AWP refers to Austrian winter peas.
The psychrometric chart is a very helpful device in determining the various effects on air as it goes through a drying cycle. We notice (Figure 1) that point 1 is the ambient conditions of the air which we are assuming to be 85° dry bulb temperature, and 80% relative humidity. The air is passed through the heater with a constant absolute humidity of 149 grains of moisture per pound of dry air. The heating increases the air temperature to 110°F, the relative humidity has decreased to approximately 38% at point 2. The air enters the seed and drying takes place adiabatically, which means there is a heat energy balance as the drying air goes through the seed. In other words, the heat is removed from the air in the form of lowering the temperature of the air and this heat goes into evaporating the moisture from the seed and the air exhausts with the same heat content at a lower temperature but at a higher moisture content with increased heat tied up as heat of the vaporization. Thus, we have adiabatic drying which moves along a constant wet bulb temperature line and constant enthalpy as shown on the psychrometric chart. Assuming at point 3 that the exhaust air leaves the seed at 90°F, the relative humidity has increased to approximately 86%. Thus, we can see the moisture content of the air is raised from 149 grains of moisture per pound of dry air to approximately 190 grains of moisture per pound of dry and this moisture comes from the seed.

Design of a Drying Facility

The objectives of designing a drying facility can be stated as follows:

1. Having adequate drying capacity equal to the harvesting rate or the rate at which seeds will be received by the plant.

2. Having a fan of sufficient size to deliver a minimum drying air flow of ten CFM per bushel.

3. Having efficient heating capacity to raise the air temperature to 110°F.

4. Having adequate control to maintain the air at 110°F or less.

Normally most seed drying will take place in a bin type drier with an axial fan having backward curve blades and a heater using natural, butane, or propane gas. For unusually high capacity seed plants, it may be advisable to use a tower type drier. However, in most cases, the minimum capacity tower drier is so large that it is not feasible to use for seed drying.

Number and size of bin dryers needed in a drying facility are dependent upon the seasonal capacity of the plant and the number of varieties or different seeds processed in a season. Thus, the more varieties you process, the smaller and the more bins you need to prevent mechanical mixing. It should be pointed out that the bins can double for storage after the drying has been completed. In preliminary design, it should be decided how many bins of what size are needed in order to store the variety of seeds which you obtain in the plant for a season. Once this is decided, the problem is to match the drying with the storage needs. Thus, you would start off with a particular size bin with a certain diameter, then design for your drying. The minimum requirement for good
Figure 2. An example of the drying cycle of air in a deep seed bed using a psychrometric chart.
drying is an air flow of 10 CFM per bushel of seed in your drier and a maximum temperature of 110 degrees Fahrenheit.

The first step is to determine what size fan is required for drying. In order to purchase a fan, we must specify total air flow in CFM the fan can deliver against a given static pressure caused by the resistance of the seed to the air flow. Most seed drying fans are designed to act more efficiently against static pressures less than 3 1/2 inches of water. When static pressure exceeds this amount, the volume which the fans can deliver will drop sharply. Therefore, it is a good idea not to exceed 3 1/2 inches static pressure in the plenum chamber. The static pressure is caused by the resistance of the seeds to the air flow. Thus, as we increase the air flow, we increase the static pressure. As we increase the depth of seed, we must increase the air flow to maintain 10 CFM per bushel air flow and this results in an increase of the static pressure. Thus, there is a maximum depth at which we can dry seed obtaining the minimum air flow of 10 CFM/bushel with less than 3 1/2 inches static pressure.

It is recommended for seed drying design that the following depths be used in determining the total capacity of the drying bins:

- Ear corn, shell corn: 9 ft.
- Soybeans, shell corn: 4 ft.
- Rice, wheat, sorghum: 3 ft.
- Clover, alfalfa, lespedeza: 1 1/2 ft.

Please keep in mind that these depths are used in designing a seed drying facility. In some cases, we can exceed these depths for drying. However, as a safety factor, if we made a conservative estimate on how much space we have, we will not underdesign our drying facilities. It is only necessary to determine our total volume in a bin for the seed we are using and multiply this volume by 10 and this gives the total air flow of the fan required for that bin and then select a fan which will deliver this air flow against the 3 1/2 inch static pressure.

The next component of our seed dryer equipment is the heater. A rather simple equation for determining your heater capacity is to take the total air flow which you have just determined and multiply it by the maximum temperature rise to heat the ambient air to 110°F. In other words, suppose for some drying conditions the air may go down to 60°F; then it is only necessary to multiply your total air flow by 50 and this will give you the approximate heater capacity required in BTU's per hour. Heater capacities are normally changed easily by changing a nozzle with a different size orifice. It is very difficult to obtain a closer control than 100,000 BTU's/hour where one size orifice might give you 250,000 BTU's/hour and the next size orifice might give you 350,000 BTU's/hour. Thus, accuracy in this estimation is not extremely critical.

In determining your total drying capacity, it is necessary to estimate how long it would take a batch of seed to dry in the bin. An equation for estimating the time in hours for drying seed in a deep bed is as follows:
Dry Time (Hr) = \( \frac{1100 \times \text{Moisture to be removed (lbs/bu)}}{\text{CFM/bu} \times \text{Temp. Drop Through Seed (°F)}} \)

It is necessary to estimate the temperature drop for the drying air; that is, the temperature of exhaust air subtracted from the temperature of the incoming air. From experimental data this quantity ranges from 15°F to 20°F. Thus, to be on the conservative side and make sure we are taking the maximum length of time required for drying, let's assume that it is 15°F. Upon solving this phase of our design problem, we determine how long it takes to dry seed at a particular depth; thus, the rate of drying for one batch of seed. Thus, by knowing the maximum rate of receiving seed, we can determine how many bins it will take to accomplish our drying needs.

The next factor we will consider in drying design is the design of transition of air from the fan to the bin. The theory exists that if a fan has six square feet of outlet open area, the transitions entering into the bin should also have 6 square feet open area or more. This is known as the Equal Area Theory. This theory based on the assumption that pressure losses are negligible in a transition having the same openings as the connection to the fan and the connection to the bin. However, in some cases, the manufacturer makes the transition to the fan larger than necessary in order to standardize his equipment. In other words, for a large fan he makes a transition of seven square feet, and for the small fan he really only needs four, but it is easier to make all the transitions the same size; thus, he uses one of seven square feet. Thus, the seedsman, not knowing this, may go to the expense of making a large transition when it is not necessary for this size fan. A good rule is that if the velocity of the air through a transition does not exceed 2500 ft. per minute, the pressure loss would be negligible and the transition would be sufficiently large. In order to determine your transition size, it is necessary to determine the maximum CFM capacity of your fan and divide this by 2500, thus arriving at a square foot area necessary for the transition.

Operational Management of Drying

Drying takes place in a bin from the lower level of the seed to the upper level of the seed. This is due to the dry air entering from the bottom moving the moisture up and out of the top of the seed. The moisture characteristics of the seed in a seed bed change at the drying front. This drying front is described as the location in the seed where conditions below the drying front are high temperature and dry seed and above the drying front are lower temperature and moist seed. The lower temperature is called the pseudo-saturation temperature. The seeds above the drying front reach the pseudo-saturation temperature shortly after drying commences. Figure 3 illustrates the location of the drying front in a deep bed of seed.

Figure 4 illustrates the pseudo-saturation temperature at which all levels above the lower level of the seed reach within the first hour of drying. As the drying front reaches a particular level, it is evidenced by the tempera-
Figure 3. Description of a drying front in a deep-bed seed dryer.
Figure 4. Temperature versus time for various depths of seed drying in a deep bed.
ture rise as shown in Figure 4. Note that at 1 hour the temperature starts to rise at the 5.6 inch depth. At 2 hours, the temperature starts to rise at the 8.4 inch depth. At 3 hours, the temperature starts to rise at 11.2 inch depth and so on. Thus, when the temperature commences rising in the upper level of the seed, we know that the drying in the upper level of the seed is commencing and the drying of the seed bed is reaching completion. When the upper level of the seed approaches the drying air temperature, drying of the seed has been completed. One method of determining progress of drying is to install a thermometer or temperature recorder with sensing elements in the upper level of the seed. Figure 5 gives an illustration of how this temperature would look on a temperature recorder. At the bottom part of the figure we see the temperature being recorded at approximately 78°F. As the top layer commences drying, the temperature starts to increase and assuming there is a drying air temperature of 100°F, notice in the upper part of the chart paper that the top layer has completed drying as the temperature reaches approximately 98°F and levels off. Thus, we can see that actually the temperature is an indication of the moisture content at different depths in the seed.

Before drying commences, it is a good idea to measure the initial moisture content of the seed. When the bin has been fitted for drying, be sure to level the seed at the top. This is necessary to provide equal air flow. If the seed is higher in the middle, there would be less air going through the center of the seed than around the edges. Immediately upon placing seed in the bin, drying should commence even though it is not filled to full drying depth. Drying should not be delayed because this will result in heating of the seed and it will be detrimental to the viability of the seed. If there are no facilities available to commence drying immediately, the seed should be placed in a bin with aeration until drying can commence. Even small amounts of air will prevent heat build-up and damage to the seed. During drying the seed should be sampled randomly at different depths and different locations in the bin at least twice a day to keep up with the process of drying. After the seed has completed drying, they should be sampled thoroughly to determine there are no "wet spots" due to poor air distribution.

If seed germination is dropping more than 1 or 2 percent during drying, check for:

1. Excessive holding time before drying commences.
2. Insufficient air flow, less than 10 CFM/bushel.
3. Excessive static pressure, greater than 3½ inches of water.
4. High relative humidity of drying air, in excess of 60%.
5. Drying air temperature greater than 110°F.
6. Excessive seed depth.
7. Uneven air flow through the seeds.

The best teacher for doing a good job of drying is the records which you maintain to increase your experience as a seed dryer. By keeping good records of temperature, air flow, time required for drying, moisture content, different types of seed, and depth of seed drying, you can gain experience. Each time you dry, you can do it with more assurance that you are doing a good job. No
Figure 5. A temperature recording of a layer of seed experiencing drying.
Remember that there are two ways to get experience. One man worked on the job 10 years, kept records, was mindful of what was going on, and he gained experience. We can say this man has 10 years experience, and he is better qualified to do his job because of it. At the same time, another man worked on a job. He was unmindful of what was going on, he came and did his work each day rather disinterested and did not maintain records. We can say this man got 1 year’s experience 10 times and he is probably worse off than a new man who has had no experience. Thus, hopefully, you will be like the man with 10 years experience. Each year your plant should do a better job of drying, you should come out at a higher quality, and you should do it more economically. Your system can be better with the experience that you have had drying seed.
Processing-Handling Workshop: Duane Tyler discusses conveying.

Howard Potts discourses on finer points of processing.