# Practical Manual

## Drying and Storage Engineering

**APE – 304**

**Credits 4(3+1)**

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# Practical Manual
**on**
# Drying and Storage Engineering


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**Practical 1**

## Objectives

To estimate the moisture content of food material

## Theory

According to the convention moisture contents of grains are usually measured on a wet basis, i.e. the mass of moisture per unit mass of wet grain and written as X % (wb). The alternative measure refers to the measurement on a dry basis as (X%(db)) which is the mass of moisture per unit mass of completely dry grain. All moisture contents given in the text are on a wet weight basis, unless otherwise stated.

The moisture content on wet basis (wb) in food is the amount of water present in the food to the total amount of material. It can be represented by the following formula -

$$Moisture\ content\ (wb),\% = \frac{Amount\ of\ water\ present\ in\ food, g}{Total\ amount\ of\ food, g} \times 100$$

The moisture content on dry basis (db) in food is the amount of water present in the food to the amount of dry material. It can be represented by the following formula -

$$Moisture\ content\ (db),\% = \frac{Amount\ of\ water\ present\ in\ food, g}{Amount\ of\ dry\ material\ in\ food, g} \times 100$$

## Conversion of dry basis to wet basis

Let Total mass of Sample= $M$, Mass of water present=$M_w$, and Mass of solid content=$M_s$

As we know,

$$Moisture\ content\ (wb),\% = \frac{Amount\ of\ water\ present\ in\ food, g}{Total\ amount\ of\ food, g} \times 100$$

$$Moisture\ content\ (wb),\% = \frac{Mw}{M} \times 100$$

We also know that,

$$M = Mw + Ms$$

Therefore, the equation can be written as -

$$Moisture\ content\ (wb),\% = \frac{Mw}{Mw + Ms} \times 100$$

By inverting, the equation can be written as -

$$\frac{1}{Moisture\ content\ (wb),\%} = \frac{Mw + Ms}{Mw \times 100}$$

$$\frac{100}{Moisture\ content\ (wb),\%} = \frac{Mw + Ms}{Mw}$$

$$\frac{100}{Moisture\ content\ (wb),\%} = \frac{Mw}{Mw} + \frac{Ms}{Mw}$$

$$\frac{100}{Moisture\ content\ (wb),\%} = 1 + \frac{Ms}{Mw}$$

$$\frac{100}{Moisture\ content\ (wb),\%} - 1 = \frac{Ms}{Mw}$$

$$\frac{100 - \ Moisture\ content\ (wb),\%}{Moisture\ content\ (wb),\%} = \frac{Ms}{Mw}$$

By inverting again,

$$\frac{Moisture\ content\ (wb),\%}{100-\ Moisture\ content\ (wb),\%}=\frac{Mw}{Ms}$$

$$\frac{Mw}{Ms}=\frac{Moisture\ content\ (wb),\%}{100-\ Moisture\ content\ (wb),\%}$$

Multiplying with 100 on both sides,

$$\frac{Mw}{Ms}\times 100=\frac{Moisture\ content\ (wb),\%}{100-\ Moisture\ content\ (wb),\%}\times 100$$

$$Moisture\ content\ (db),\%=\frac{Moisture\ content\ (wb),\%}{100-\ Moisture\ content\ (wb),\%}\times 100$$

## Conversion table

| Wet Basis % | Dry Basis % | Wet Basis % | Dry Basis % | Wet Basis % | Dry Basis % | Wet Basis % | Dry Basis % | Wet Basis % | Dry Basis % |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 21 | 26.6 | 41 | 69.5 | 61 | 156.4 | 81 | 426.3 |
| 2 | 2.0 | 22 | 28.2 | 42 | 72.4 | 62 | 163.2 | 82 | 455.6 |
| 3 | 3.1 | 23 | 29.9 | 43 | 75.4 | 63 | 170.3 | 83 | 488.2 |
| 4 | 4.2 | 24 | 31.6 | 44 | 78.6 | 64 | 177.8 | 84 | 525.0 |
| 5 | 5.3 | 25 | 33.3 | 45 | 81.8 | 65 | 185.7 | 85 | 566.7 |
| 6 | 6.4 | 26 | 35.1 | 46 | 85.2 | 66 | 194.1 | 86 | 614.3 |
| 7 | 7.5 | 27 | 37.0 | 47 | 88.7 | 67 | 203.0 | 87 | 669.2 |
| 8 | 8.7 | 28 | 38.9 | 48 | 92.3 | 68 | 212.5 | 88 | 733.3 |
| 9 | 9.9 | 29 | 40.8 | 49 | 96.1 | 69 | 222.6 | 89 | 809.1 |
| 10 | 11.1 | 30 | 42.9 | 50 | 100.0 | 70 | 233.3 | 90 | 900.0 |
| 11 | 12.4 | 31 | 44.9 | 51 | 104.1 | 71 | 244.8 | 91 | 1011.1 |
| 12 | 13.6 | 32 | 47.1 | 52 | 108.3 | 72 | 257.1 | 92 | 1150.0 |
| 13 | 14.9 | 33 | 49.3 | 53 | 112.8 | 73 | 270.4 | 93 | 1328.6 |
| 14 | 16.3 | 34 | 51.5 | 54 | 117.4 | 74 | 284.6 | 94 | 1566.7 |
| 15 | 17.6 | 35 | 53.8 | 55 | 122.2 | 75 | 300.0 | 95 | 1900.0 |
| 16 | 19.0 | 36 | 56.3 | 56 | 127.3 | 76 | 316.7 | 96 | 2400.0 |
| 17 | 20.5 | 37 | 58.7 | 57 | 132.6 | 77 | 334.8 | 97 | 3233.3 |
| 18 | 22.0 | 38 | 61.3 | 58 | 138.1 | 78 | 354.5 | 98 | 4900.0 |
| 19 | 23.5 | 39 | 63.9 | 59 | 143.9 | 79 | 376.2 | 99 | 9900.0 |
| 20 | 25.0 | 40 | 66.7 | 60 | 150.0 | 80 | 400.0 | | |

## Numerical problems based on moisture content

**Example 1: In an experiment, a fruit having 85g mass dried in hot air oven till all the moisture evaporated. The final mass of the sample was 20g, calculate the moisture content of the sample in wet and dry basis.**

Solution:

Given: M = 85g and Ms=20g

Now, Mw = M - Ms = 85 - 20 = 65g

$$Moisture\ content\ (wb),\%=\frac{Amount\ of\ water\ present\ in\ food,g}{Total\ amount\ of\ food,g}\times 100$$

$$Moisture\ content\ (wb), \% = \frac{65}{85} \times 100 = 76.47\%$$

$$Moisture\ content\ (db), \% = \frac{Amount\ of\ water\ present\ in\ food, g}{Amount\ of\ dry\ material\ in\ food, g} \times 100$$

$$Moisture\ content\ (db), \% = \frac{65}{20} \times 100\ =\ 325\%$$

Also,

$$Moisture\ content\ (db), \% = \frac{76.47}{(100 - 76.47)} \times 100\ = \frac{76.47}{23.53} \times 100\ =\ 324.98\%\ \approx 325\ \%$$

## Unsolved problems

**Q.1:** In an experiment, an apple having 225g mass dried in hot air oven till all the moisture evaporated. The final mass of the sample was 70g, calculate the moisture content of the sample in wet and dry basis.

**Q.2:** In an experiment, maize samples having 25g mass dried in hot air oven and 7g of moisture evaporated till the end of process. Calculate the moisture content of the sample in wet and dry basis.

**Q.3:** 100kg of potatoes were procured from the local market, if the moisture content of potatoes is 80% on wet basis. Estimate the amount of water and solid present in the potatoes.

**Q.4:** If the potatoes in Q. No. 3 are dried to 5% for the preparation of potato chips. Estimate the amount of chips prepared using these potatoes.

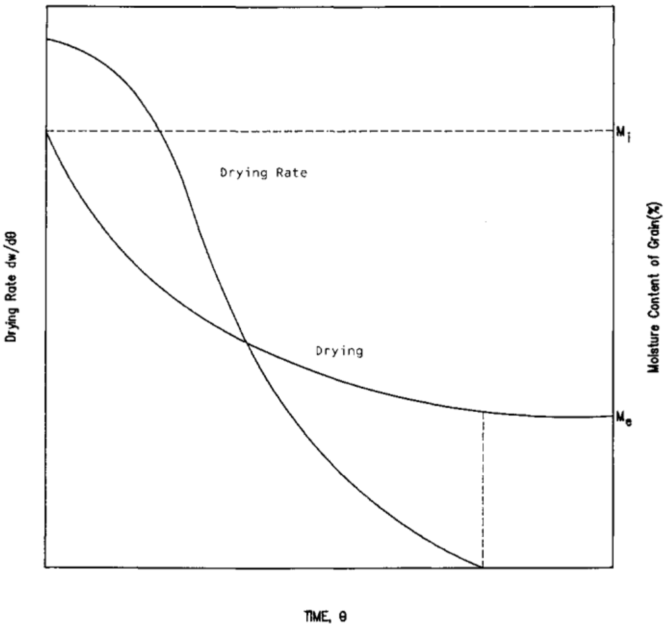
# Practical 2

**Objective: Study of mechanics of bulk solids affecting drying and storage of grains**

**Drying Mechanisms**

In the process of drying heat is necessary to evaporate moisture from the grain and a flow of air is needed to carry away the evaporated moisture. There are two basic mechanisms involved in the drying process; (i) the migration of moisture from the interior of an individual grain to the surface, and (ii) the evaporation of moisture from the surface to the surrounding air. The rate of drying is determined by the moisture content and the temperature of the grain and the temperature, the (relative) humidity and the velocity of the air in contact with the grain.

Figure 1 demonstrates the drying of a single layer of grain exposed to a constant flow of air. The moisture content falls rapidly at first but as the grain loses moisture the rate of drying slows. In general the drying rate decreases with moisture content, increases with increase in air temperature or decreases with increase in air humidity. At very low air flows increasing the velocity causes faster drying but at greater velocities the effect is minimal indicating that moisture diffusion within the grain is the controlling mechanism.




$M_i$ = Initial Moisture content, and $M_e$ = Equilibrium Moisture content

**Figure 1. Drying and Drying Rate Curves**

Grains are hydroscopic and will lose or gain moisture until equilibrium is reached with the surrounding air. The equilibrium moisture content (EMC) is dependent on the relative humidity and the temperature of the air; EMCs for a range of grains are shown in Table 1.

The relationship between EMC, relative humidity and temperature for many grains has been modelled by numerous researchers; the results of which have been summarized by Brooker et al. (1974). It is very important to appreciate the practical significance of the EMC. Under no circumstances is it possible to dry to a moisture content lower than the EMC associated with the temperature and humidity of the drying air; e.g. the paddy can only be dried to a moisture content of 16.7% when exposed to air at 25°C and 90% relative humidity. If paddy at a moisture content less than 16.7% is required then either the temperature of the drying air has to be increased or its humidity reduced.

**Table 1: Grain Equilibrium Moisture Contents**

| Grain | Relative Humidity (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| | Equilibrium Moisture Content (%wb*) at 25°C | | | | | | | |
| Barley | 8.5 | 9.7 | 10.8 | 12.1 | 13.5 | 15.8 | 19.5 | 26.8 |
| Shelled Maize | 8.3 | 9.8 | 11.2 | 12.9 | 14.0 | 15.6 | 19.6 | 23.8 |
| Paddy | 7.9 | 9.4 | 10.8 | 12.2 | 13.4 | 14.8 | 16.7 | - |
| Milled Rice | 9.0 | 10.3 | 11.5 | 12.6 | 12.8 | 15.4 | 18.1 | 23.6 |
| Sorghum | 8.6 | 9.8 | 11.0 | 12.0 | 13.8 | 15.8 | 18.8 | 21.9 |
| Wheat | 8.6 | 9.7 | 10.9 | 11.9 | 13.6 | 15.7 | 19.7 | 25.6 |

* wet basis Source: Brooker *et al.* (1974)

The drying of grains in thin layers where each and every kernel is fully exposed to the drying air can be represented in the form:

$$Moisture\ ratio\ (MR) = f(temperature, relative\ humidity, drying\ time)$$

$$MR = \frac{Moisture\ content\ of\ grain\ at\ any\ level\ and\ time, \%db - Equilibrium\ moisture\ content, \%db}{Initial\ moisture\ content, \%db - Equilibrium\ moisture\ content, \%db}$$

$$MR = \frac{M - Me}{Mo - Me}$$

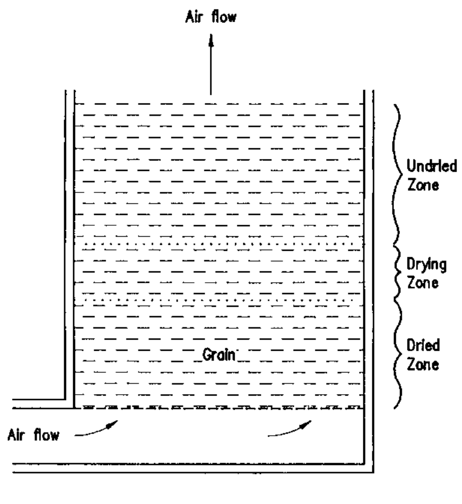
Empirical data have been used to determine mathematical approximations of the relationship between drying rate and air conditions. Relationships for many grains have been summarized by Brook & Foster (1981).

A thin layer equation for paddy is:

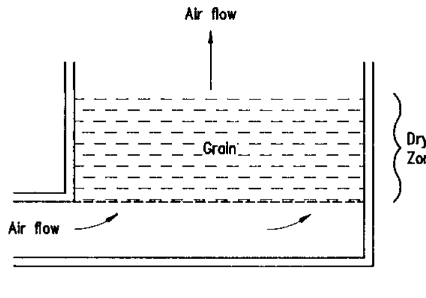
$$MR = \exp(-kt^n)$$

where, k = 0.026 - 0.0045 h + 0.01215 T; and n = 0.013362 + 0.194h - 0.000177h$^2$ + 0.009468T, h=relative humidity, %; T= drying temperature, °C

In the drying of grain in a deep bed, whilst individual kernels may all be losing moisture at different rates, the overall drying rate will remain constant for a long period. The air absorbs moisture as it moves through the bed until it becomes effectively saturated and moves through the remaining layers of grain without effecting further drying.




A. Thick drying bed.




B. Shallow drying bed.

Figure 2.A shows the three zones present within a thick drying bed at an intermediate time within the drying operation. Drying takes place within a discrete zone, the size of which depends on the moisture content of the grain and the temperature, humidity and velocity of the air. Below the drying zone is the dried zone where the grain is in

equilibrium with the air. Above the drying zone is the un-dried zone wherein the grain remains unchanged from its initial condition. In a shallow bed as in Figure 2B the drying zone is thicker than the bed depth and drying would occur initially throughout the bed.

The change in temperature and humidity of air as it moves through a bed of grain depends on the rate at which moisture is being evaporated from each kernel as an individually exposed element. Knowledge of the effect of grain moisture content, other grain properties, the temperature, humidity and flow rate of the air upon fully exposed kernels is essential to an understanding of how drying would proceed within a bed.

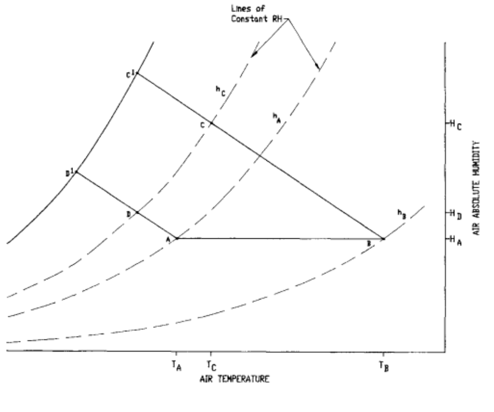
Unfortunately no theory has been developed that accurately and practically describes the thin layer drying rate. As described above many empirical relationships have been established and these have to be used in prediction of drying time. Accurate prediction of drying time is further inhibited by the variability of key factors encountered in practice, particularly so for the simple drying systems that are the most appropriate for use in developing countries. For example the moisture content of individual grains is likely to vary considerably within a batch and in the case of drying with a heater of constant heat output the temperature of the drying air will vary with changes in ambient air temperature.

**Air Properties**

The properties of the air flowing around the drying grain are a major factor in determining the rate of removal of moisture. The capacity of air to remove moisture is principally dependent upon its initial temperature and humidity; the greater the temperature and lower the humidity the greater the moisture removal capacity of the air.

The relationship between temperature, humidity and other thermodynamic properties is represented by a psychrometric chart as shown in Figure 3. It is important to appreciate the difference between the absolute humidity and relative humidity of air. The absolute humidity is the moisture content of the air (mass of water per unit mass of air) whereas the relative humidity is the ratio, expressed as a percentage, of the moisture content of the air at a specified temperature to the moisture content of air if it were saturated at that temperature.

The changes in air conditions when air is heated and then passed through a bed of moist grain are shown in Figure 4. The heating of air from temperature TA to TB is represented by the line AB. During heating the absolute humidity remains constant at HA whereas the relative humidity falls from hA to hB. As air moves through the grain bed it absorbs moisture. Under (hypothetical) adiabatic drying sensible heat in the air is converted to latent head and the change in air conditions is represented along a line of constant enthalpy, BC. The air will have increased in both absolute humidity, Hc, and relative humidity, hc, but fallen in temperature, Tc. The absorption of moisture by the air would be the difference between the absolute humidities at C and B. (HC-HA).



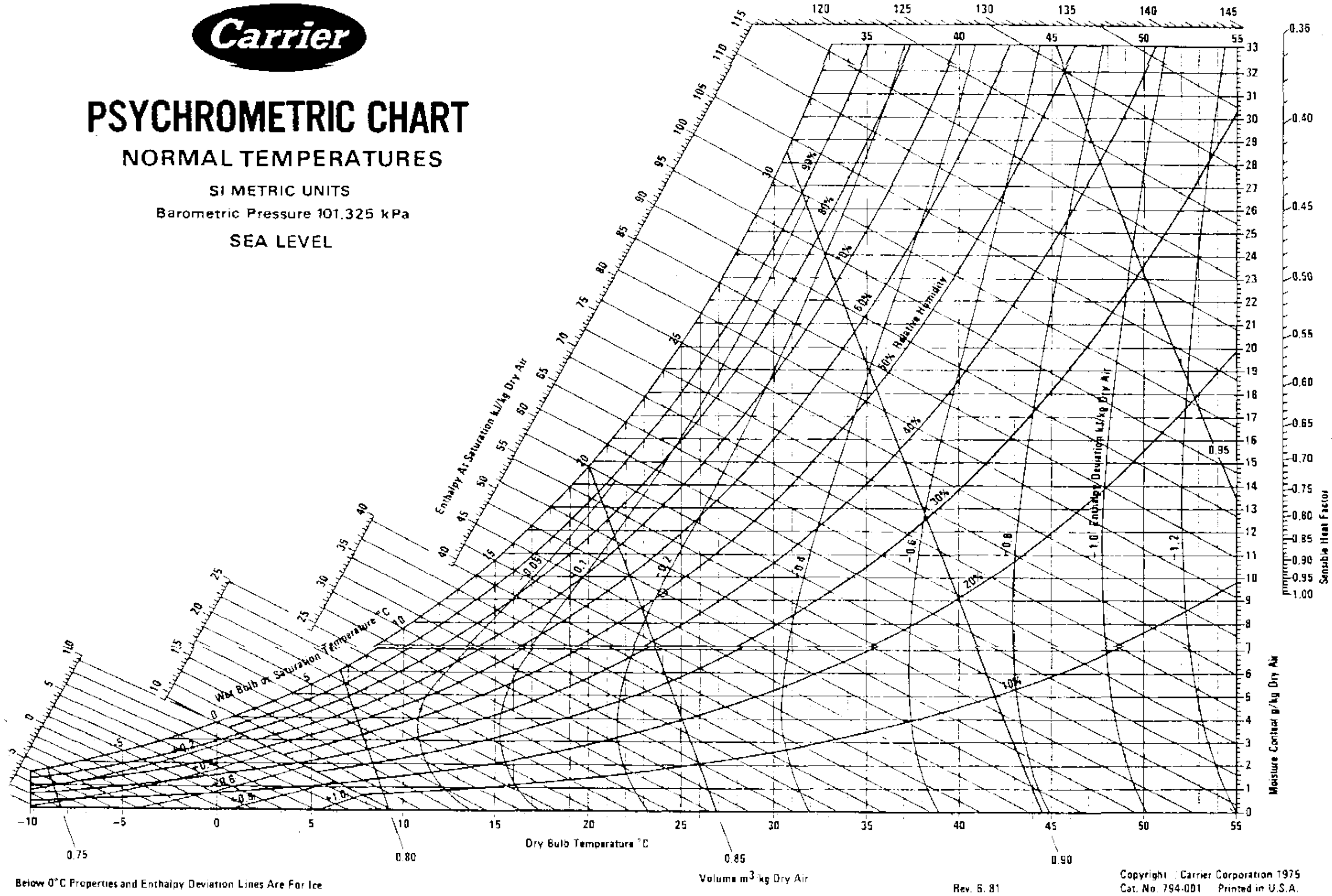



**Figure 3: Psychrometric chart**

If unheated air was passed through the bed the drying process would be represented along the line AD. Assuming that the air at D was at the same relative humidity, hc, as the heated air at C then the absorbed moisture would be (HD-HA), considerably less than that absorbed by the heated air (HC-HA)

**Bulk Density.**

The bulk density of grain is the weight per unit volume. Moisture content has an appreciable effect on the bulk density.

**Resistance to Air Flow.**

The energy required to force air through a bed of grain is dependent on the air flow, the grain depth and physical properties of the grain such as surface and shape factors, the kernel size distribution, moisture content, and the quantity and nature of contamination, stones, straw, weeds etc. The relation between air flow and the pressure drop generated across the bed for selected grains is illustrated in Figure 5. The data generally refer to clean and dry grain and correction factors of up to 1.4 are used for very wet and dirty grain (Teter 1987).

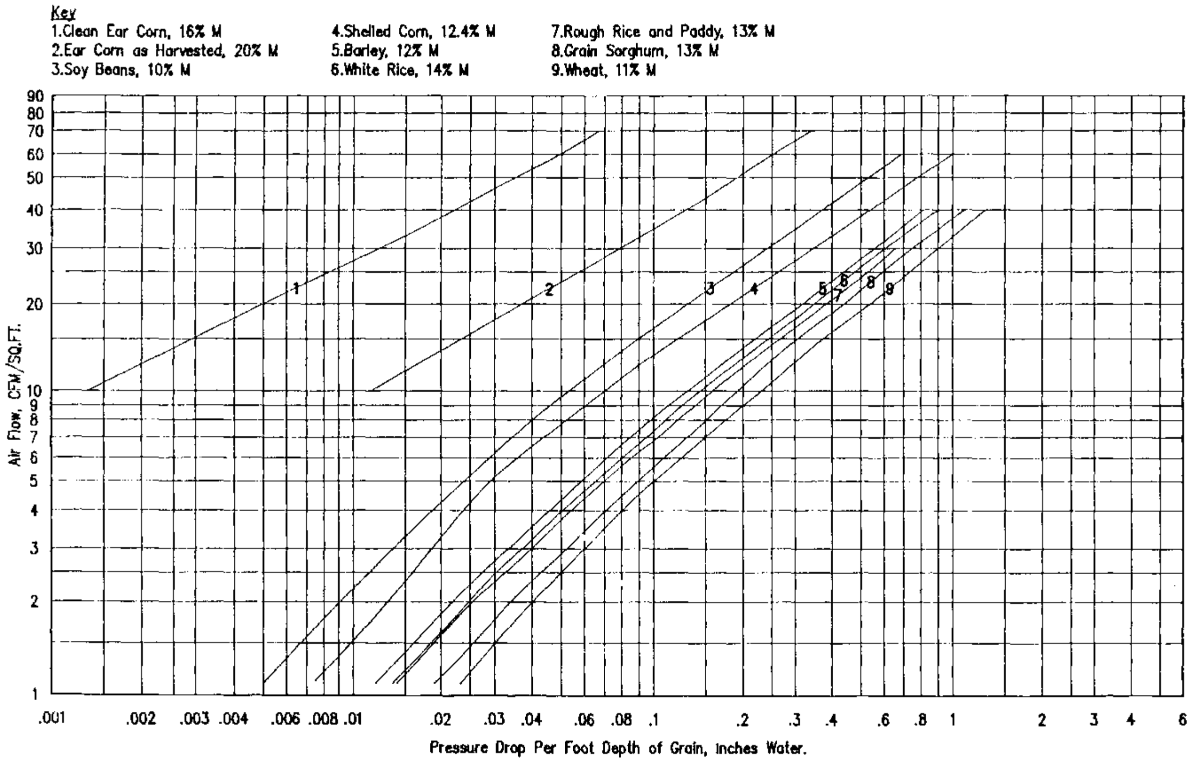



FIGURE 5: RESISTANCE OF GRAINS AND SEEDS TO AIR FLOW.

**Figure 5. Resistance of Grains and Seeds to Air Flow**

**Latent Heat of Vaporization.**

Energy in the form of heat must be supplied to evaporate moisture from the grain. The latent heat of vaporization, Lh, for a grain depends on its moisture content and temperature and is appreciably greater than the latent heat of evaporation of water. The latent heat of vaporization for paddy at selected moisture contents and temperatures is shown in Table 2. Data for other grains have been reported by Brooker et al. (1974).

**Table 2. Latent Heat of Vaporization of Paddy**

| Temperature °C | Latent Heat of Vaporization (kJ/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Free Water | Moisture Content %(wb) | | | | |
| | | 14 | 16 | 18 | 20 | 22 |
| 25 | 2,443 | 2,605 | 2,518 | 2,483 | 2,464 | 2,453 |
| 30 | 2,431 | 2,593 | 2,506 | 2,471 | 2,452 | 2,441 |
| 35 | 2,419 | 2,580 | 2,493 | 2,458 | 2,440 | 2,429 |
| 40 | 2,407 | 2,567 | 2,482 | 2,447 | 2,428 | 2,417 |
| 45 | 2,395 | 2,555 | 2,469 | 2,434 | 2,416 | 2,405 |
| 50 | 2,383 | 2,542 | 2,456 | 2,422 | 2,404 | 2,393 |
| 55 | 2,371 | 2,529 | 2,444 | 2,410 | 2,391 | 2,381 |
| 60 | 2,359 | 2,516 | 2,432 | 2,398 | 2,379 | 2,369 |

**Estimation of Drying Time**

A basic design procedure for the field worker is best illustrated for the design of a batch type dryer although the principles can be applied to a certain extent in the design of continuous multi-stage systems.

Assumed ambient air conditions are a dry bulb temperature of Ta and a relative humidity of RHa; from the psychrometric chart the wet bulb temperature, Twa, the enthalpy, Ha, and the absolute humidity ha can be derived. The air is heated to a selected safe drying temperature, Tb, thereby raising the enthalpy of the air to Hb.

The wet grain of equivalent bone-dry mass **G** has a moisture content of **MCw%(**db) and is to be dried to a moisture content of **MCd**%. A mass air flow of V is available. The moisture, **M**, to be removed,

$$\boldsymbol{M = G \times (MCw - MCd)}$$

It is assumed that throughout the drying period the air will exhaust from the bed at a constant wet bulb temperature and in equilibrium with the uppermost layers of grain. Initially the exhaust air will be in equilibrium with grain at **MCw** moisture and finally in equilibrium with grain at **MCd** moisture. By superimposing equilibrium moisture content data on to the psychrometric chart for the initial and final moisture contents the humidity of the exhaust air at the beginning and end of drying can be found. An average of the initial and final exhaust air relative humidities, **hea** is taken for calculation of drying time, **td**:

$$\boldsymbol{t_d = \frac{M}{V \times (ha - hea)}}$$

**Hukill's method**

An alternative, more complex but more accurate method for the estimation of drying performance is the technique based on dimensionless drying curves as initially developed by Hukill (1947). The methodology permits the estimation of the moisture content of grain at any level within the bed at any time after initiation of drying. It can be used for any grain for which EMC and thin layer drying data are available as is the case for most cereal grains.

The methodology involves the use of bulk drying curves as depicted in Figure 6 and calculation of three parameters, moisture ratio, time unit and depth factor.

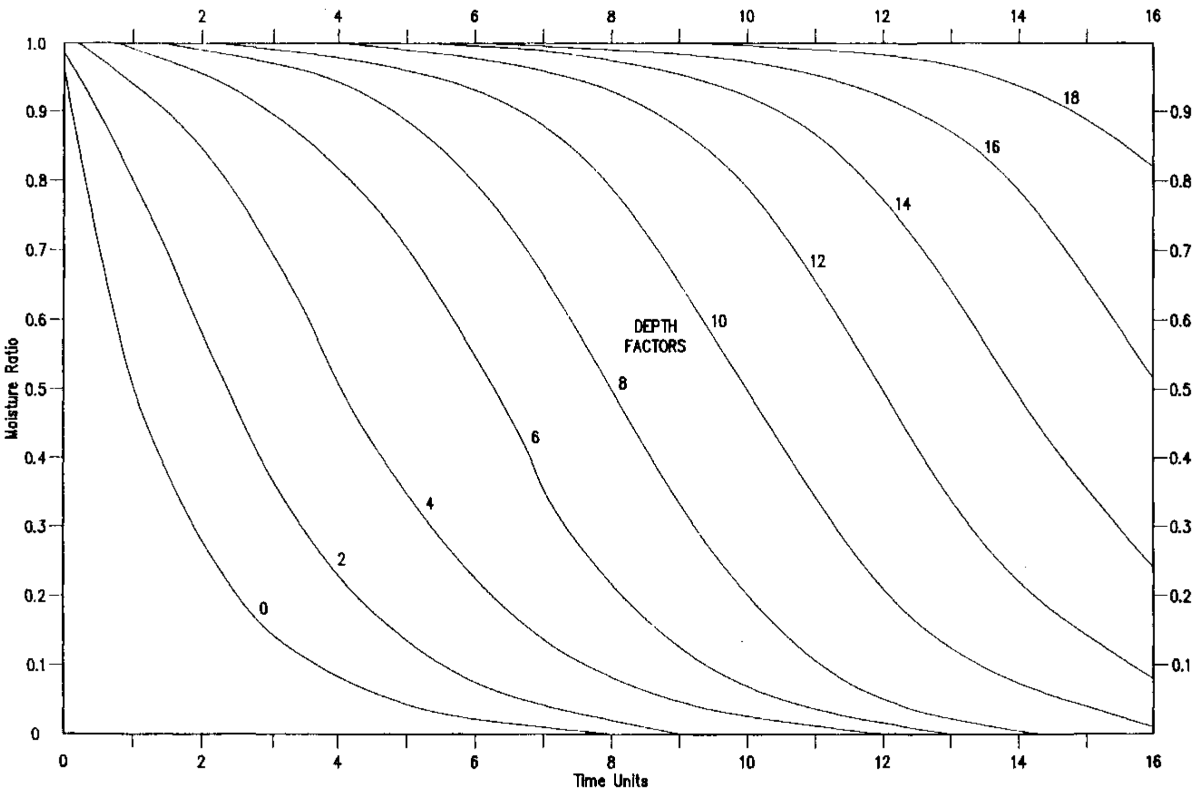



FIGURE 6: DIMENSIONLESS DRYING RATE CURVES

The moisture ratio, MR is calculated from the following equation:

$$MR = \frac{M - Me}{Mo - Me}$$

The time unit, Y, is calculated using the equation:

$$Y = \frac{t_d}{t_{0.5}}$$

where $t_{0.5}$ is the half-response time, the time required for fully exposed grain to reach a moisture ratio of 0.5 under the drying air conditions employed. It can be calculated from the thin layer drying equations with MR assigned a value of 0.5.

**Depth factor**

The depth factor, D, is defined as the depth of the bed that contains the mass of grain, DM, that can be dried from the initial moisture ratio MR = 1 to a final moisture ratio MR = 0 with the sensible heat available over the period of one half-response time as the air cools to its wet bulb temperature. DM is calculated thus:

$$\boldsymbol{DM = \frac{V \times C_p \times t_{0.5} \times (T_{dh} - T_{wa})}{L_h \times (Mo - Me)}}$$

where Cp is the specific heat of air. The number of depth factors within the bed is found from the expression:

$$\boldsymbol{D = d \times \frac{G}{DM}}$$

where d is the bed depth. The curves in Figure 6 are represented by the equation:

$$\boldsymbol{MR = \frac{2^D}{2^D + 2^Y - 1}}$$

By transposing the drying conditions to these units and using either Figure 6 or the above equation it is possible to predict when any layer within the bed reaches a desired moisture content. More rigorous approaches to the design of drying systems have been developed. These include the methods based on thin layer drying equations described by Brook & Foster (1981) and Brooker et al. (1974). Many of these have been developed into sophisticated simulation techniques (Brooker et al. 1974). The drying conditions for specific grains and situations are many and varied. Drying will take place under any conditions where grain is exposed to a flow of unsaturated air. Very fast drying can be accomplished using large volumes of high temperature air but, if carried through to completion, is likely to be inefficient in energy use and liable to damage the grain by over-heating and/or over-drying. Conversely slow drying, as in sun drying in inclement weather, provides conditions for continued respiration and deterioration of the grain leading to both quantitative and qualitative losses and the growth of moulds.

**Drying Efficiency**

The efficiency of the drying operation is an important factor in the assessment and selection of the optimum dryer for a particular task. There are three groups of factors affecting drying efficiency:

* those related to the environment, in particular, ambient air conditions;
* those specific to the crop;
* those specific to the design and operation of the dryer.

There are several different ways of expressing the efficiency of drying, of which the **sensible heat utilization efficiency (SHUE)**, The fuel efficiency, and the drying efficiency are the most useful.

The SHUE takes into account the sensible heat attributable to the condition of the ambient air and any heat added to the air by the fan as well as the heat supplied by combustion of the fuel. It is defined as:

$$SHUE = \frac{Heat\ utilized\ for\ moisture\ removal}{Total\ sensible\ heat\ in\ the\ drying\ air}$$

The fuel efficiency is based only on the heat available from the fuel:

$$Fuel\ efficiency = \frac{Heat\ utilized\ for\ moisture\ removal}{Heat\ supplied\ from\ fuel}$$

It can be appreciated that the fuel efficiency would be significantly different for the operation of the same dryer at two locations with widely different ambient conditions. With low temperature drying, particularly in dry climates, the heat supplied from the fuel may be less than half of the total sensible heat and the fuel efficiency may exceed 100%. Direct comparison of the performance of dryers at separate locations is not possible using the fuel efficiency.

The drying efficiency, defined as:

$$Drying\ efficiency = \frac{Heat\ utilized\ for\ moisture\ removal}{Heat\ available\ for\ moisture\ removal}$$

is the expression to be used for evaluation of dryer designs or comparison between dryers, since it is a measurement of the degree of utilization of the sensible heat in the drying air.

Foster (1973) evaluated the fuel and drying efficiencies of several types of dryers used with maize. Over a wide range of conditions, continuous-flow dryers were found to have a fuel efficiency of 38% and a drying efficiency of 51%, batch dryers 42% and 58% and two-stage drying, 60% and 79%, respectively.

**Effect of Drying on Grain Quality**

The drying operation must not be considered as merely the removal of moisture since there are many quality factors that can be adversely affected by incorrect selection of drying conditions and equipment. The desirable properties of high-quality grains include:

- low and uniform moisture content;
- minimal proportion of broken and damaged grains;
- low susceptibility to subsequent breakage;
- high viability;
- low mould counts;
- high nutritive value;
- consumer acceptability of appearance and organoleptic properties.

**Moisture Content.** It is essential that the grain after drying is at a moisture content suitable for storage. As discussed the desired moisture content will depend on the type of grain, duration of storage, and the storage conditions available. It is also important that the drying operation is carried out to minimize the range of moisture levels in a batch of dried grain. Portions of under-dried grain can lead to heating and deterioration.

**Stress Cracking and Broken Grains.** Drying with heated air or excessive exposure to sun can raise the internal kernel temperature to such a level that the endosperm cracks. The extent of stress cracking is related to the rate of drying. Rapid cooling of grain can also contribute to stress crack development.

**Nutritive Value.** Grain constituents such as proteins, sugars and gluten may be adversely affected when the grain attains excessive temperatures. The feeding value of grains can be lowered if inadequately dried.

**Grain Viability.** Seed grain requires a high proportion of individual grains with germination properties. The viability of grain is directly linked to the temperature attained by grains during drying (Kreyger 1972).

**Mould Growth.** Many changes in grain quality are linked to the growth of moulds and other microorganisms. The rate of development of microorganism is dependent on the grain moisture content, grain temperature, and the degree of physical damage to individual grains. Mould growth causes damage to individual grains resulting in a reduction in value. Under certain circumstances mycotoxin development can be a particular hazard.

**Appearance and Organoleptic Properties.** The colour and appearance as perceived by the customer and/or consumer. For example, the colour of milled rice can be adversely affected if the paddy is dried with direct heated dryers with poorly maintained or operated burners or furnaces.

# Storage

The store must satisfy the following parameters in so far as possible: (i) a the grain must be kept dry; (ii) the grain should be kept at a uniform temperature; (iii) the grain should be protected from insect attack; (iv) rodents and birds should be excluded.

It is evident from previous sections that drying and storage are in many cases provided for in same structure. Combining these functions is economical and allows further conditioning at later stages if required. For example, if a hot spot develops in a storage bin, it can be easily ventilated again. It may also be possible to provide some low-volume ventilation in an otherwise pure storage system. There are however, situations when the storage is considered quite separately from drying, ranging from the storage of naturally dried crops, to the storage of grain from a continuous-flow or batch dryer.

The size and type of storage facilities is likely to be dictated by

(i) a Total volume of crop to be stored

(ii) The storage requirements for the crop to be stored

(iii) The unit cost of various types of storage
(iv) The form in which the crop is stored, i.e. cob maize vs shelled maize or bagged wheat vs bulk wheat.
The volume of the store required can be estimated from the expected yield and the land area. A comparison between different forms of storage is normally done through calculation of costs/tonne of capacity. The form of storage depends not only on how the crop is harvested, the volume and the way it is delivered to the market, but also the overall costs.
Where drying is a problem bag storage has the advantage that it allows higher moisture content than bulk storage. For maize, the requirement for safe storage is maximum 15 and 12% moisture content respectively. in general terms the advantages and disadvantages of bag and bulk storage respectively, are:

| Bags | Bulk |
|---|---|
| Flexibility of storage | Inflexible storage |
| Partly mechanizable | Mechanizable |
| Slow handling | Rapid handling |
| Considerable spillage | Little spillage |
| Low capital costs | High capital costs |
| High operating costs | Low operating costs |
| Easy inspection | Inspection more difficult |

**Soild-wall bins and silos for bulk storage**
Soild wall bins may be anything from a small plastered basket to large steel or concrete silos holding several thousand tons. The traditional bins used by the African farmers are small with capacity of up to 2-3 tonnes and include gourds, clay pots, mud plastered baskets raised off the ground and mud walled silos ("rumbus'). Many of these have limitations, particularly in durability, protection against rodents and insects as well as moisture from ambient air. Solid wall bins or silos should only be used in areas where the produce can be dried sufficiently before storage. Several attempts have been made to improve on the traditional stores to make them more suitable for long term storage.
**Grain bin wall pressure**
The design of bulk storage for grain and oilseeds requires a compromise between the conflicting requirements of structural strength, economical construction and convenience in handling. Frequently bin wall pressure is calculated using Janssen's equation. Experimental determinations of bin wall pressures on models and actual bins have confirmed that Janssen's theory is only applicable to static or filling conditions. Sometimes, pressures are larger than calculated pressure while emptying.

# Practical No. 3

**Objective: Measurement of moisture content during drying and aeration.**

**Apparatus/ equipments required:**
(i) Weighing device: A balance or scale sensitive to 0.1 % of the mass of the test sample, and having a capacity equal to, or greater than, the wet mass of the sample to be tested; (ii) Drying device: An oven or other suitable thermostatically controlled heating chamber capable of maintaining a temperature of 110 ± 5°C; (iii) Containers: Any pan or other container, that will not be affected by the drying temperature, and is suitable for retaining the test sample without loss while permitting the water to evaporate.

**Procedure:**

(i) Determine the mass of the test sample and record this mass as the "wet mass".
   a. The most convenient procedure for determining the mass of the sample before and after drying is to place it in a tared container where it will remain throughout the test. The mass of the container and sample are determined and the mass of the container subtracted.
   b. If the mass of the test sample is not determined immediately after preparation, place the moisture-tight cover on the container to prevent evaporation.

(ii) Dry to constant mass at 110 ± 5°C for 16 h or 130°C for 1 to 2 h.
   a. The drying time required to achieve constant mass will vary depending on the type, quantity, and condition of the material. In most cases, an overnight drying period is sufficient. About 25-30 g sample may require significantly longer drying periods.
   b. To reduce the drying time, the samples may by be ground into small fragments and spread in a thin layer over the bottom of the containers. Position the containers in the drying device to allow the maximum air circulation and exhaust of the moisture laden air.
   c. Constant mass has been achieved when less than 0.1 % of the test sample wet mass is lost during an additional exposure to the drying process. Subsequent drying periods to verify constant mass shall be of at least 1 h duration.
   d. Verification of constant mass will not be necessary for each sample, provided the drying time exceeds the minimum time established for similar materials and conditions in the same drying device.

(iii) Remove the sample from the drying device and cool to room temperature.

(iv) Determine the mass of the test sample and record this weight as the "dry mass".

Result: The moisture content of the ___________ is __________%wb and ________%db.

**Precautions**

(i) If the mass of the test sample is not determined immediately after cooling, place the moisture-tight cover on the container to prevent absorption of moisture from the air.

(ii) A broad shallow pan is normally most suitable for promoting drying; however, containers with moisture-tight covers are required when the mass of the test samples are not determined immediately after preparation or after cooling following the drying period.

(iii) Wearing dust masks and protective gloves when handling materials is advised.

(iv) The use of heat resistant gloves/mitts or pot holders to remove samples from the ovens is recommended

**Observations**

| S. No. | Mass of the moisture box, g (M1) | Initial mass of sample with plate, g (M2) | Dried mass of sample with plate, g (M3) | Mass of water, g Mw=M2-M3 | Mass of dry sample, g Ms=M3-M1 | Moisture content (wb), % | Moisture content (db), % |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | | | | | **Average** | | |

The moisture content on wet basis (wb) in food is the amount of water present in the food to the total amount of material. It can be represented by the following formula -

$$Moisture\ content\ (wb), \% = \frac{Amount\ of\ water\ present\ in\ food, g}{Total\ amount\ of\ food, g} \times 100$$

The moisture content on dry basis (db) in food is the amount of water present in the food to the amount of dry material. It can be represented by the following formula -

$$Moisture\ content\ (db), \% = \frac{Amount\ of\ water\ present\ in\ food, g}{Amount\ of\ dry\ material\ in\ food, g} \times 100$$

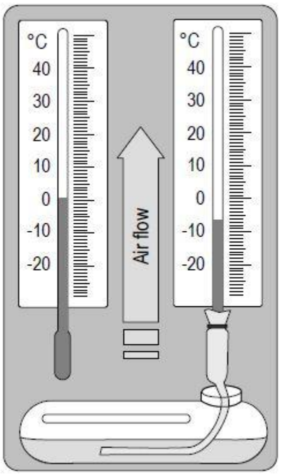
# Practical No. 4

**Objective: Measurement of relative humidity during drying and aeration.**

A sling psychrometer can be used to find relative humidity, which is expressed as a percentage. It is computed by multiplying the amount of moisture in the air at a given temperature, dividing by the maximum amount of moisture the air could contain at that same temperature, and then multiplying the quotient by 100. The dew-point temperature is always lower than the dry-bulb temperature, unless the air is saturated, in which case they are identical. Also, the wet bulb temperature is higher than the dew-point temperature, except when the air is saturated; in that case, the two are equal. Dew point is the temperature at which water vapor starts to condense out of air that is cooling, whereas wet-bulb temperature represents how much moisture the air can evaporate.

A sling psychrometer consists of two thermometers. One is a wet bulb and the other is a dry bulb. To make a wet-bulb thermometer, wrap a piece of white, porous cloth (a hollow white shoelace is ideal) which has been soaked in water around the bulb of one of the thermometers and secure it with a rubber band or twine.

After twirling the sling psychrometer for 10 to 20 seconds, take readings (in °C) from both thermometers and record the results. Next, use the relative humidity chart to determine the relative humidity of the air.



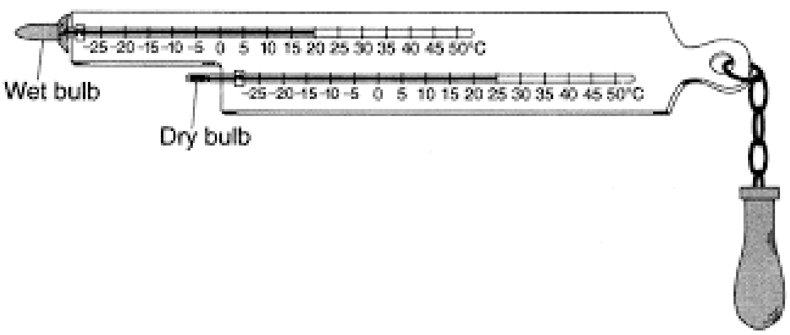




Table 1 or psychrometric chart may be used to determine relative humidity. The numbers in the center of the chart represent relative humidity in percentages. Relative humidity is determined by finding the differences in degrees between the dry-bulb and wet-bulb readings on the horizontal scale at the top, and then reading off where this column intersects the horizontal row containing the dry-bulb temperature reading. The difference between

**Relative Humidity (%)**

| Dry-Bulb Temp.,°C | Dry-Bulb Temperature Minus Wet-Bulb Temperature (Dry-Bulb Depression), °C | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 | 18 | 20 |
| 2 | 84 | 68 | 52 | 37 | 22 | 8 | | | | | | | | | |
| 4 | 85 | 71 | 57 | 43 | 29 | 16 | 3 | | | | | | | | |
| 6 | 86 | 73 | 60 | 48 | 35 | 24 | 11 | | | | | | | | |
| 8 | 87 | 75 | 63 | 51 | 40 | 29 | 19 | 8 | | | | | | | |
| 10 | 88 | 77 | 66 | 55 | 44 | 34 | 24 | 15 | 6 | | | | | | |
| 12 | 89 | 78 | 68 | 58 | 48 | 39 | 29 | 21 | 12 | | | | | | |
| 14 | 90 | 79 | 70 | 60 | 51 | 42 | 34 | 26 | 18 | 10 | | | | | |
| 16 | 90 | 81 | 71 | 63 | 54 | 46 | 38 | 30 | 23 | 15 | | | | | |
| 18 | 91 | 82 | 73 | 65 | 57 | 49 | 41 | 34 | 27 | 20 | 7 | | | | |
| 20 | 91 | 83 | 74 | 66 | 59 | 51 | 44 | 37 | 31 | 24 | 12 | | | | |
| 22 | 92 | 83 | 76 | 68 | 61 | 54 | 47 | 40 | 34 | 28 | 17 | 6 | | | |
| 24 | 92 | 84 | 77 | 69 | 62 | 56 | 49 | 43 | 37 | 31 | 20 | 10 | | | |
| 26 | 92 | 85 | 78 | 71 | 64 | 58 | 51 | 46 | 40 | 34 | 24 | 14 | 5 | | |
| 28 | 93 | 85 | 78 | 72 | 65 | 59 | 53 | 48 | 42 | 37 | 27 | 18 | 9 | | |
| 30 | 93 | 86 | 79 | 73 | 67 | 61 | 55 | 50 | 44 | 39 | 30 | 21 | 13 | 5 | |
| 32 | 93 | 86 | 80 | 74 | 68 | 62 | 57 | 51 | 46 | 41 | 32 | 24 | 16 | 9 | |
| 34 | 93 | 87 | 81 | 75 | 69 | 63 | 58 | 53 | 48 | 43 | 35 | 26 | 19 | 12 | 5 |
| 36 | 94 | 87 | 81 | 75 | 70 | 64 | 59 | 54 | 50 | 45 | 37 | 29 | 21 | 15 | 8 |
| 38 | 94 | 88 | 82 | 76 | 71 | 66 | 61 | 56 | 51 | 47 | 39 | 31 | 24 | 17 | 11 |
| 40 | 94 | 88 | 82 | 77 | 72 | 67 | 62 | 57 | 53 | 48 | 40 | 33 | 26 | 20 | 14 |
| 42 | 94 | 88 | 83 | 77 | 72 | 67 | 63 | 58 | 54 | 50 | 42 | 34 | 28 | 21 | 16 |
| 44 | 94 | 89 | 83 | 78 | 73 | 68 | 64 | 59 | 55 | 51 | 43 | 36 | 29 | 23 | 18 |

**Observations**

| S. No. | Location | Time | Dry bulb temperature, °C | Wet bulb temperature, °C | Relative humidity from table/ chart, % |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| | | | | Average | |

**Result:** The average relative humidity at Drying and Dehydration Laboratory on ____/____/________ at ___:___ AM/PM was ______%.

## Practical No. 5

### Objective: Measurement of air velocity during drying and aeration

**Apparatus used:** Anemometer, Tray dryer

**Theory:**
When drying begins with green or high moisture content crop, there is a considerable amount of water. Thus, a considerable amount of water molecules have only a short distance to travel (diffuse) to reach the surface. The water is essentially waiting for the air to transfer energy to the wood (to evaporate the water) and then to carry the water vapor away. When the crop has a low moisture content, the amount of water at the surface is much less and the water molecules in the core have farther to travel to reach the surface. This diffusion of water toward the surface is slow. Therefore, as an analogy, rather than the water waiting for the air, as is the case with green crop, the air is waiting for the water in dry crop.

In general, for high moisture content crop, as the air velocity increases, the drying rate increases, the drying is more uniform and there is less warp and stain. However, with the higher air velocity comes the greater risk of checking, splitting and honeycomb. Conversely, with low air velocity at the higher moisture contents comes the increased risk of warp (especially cup), staining and non-uniform drying. Therefore, air velocity is a tool (just like temperature and humidity) to control the rate of drying. However, it is a tool that is useful above 40 percent moisture content. At 20 percent and below, air velocity beyond the minimum has little effect on drying rates. Between 40 and 20 percent moisture content, air velocity plays a proportionally decreasing role. As the air moves across a stack of crop, its temperature decreases and its relative humidity increases. This temperature drop and relative humidity rise depends on the volume of airflow. As the velocity increases, there is an increase in volume of airflow through the sticker spaces. If there is more volume of air moving across the crop surface, there will be a smaller temperature drop and a smaller relative humidity rise. With a lower volume of air, the reverse is true.


**Procedure:**
1. Switch on the dryer and maintain the temperature.
2. Select the " Off/On/Hold Switch " to the " On " position.
3. Select the " Function Switch " to the " m/s ", " km/h ", " ft/min " or " knots " position according to the measuring requirement.
4. Hold the " Vane Probe Handle " by hand & let the " Vane Probe Head " is opposite to the measuring air flow source, then the Display will show air velocities directly.

## Practical No. 6

**Objective: Drying characteristic and determination of drying constant**

**Apparatus/ equipments required:**
Tray dryer, weighing balance

**Theory**
Drying is a means of removing water from semi-solid, and occasionally liquid, products typically to preserve the food or impart a desirable texture. Many types of dryers exist including tray, rotary, vacuum, drum and spray drying. In tray dryers, be they batch or continuous, a hot air stream passes over the surface of the product, providing some of the heat of evaporation, and acting as a medium by which water vapor is carried away from the food.

Many mechanisms come into play controlling the rate of drying. During initial drying, in the constant-rate drying period, water evaporates freely away from the surface. During later periods, water must move from the interior of the product to the surface. This may happen due to liquid diffusion, capillary movement, surface diffusion, gaseous diffusion, or may be related to product shrinkage. Drying curves can be determined for a food product in a given dryer and drying conditions, and these will usually show characteristic drying periods, including constant rate drying and falling rate drying periods. Following formula are used to determine drying rate, moisture rate and drying constant.

$$Drying\ rate, kg/kg\ min = \frac{Mass\ of\ water\ removed\ during\ given\ interval, kg}{Mass\ of\ solid\ in\ sample, kg\ \times Drying\ duration, min}$$

$$Moisture\ ratio\ (MR) = \frac{Instanteous\ moisture\ content - Equilibrium\ moisture\ content}{Initital\ moisture\ content - Equilibrium\ moisture\ content}$$
$$= \frac{M - Me}{Mo - Me}$$

According to Lewis (1921) formula -
$$MR = e^{-k\theta}$$
$$-k\theta = \ln\ (MR)$$
$$k = -\frac{\ln\ (MR)}{\theta}$$
$$Drying\ constant = -\frac{\ln(MR_{0.5})}{\theta_{0.5}}$$

Where, $\theta_{0.5}$ = Time required to reach moisture ratio from 1 to 0.5 (One half response time).

## Experimental procedure

1. Preheat the dryer to the desired temperature (60 to 80°C).
2. Cut ant fruits/ vegetable into uniform slices using the slicer. Record the slice thickness. Save some samples for moisture determination and obtain moisture content using any moisture content determination method..
3. Dip samples in 10% sugar solution containing lemon juice (or ascorbic acid), if required.
4. Distribute the slices on the tray.
5. Take measurements of the product weight at for the first 5 minutes till the equilibrium is reached
6. Record the dry and wet bulb temperatures of the air at different points in the dryer.

Observation

**Moisture content determination**

| S. No. | Mass of the moisture box, g (M1) | Initial mass of sample with plate, g (M2) | Dried mass of sample with plate, g (M3) | Mass of water, g Mw=M2-M3 | Mass of dry sample, g Ms=M3-M1 | Moisture content (wb), % |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| | | | | | **Average** | |

The moisture content on dry basis (db) in food is the amount of water present in the food to the amount of dry material. It can be represented by the following formula -

$$Moisture\ content\ (wb), \% = \frac{Amount\ of\ water\ present\ in\ food, g}{Total\ mass\ of\ food, g} \times 100$$

Now take the amount of sample for drying kinetics, let the mass of sample = $M_1$;

$$Amount\ of\ water\ present\ in\ sample, g = \frac{Mositure\ content\ \times M_1}{100}$$

$$Mass\ of\ solid\ (M_s) = Total\ mass - Mass\ of\ water\ present\ in\ food$$

**Drying characteristics**

| Time, min | Mass of the sample - mass of plate, g (M1 | Mass of water removed, g | Mass of water in sample ($M_w$), g = $M_1$ - $M_s$ | Moisture content, %db = (Mw/Ms)× 100 | Drying rate, | Moisture ratio, MR |
|---|---|---|---|---|---|---|
| 0 | $M_1$ | 0.0 | | | - | |
| 5 | $M_2$ | $M_2$- $M_1$ | | | $\frac{M_2 - M_1}{Ms \times 5}$ | |
| 10 | $M_3$ | $M_3$- $M_2$ | | | $\frac{M_3 - M_2}{Ms \times 5}$ | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**Result:** The moisture content of sample was ____________. The maximum drying rate was observed as _____________g/g-min. The value of drying constant is __________________.

# Practical No. 7

**Objective:** To determine the equilibrium moisture content (EMC) of given food grain

**Equipment/ Apparatus required:**
Desiccators, sulphuric acid or different salts, weighing balance, incubator, dried food product, hygrometer

**Theory:**

**Equilibrium moisture content**

It is defined as the moisture content attained by a food product for a given set of temperature and relative humidity at which product neither gains or loose moisture content with the surroundings. Vapour pressure of grain becomes equal with the water vapor pressure of the surrounding air.

EMC of paddy under different storage conditions can be observed from the Fig. 1. The B section represent the desirable environmental conditions for safe storage of paddy or rough rice in the tropics. The A section represent conditions for safe seed storage. Grain needs to be stored at less than 14% moisture and seed at less than 12%.

| | Relative Humidity, % | Temperature, °C | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 22 | 24 | 28 | 32 | 36 | 40 | 44 | |
| Safe | 50 | 11.2 | 10.9 | 10.7 | 10.5 | 10.2 | 10.0 | 9.9 | A |
| | 55 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.6 | 10.4 | |
| | 60 | 12.3 | 12.0 | 11.8 | 11.6 | 11.4 | 11.2 | 11.0 | |
| | 65 | 12.7 | 12.6 | 12.4 | 12.2 | 12.0 | 11.8 | 11.6 | |
| | 70 | 13.5 | 13.3 | 13.1 | 12.8 | 12.6 | 12.5 | 12.3 | B |
| Unsafe | 75 | 14.3 | 14.0 | 13.8 | 13.6 | 13.4 | 13.2 | 13.0 | |
| | 77 | 14.6 | 14.3 | 14.1 | 13.9 | 13.7 | 13.5 | 13.4 | |
| | 79 | 14.9 | 14.7 | 14.5 | 14.3 | 14.1 | 13.9 | 13.7 | |
| | 81 | 15.3 | 15.1 | 14.9 | 14.6 | 14.5 | 14.3 | 14.1 | C |
| | 83 | 15.7 | 15.7 | 15.3 | 15.1 | 14.9 | 14.7 | 14.5 | |
| | 85 | 16.1 | 15.9 | 15.7 | 15.5 | 15.3 | 15.1 | 15.0 | |
| | 87 | 16.6 | 16.4 | 16.2 | 16.0 | 15.8 | 15.6 | 15.5 | |
| | 89 | 17.2 | 17.0 | 16.8 | 16.6 | 16.4 | 16.2 | 16.1 | |
| | 91 | 17.9 | 17.7 | 17.5 | 17.3 | 17.1 | 16.9 | 16.7 | |

Static method of domination is simple is a simple process. In this method product is kept in the ambience of known relative humidity for a longer period till it will reach attain equilibrium. The desired relative humidity is being maintained different level of sulphuric and hydrochloric acid concentrations. It takes very long period to bring the grain to equilibrium conditions. Generally, 3 to 4 weeks time is required and there are chances to be attacked by the attack of molds. Sometimes, decomposition and change is grain structure also takes place. It is also difficult to maintain relative humidity throughout the experiment. The temperature is being maintained by incubator and the samples are kept in desiccators. The concentration of sulphuric acid at various relative humidity can be observed using Table 1.

*Relative humidity values on the different concentration of sulphuric acid solution in water*

| Temperature, °C | Acid by weight basis, % | | | |
|---|---|---|---|---|
| | 20 | 40 | 60 | 80 |
| 10 | 87.4 | 56.6 | 15.8 | 3.8 |
| 20 | 87.4 | 56.7 | 16.3 | 4.7 |
| 30 | 87.4 | 56.6 | 17.0 | 5.7 |
| 40 | 87.4 | 57.5 | 17.8 | 6.9 |
| 50 | 88.8 | 58.0 | 18.8 | 8.2 |

**Procedure:**

1. Take five or ten desiccators or air tight containers.
2. Pour $H_2SO_4$ solution or saturated salt solution in to each air tight container and room temperature to Rh in the range of 20 to 80%. By using hygrometer, ensure the Rh level in each container.
3. Collect the sample on petri dish to hold the sample and note the mass of sample.
4. Determine the initial moisture content of the sample using hot air oven method.
5. Weigh the sample and spread the sample uniformly and keep in the air tight containers.
6. Determine the loss or gain in the mass of the sample at the end of specified time period.
7. Note the mass of sample till the equilibrium attained.

**Observations:**

Initial mass of food product (m) = _____ g

Dry matter content in sample ($m_s$)= _______ g

$$Initial\ moisture\ content\ (wb), \% = \frac{m - m_s}{m} \times 100$$

Initial moisture content of the product = _______ g

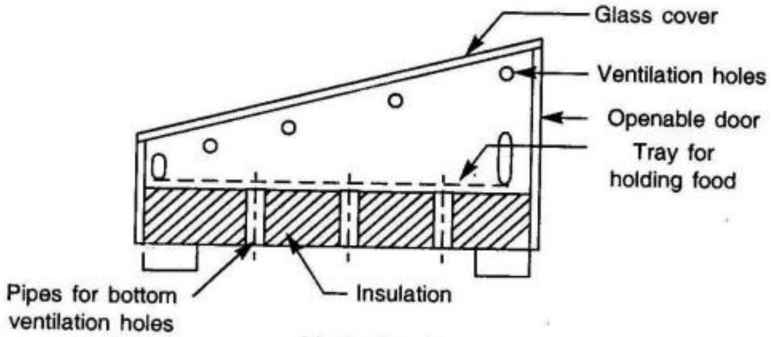
Temperature of the incubator = ________ ◦C

| S. No. | Relative humidity | Initial mass | Final mass | Mass of solids | Mass of water at EMC = (4)-(5) | Equilibrium moisture content (wb), % = $\frac{(6)}{(3)} \times 100$ |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | Equilibrium moisture content, % | |

**Result:** The equilibrium moisture content (EMC) of _______ sample at _____◦C temperature and _____% relative humidity is _____________.

# Practical No. 08

**Objective:** Study of various types of dryers
**Equipments required:** Laboratory models of dryers
**Theory:**
**Solar cabinet dryer:** The solar cabinet dryer in its simple form consists of a wooden (or of any other material) box of certain width and length (length is generally kept as three times its width), insulated at its base and preferably at the sides and covered with a transparent roof. The inside surfaces of the box are coated with black paint and the product to be dried is kept in the trays made of wire mesh bottom. These trays loaded with product are kept through an openable door provided on the rear side of the drier. Ventilation holes are made in the bottom through which fresh outside air is sucked automatically. Holes are also provided on the upper sides of the dryer through which moist warm air escapes. This dryer has given encouraging results and reduced the drying time by one third compared to open sun drying.

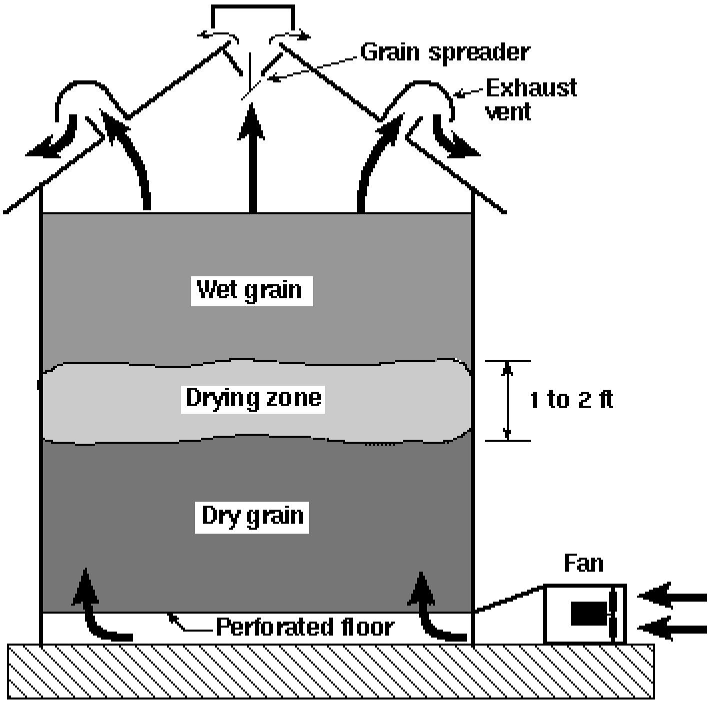



In the mixed mode type of solar dryers, the solar air heater with or without any electric fan along with a drying bin is used. Such simple mixed mode type solar dryer was developed at AIT Bangkok for drying paddy and therefore named as rice dryer. It consists of a solar air heater made of a frame of bamboo poles and wire covered with 0.15 mm thick transparent PVC sheet. The ground is covered with burnt rice husk which absorbs the solar radiation and heats the air in contact. The hot air in this air heater rises to the drying chamber which either consists of transparent PVC sheets on bamboo frame absorbing directly the solar radiation or a bamboo frame covered from all the four side with some opaque material. The drying material (rice etc.) is kept on the nylon net tray in thin layer through which hot air heated from air heaters enters its bottom and goes up into the chimney. The chimney is a long cylinder made of bamboo frame covered with black PVC to keep the inside air warm. There is a cap at the top of the chimney, leaving some space in between chimney top and cap to allow warm humid air to go out and protecting the product from rain and other foreign materials. The height of the chimney and the hot air inside it creates a pressure difference between its top and bottom thereby creating forced movement of air through the rice bed to the top of the chimney. The drying rate will depend on the depth of the bed, initial moisture content of the material, solar insolation, ambient temperature, and the design of the dryer. Solar cabinet dryers possesses some problems regarding slower drying rates, no control on temperature and humidity and change in sensory characteristics of the product.

**2. Deep bed dryers**

These dryers have large capacities upto several hundred tonnes and generally round or rectangular in shape. The air flow rate are generally kept in the range of 2.94 to 3.92 $m^3$/min. If the moisture content of grain is upto 18%, the layer depth of grain should be limited to 3m. For grain whose moisture content is above 18%, the maximum depth is recommended 2.5m.

Paddy with 2.5m deep layer may take 20 days to dry during favourable weather and up to 40 days during bed weather. In tropics area these dryer are not very successful. The net perforated area of the floor should be 15% of the total floor area. Air velocity of 300m/min through the opening is preferable.




### 3. Flat bed dryers

These are similar to the deep bed dryer except that the surface area of dryer is more and the depth of the drying layer is less. These dryers are usually designed for farm level operation. Grains are spread 0.6 to 1.2m deep over the perforated floor and dried. The grains are dried at faster rate, therefore the chances of spoilage is very less. Less possibility of over drying of grain is possible. Lower air pressure of air is required.

### 4. Continuous flow dryers

These dryers are columnar type in which wet grains flow from the top to the bottom of the dryer. The rate of flow of grains through the columns can be regulated by the conveyers. Drying is accomplished by forcing heated air across the falling layers of grains. These dryers can be grouped in to two types –

**(i) Non – mixing type dryer**

If the grain flow in a straight path, the dryer is called a mixing is called non-mixing type. In these dryers, baffles are not provided in the column and drying takes place between two parallel screens, 15-25 cm apart. In these dryers, high air flow rates of 125-250m$^3$/min-tonne can be used. It permits a faster movement of grains in columns. Generally, drying air temperature of 54°C is used in non-mixing dryers.

**(ii) Mixing type dryer-**

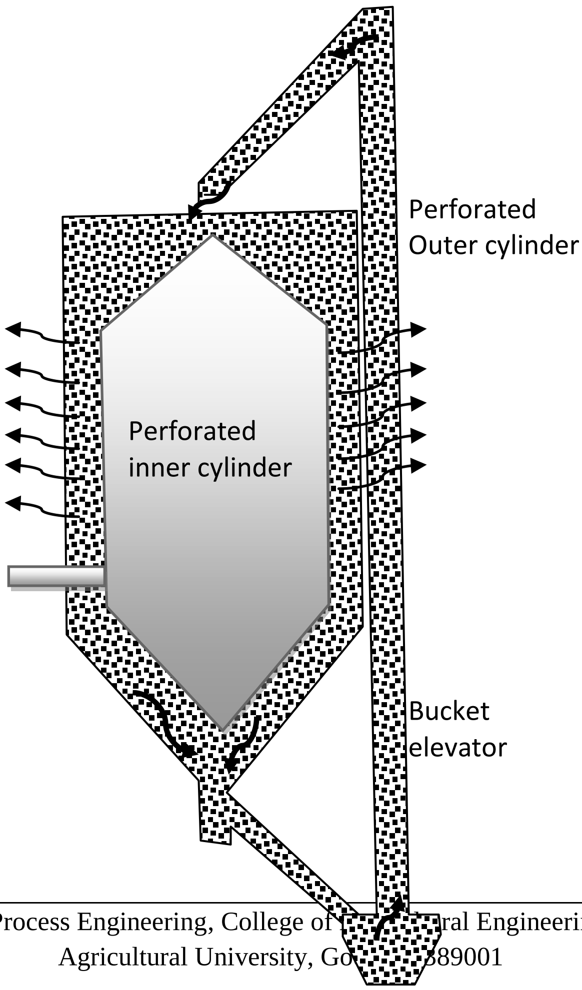
When the grains are divided in the dryer, it is called mixing type dryer. In these dryers, baffles are provided to cause the

(iii) a

**Recirculatory Batch Dryer (PHTC type)**

This is a continuous flow non mixing type of grain dryer. Construction The dryer consists of two concentric circular cylinders made of perforated (2mm dia) mild steel sheet of 20 gauge. The two cylinders are set 15 to 20cm apart. These two cylinders are supported on four channel sections. The whole frame can be supported by a suitable foundation or may be bolted to a frame made of channel section. A bucket elevator of suitable capacity is used to feed and recirculate the grain into the dryer. A centrifugal blower blows the hot air into the inner cylinder which acts as a plenum. The hot air from the plenum passes through the grain moving downward by gravity and comes out of the outer perforated cylinder. A torch burner is employed to supply the necessary heat with kerosene oil as fuel. The designs of PHTC dryer for ½ , 1 and 2 tonnes holding capacity are available. The PHTC dryer of 2 tonnes holding capacity developed at PHTC, IIT, Kharagpur, India.

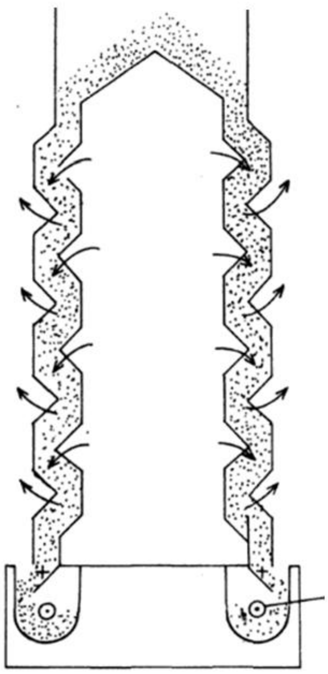
The grain is fed to the top of the inside cylinder. While descending through the annular space from the feed end to the discharge end by gravity, the grain comes in contact with a cross flow of hot air. The exhaust air comes out through the perforations of the outer cylinder and the grain is discharged through the outlet of the hopper. The feed rate of grain is controlled by closing or opening the gate provided with the outer pipe of the discharge hopper. The grain is recirculated till it is dried to the desired moisture level.



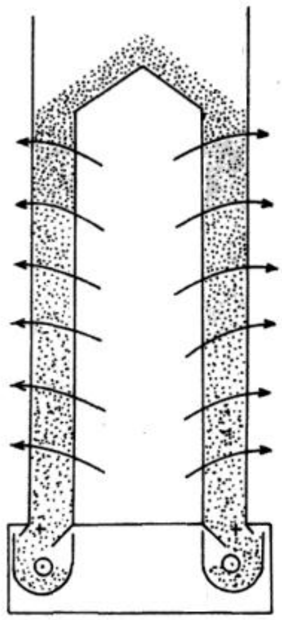
Continuous flow dryers : These dryers are columnar type in which wet grains flow from the top to the bottom of the dryers. The rate of flow of grains through columns can be regulated by conveyors. These dryers are of two types,

(1) mixing, and (2) non-mixing. If the grains flow in a straight path, the dryer is called a non-mixing type, and wh"n the grains are diverted in the dryer, it is called a mixing type dryer. Drying is ?_C0" ^'used by forcing heated air across the falling layers of grains.

In mixing dryers, baffles are provided to cause the grains to mix during their downward flow. These dryers use low air flow rates of 50-95 mVmin-tonne and high drying temperature of 65°C. Zig-Zag columns enclosed by screens on both sides are used primarily to achieve mixing action during drying process. In non-mixing dryers, baffles are not provided in the columns and drying takes place between two parallel screens, 15-25 cm apart. In these dryers high air flow rates of 125-250 mVmin-tonne can be used. It permits a faster movement of grains in columns. Drying air temperature of 54°C is used in non-mixing dryers.



Mixing type dryer



Non mixing type dryer

**Louisiana State University Dryer**

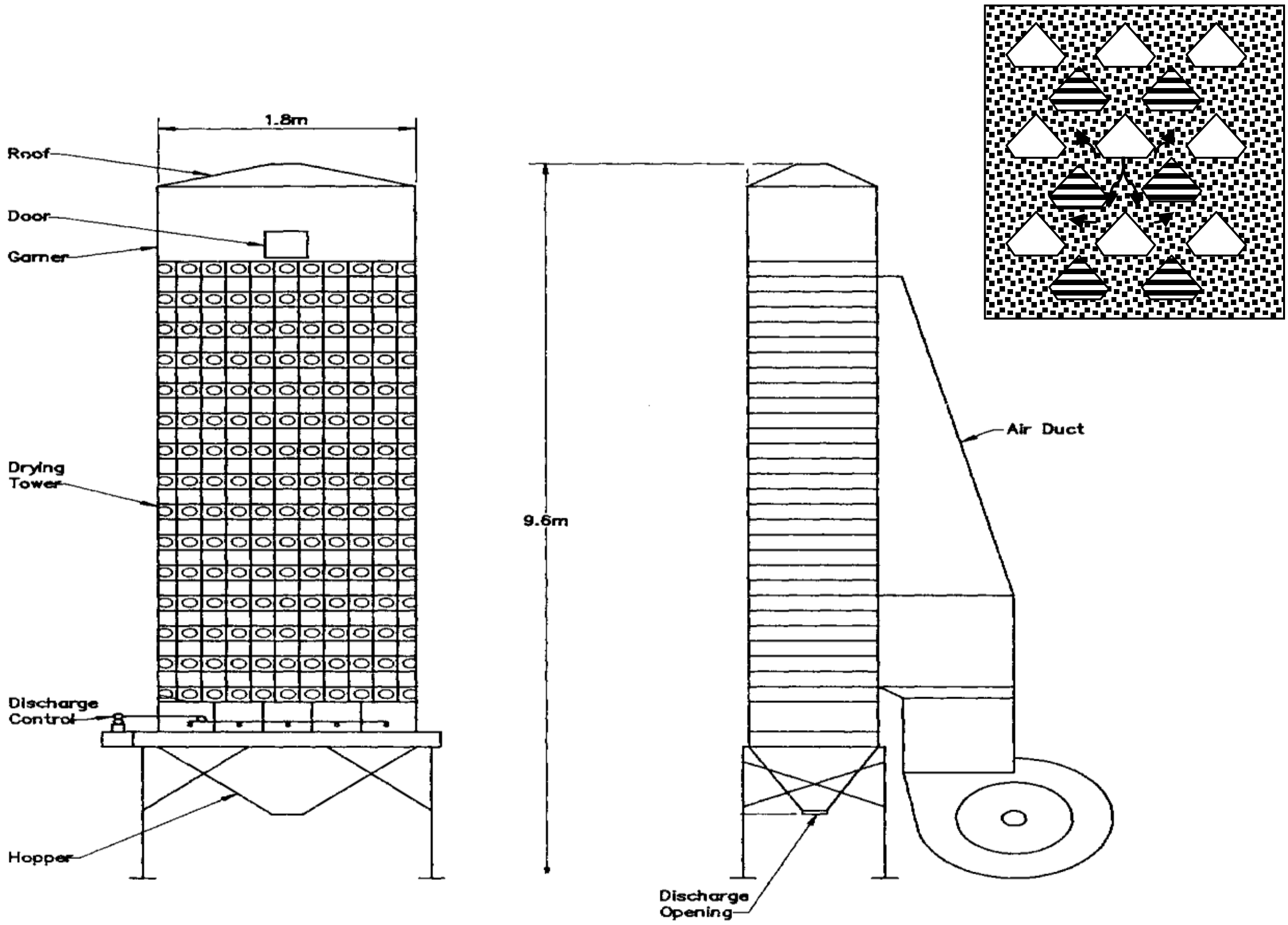
This is a continuous flow-mixing type of grain dryer which is popular in India and the U.S.A. Construction It consists of 1) a rectangular drying chamber fitted with air ports and the holding bin, 2) an air blower with duct, 3) grain discharging mechanism with a hopper bottom, and 4) an air heating system.

1) Rectangular bin: Usually the following top square sections of the bin are used for the design of LSU dryer. i) 1.2m x 1.2m, ii) 1.5m x 1.5m, iii) 1.8m x 1.8m and iv) 2.1m x 2.1m the rectangular bin can be divided into two sections, namely top holding bin and bottom drying chamber.

2) Air distribution system: Layers of inverted V-shaped channels (called inverted Vports) are installed in the drying chamber. Heated air is introduced at many points through the descending grain bulk through these channels. One end of each air channel has an opening and the other end is sealed. Alternate layers are air inlet and air outlet channels. In the inlet layers, the channel openings face the air inlet plenum chamber but they are sealed at the opposite wall, where as in the outlet layers, the channel openings face the exhaust but are sealed other side. The inlet and outlet ports are arranged one below the other in an offset pattern. Thus air is forced through the descending grain while moving from the feed end to the discharge end. The inlet ports consists of a few full size ports and two half size ports at two sides. All these ports of same size are arranged in equal spacing between them. The number of ports containing a dryer varies widely depending on the size of the dryer. Each layer is offset so that the top of the inverted V ports helps in splitting the stream of grain and flowing the grains between these ports taking a zigzag path. In most models, the heated air is supplied by a blower.

3) Grain discharging mechanism: Three or more ribbed rollers are provided at the bottom of the drying chamber which can be rotated at different low speeds for different discharge rates of grains. The grain is discharged through a hopper fixed at the bottom of the drying chamber. Causing some mixing of grain and air the discharge system at the base of the dryer also regulates the rate of fall of the grain.

4) Air heating system: The air is heated by burning gaseous fuels such as natural gas, butane gas, etc, or liquid fuels such as kerosene, furnace oil, fuel oil etc, or solid fuels like coal, husk, etc. Heat can be supplied directly by the use of gas burner or oil burner or husk fired furnace and indirectly by the use of heat exchangers. Indirect heating is always less efficient than direct firing system. However, oil fired burner or gas burners should be immediately replaced by husk fired furnace for economy of grain drying. The heated air is introduced at many points in the drier so as to be distributed uniformly through the inlet ports and the descending grain bulk. It escapes through the outlet ports. This type of dryer is sometimes equipped with a special fan to blow ambient air from the bottom cooling section in which the dried or partially dried warm grain comes in contact with the ambient air. In general, the capacity of the dryer varies from 2 to 12tonnes of grain, but sometimes dryers of higher capacities are also installed. Accordingly power requirement varies widely. Recommended air flow rate is 60-70 m3 /min/tonne of parboiled paddy and optimum air temperatures are 60°C and 85°C for raw and parboiled paddy respectively. A series of dryers can also be installed.

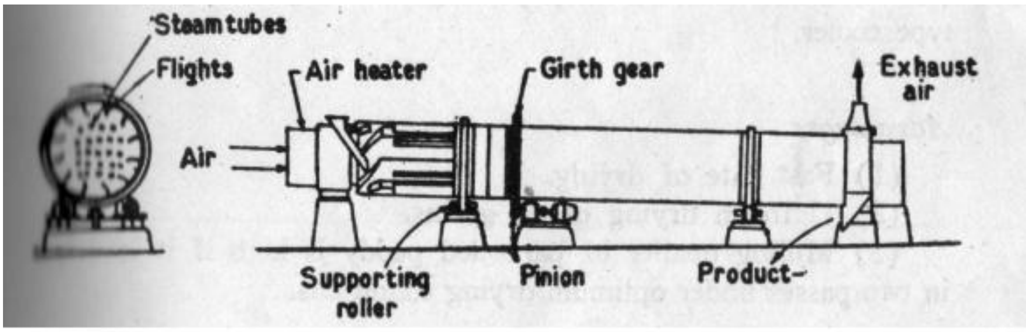



LSU Dryer

Rotary Dryer This is continuous dryer (Fig) as it produces the final dried product continuously.

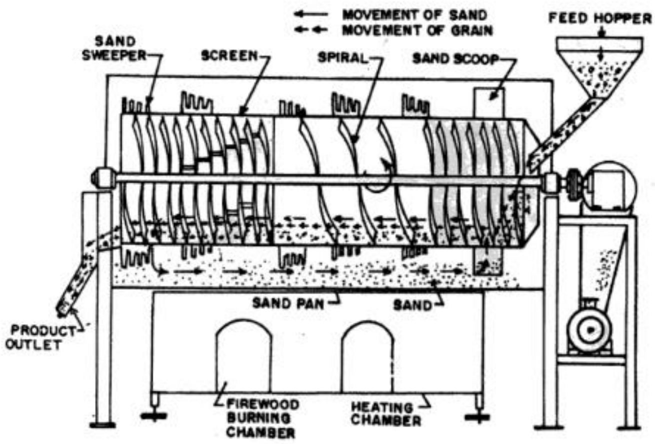
Horizontal rotary dryers of various designs have been developed by different countries for the drying of parboiled paddy. Some of them are fitted with external steam jacket and internal steam tubes as well. As parboiled paddy can stand high temperature without significant increase of cracks in grains, these dryers can be employed for rapid drying of parboiled paddy using temperatures as high as 100 to 1100C. In India, the Jadavpur University, Calcutta introduced a rotary dryer of 1 tonne/hr capacity for the drying of parboiled paddy. The construction and operation of the same dryer are described as follows.

Construction It consists of a cylindrical shell 9.15m long and 1.22m in diameter, with 48 pairs of 5 cm and 3.75cm size steam pipes in two concentric rows inside the shell in combination with common steam inlet and condensate outlet fittings. The shell is equipped with six longitudinal flights of 9.15m long and 15.24cm wide for lifting and forward movement of the parboiled paddy towards the discharge end while it is being dried. Over the feed end breeching box there are feed hopper and screw conveyor with an adjustable sliding gate. The dryer is equipped with an air blower and a small steam tube heat exchanger for supplying heated air at the entrance of the feed end breeching box. The cylindrical shell of the dryer is rotated at 2 to 6 rpm by a motor through speed reduction gear, pulley and belt drive system. Operation The soaked and steamed paddy is fed to the dryer by the screw feeder. Heated air at about 800C is blown (from the feed end) through the dryer in the same direction as the paddy moves and exhausted through the exhaust pipe. Heated air acts here mainly as a carrier of moisture from the dryer. While traveling from the feed end to the discharge end of the dryer the parboiled paddy comes in contact with the steam heated pipes for a very short time in each rotation and is gradually dried to about 16 per cent moisture content in a single pass. Therefore, drying is accomplished mainly by the conduction of heat from the steam pipe to the grain. The traveling time of the grain in the dryer is adjusted to 30 to 45 min by adjusting inclination and rpm of the dryer. The hot paddy discharged from the dryer is then aerated by passing it through a cup and cone type cooler.

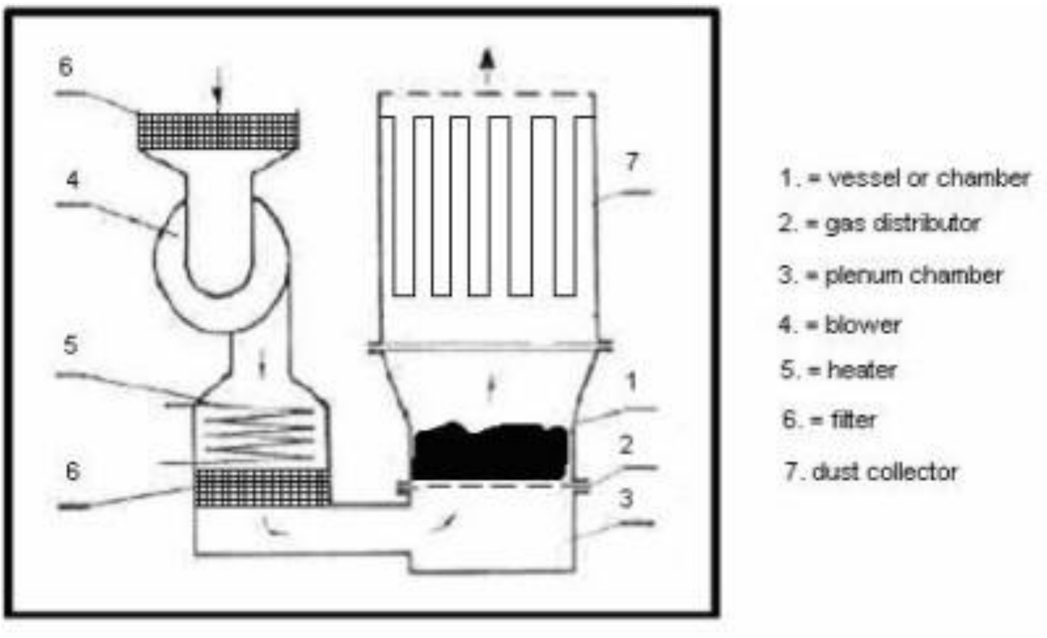



Rotary dryer : In commercial rotary dryers the diameter of drum is between 1 to 3 m and the length is from 3 to 6 m. It is operated at slight inclination. The drum rotates on its axis. The grain flows downward through the rotating drum and is periodically lifted by inclined flights, then dropped, ensuring good air/ grain con tact. However, in commercial practice the main method of drying is convective

heating by drying air whereas, in the small scale designs heating is by conduction through the walls of the drum. In small scale rotary dryers, the walls are heated by direct contact with the flue gases of a combustor, preferably biomass fired. In Tamil Nadu Agricultural University a continuous type rotary dryer has been developed. The grains are dried by direct contact with heated sand (Fig. 3.35). The dryer is used for drying of parboiled paddy as well as for dry roasting of Bengalgram and other grains.


MOVEMENT OF SAND
MOVEMENT OF GRAIN
FEED HOPPER
SAND SWEEPER
SCREEN
SPIRAL
SAND SCOOP
PRODUCT OUTLET
SAND PAN
SAND
FIREWOOD BURNING CHAMBER
HEATING CHAMBER

Fluidised bed dryers : The fluidised bed drying technique holds an important posi tion among modern drying methods. It is used mainly for granular materials, nevertheless, it is also applicable in the drying of solutions, pastes and liquids sprayed onto the fluidised inert bed. The principle of operation of fluidised bed dryer is to provide sufficient air pressure to fluidise a thin bed of grain/ product, giving excellent air/ grain contact. Above a certain pressure, related to the weight t>er unit area of the grain bed, the pressure drop across the bed becomes constant 'ith volume flow rate, so that fast drying can occur. The main advantages of 'idised bed drying are; 1. Fluidity of bed facilitates continuous and easy equipment performance even on very large scale plants. Lack of moving parts. Very good condition for heat and mass transfer, rovides good mixing i.e. uniformity of drying of the material in the bed. combining high air temperatures and suitable grain tempering, the lised bed offers better economy, gentle grain handling and reduced \g times.




Tray dryer : In a tray dryer, many shallow trays are kept one above the other with a gap in between, in the drying chamber. Tray dryer is generally used for drying of vegetables and similar semiperishables. The trays may or may not have perfo rated bottom. Perforated trays are used when the plenum chamber is at the bottom of drying chamber (Fig. 3.36). If the heated air is coming from the sides of drying chamber, the trays may not have perforated bottom. The gap in between the group of trays permits air ventilation. Products are kept in thin layers in the trays.

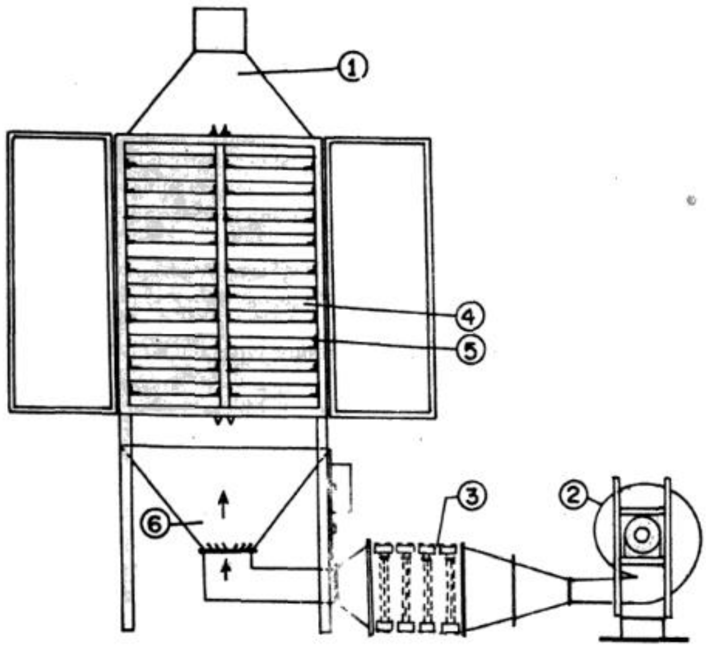



**Fig. 3.36 :** Diagra.n of a tray dryer
1. exit air 2. blower 3. heater 4. inter space between trays
5. trays 6. plenum chamber

Tunnel dryer : It is similar to tray dryer. When the group of trays is stationary, the system is called a tray dryer but when the group of trays is moving in a tunnel, the system becomes a tunnel dryer (Fig. 3.37). The flow of heated air in a tunnel dryer may be concurrent or counter current.

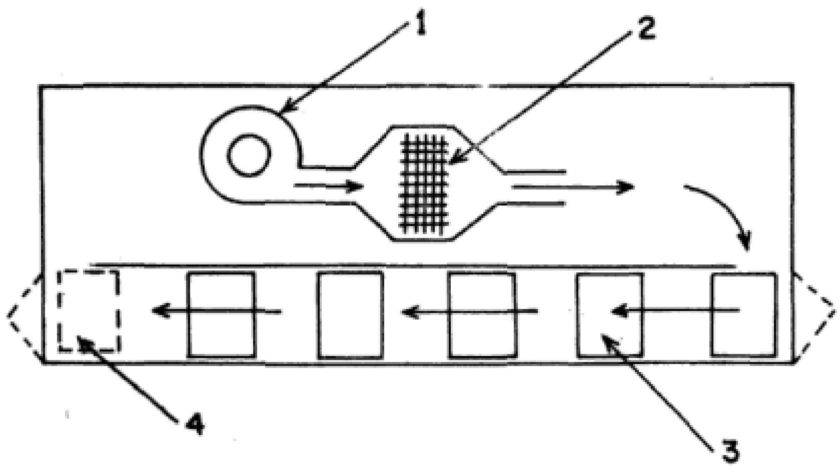
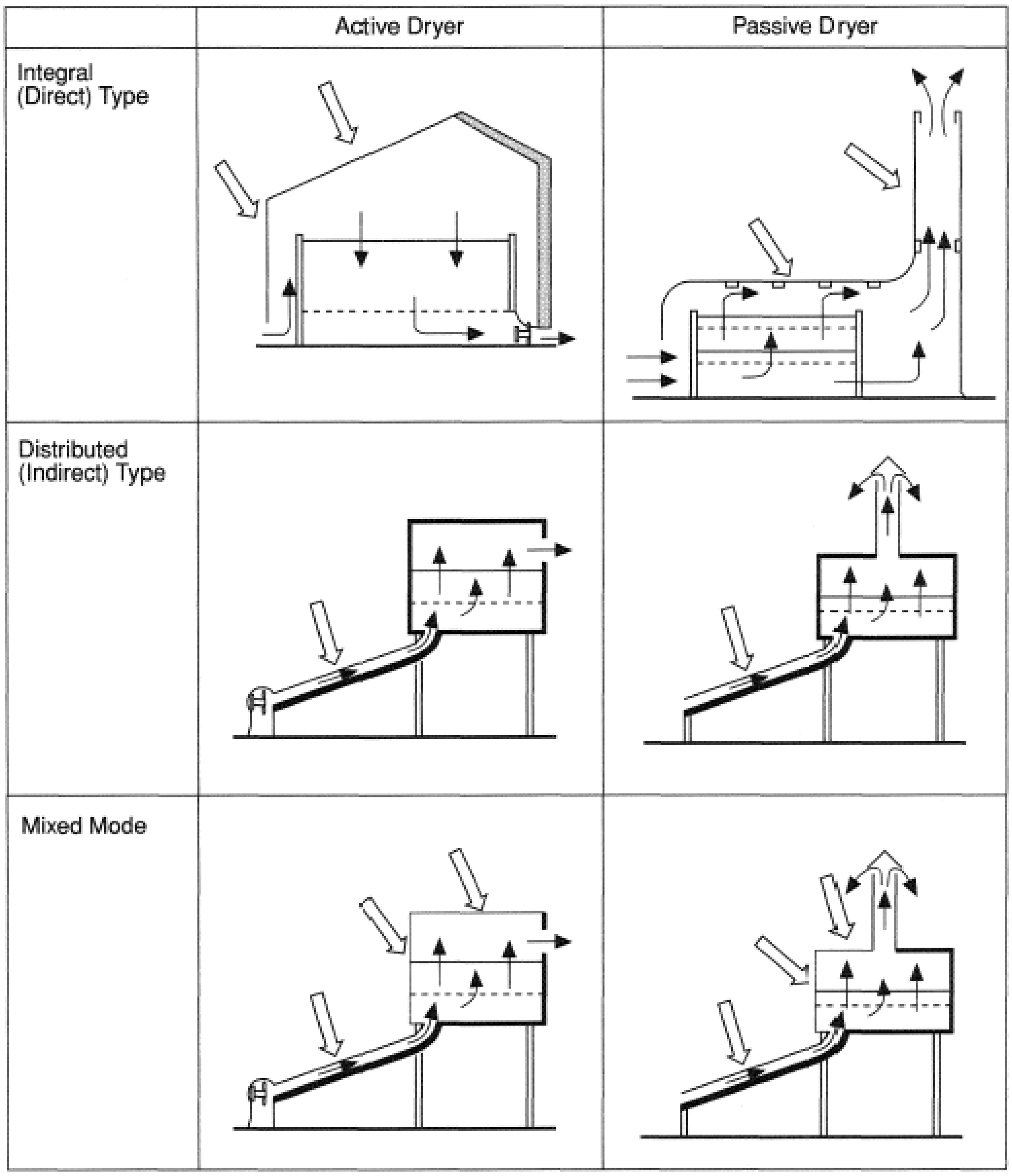



**Fig. 3.37 :** Schematic diagram of funnel dryer
1. blower 2. heater 3. trays 4. exit air chimney

Solar dryers : Solar drying of agricultural products can be advantageous alternative to sun drying for the farmers of developing nations. It can be a means of supple menting or replacing artificial dryers with consequential savings in fuels and costs. Solar drying provides higher air temperatures and lower relative humidities than simple sun drying. It enhances the drying rates and lower final moisture content of dried products. As a result the risk of spoilage is reduced, both during the actual drying process and in subsequent storage. In many cases, solar drying can be feasible alternative wholy or partially to artificial drying. In solar drying system, a source of motive power is required for some types but considerable saving in energy costs is possible.

Two basic principles are inherent in the operation of solar dryers, firstly the solar heating of air, and secondly the removal of moisture from the wet material by the heated air. Classification of solar dryers can be made on the following criteria; 1. The degree of exposure of the crop to insolation. Based on degree of expo sure the solar dryers are further classified as direct and indirect types.. 2. The mode of air flow through the dryer. Based on this criteria, the solar dryers' are further classified as natural and forced convection dryers. 3. The temperature of the air circulated to the drying chamber. On the above criteria, the commonly used solar dryers can be grouped as below: 1. Direct dryer with natural convection and with combined collector and drying chamber. 2. Direct dryer with natural convection and with separate collector and drying chamber. 3. Indirect dryer with forced convection and with separate collector and drying chamber.


Active Dryer
Passive Dryer
Integral (Direct) Type
Distributed (Indirect) Type
Mixed Mode

# Practical No. 9

**Objective:** To study the effect of relative humidity and temperature on grains stored in gunny bags

**Theory:**

All cereals, when exposed to air with high RH, will absorb water from the air. When wet cereals are exposed to air with low RH, the kernels will release water to the air. The equilibrium moisture content is the final moisture content of the grain after being stored for some time with surrounding air of a certain temperature and RH. If the grain is not protected against the humidity in the air, particularly during the rainy season when the RH is very high, the grain moisture content will increase and this will lead to intrinsic and extrinsic grain deterioration and loss of quality. If the grain is stored in an enclosed storage environment, such as a bag or silo, the air surrounding the grain, if it is well sealed, is not in free contact with outside air. In this case, the RH of the enclosed air will reach equilibrium with the moisture content in the grain. The final RH of the enclosed air is often expressed as the "equilibrium RH." The higher the grain moisture content of the stored grain, the higher the equilibrium RH, and the higher the chances of insect and mold development or loss of grain viability. Normally, an equilibrium RH inside the facilities of 65% or less is considered a safe prevention against the development of molds. The isotherm curve relates grain moisture and air RH at a given temperature (usually 20°C or 25°C) because grains absorb or desorb water according to the surrounding air RH.

**Determination of a cereal Isotherm curve**

Material required: Cereal grains, Dessicant (activated alumina), Distilled water, Set of salts, Airtight dessicators, Thermometer, Graduated cylinder, Hygrometer, Analytical scale, Plastic bags, Environmental chamber/ incubators • Glass bottles for tempering

**Relationship between Type of Saturated Salt and Air RH at 25°C**

| Salt | RH (%) at 25°C |
|---|---|
| Lithium chloride | 11 |
| Magnesium chloride | 33 |
| Potassium carbonate | 43 |
| Sodium bromide | 57 |
| Cupric chlorate | 67 |
| Sodium chloride | 75 |
| Ammonium sulfate | 79 |
| Potassium chloride | 86 |
| Potassium chromate | 87 |
| Sodium benzoate | 88 |
| Potassium sulfate | 97 |

**Method**

Remove dockage or foreign material from the grain. Split the sample into two equal lots. Determine the original grain moisture content. Temper one lot of grain to 25% moisture to conduct the desorption study. Calculate the tempering water requirement using the following equation:

Tempering water = $\{[(100 - \%\ \text{original moisture})/ (100 - 25\%)] - 1\} \times$ sample weight

Place the grain sample in a closed tempering container, add the predetermined tempering water and agitate contents for approximately 5 minutes until all the water has been absorbed by the grain. After a 5-minute rest, re-agitate contents for an additional minute. To avoid moisture loss and enhance equilibration, place the conditioned grain inside a sealed plastic bag. Dry the other lot of grain at 68°C for at least 8 hours in an air-forced convection oven to conduct the absorption study. Immediately place the dry grain in a dessicator to avoid environmental moisture uptake. Identify aluminium tins for desorption and absorption studies. Then, place containers in a convection oven set at 100°C for at least 30 minutes. Take containers out of the oven and immediately place them in an airtight dessicator for 30 minutes of cooling. Select, prepare, and place at least six different saturated salts that yield different relative humidities. Place each on the bottom of previously identified dessicators. Make sure to quickly close the dessicator to enhance the fast saturation of the internal atmosphere. Place dessicators with the saturated salt in an environmental chamber set at 25°C. Check the internal RH of each dessicator with a previously calibrated hygrometer. In an analytical balance, weigh 5 g with an accuracy of 0.001 g of dry or conditioned grains placed in tared aluminum tins. Place duplicate samples of dry and conditioned grain in each of the desiccators that were previously placed in the environmental chamber set at 25°C. Weigh samples every week until the grain achieves constant weight (constant weight is considered when the difference between two consecutive measurements is less than 0.5% of the original sample weight). Following observation may be noted to observe the effect of temperature and relative humidity.

| Week | Sample No. | Thousand kernel mass, g | Dry matter loss during storage | Odour | Insect counts | Presence of molds |
|---|---|---|---|---|---|---|
| 01 | $S_1$ | | | | | |
| | $S_2$ | | | | | |
| | $S_3$ | | | | | |
| 02 | $S_1$ | | | | | |
| | $S_2$ | | | | | |
| | $S_3$ | | | | | |
| 03 | $S_1$ | | | | | |
| | $S_2$ | | | | | |
| | $S_3$ | | | | | |
| 04 | $S_1$ | | | | | |
| | $S_2$ | | | | | |
| | $S_3$ | | | | | |

**Result:** It can be observed that the sample stored at ________ relative humidity deteriorated faster in comparison to __________ relative humidity conditions.

# Practical No. 10

**Objective:** Design and layout of commercial bag storage facilities

**Theory:**

A warehouse is built for the storage and physical protection of goods or bagged grain. It may also include materials and equipment required for the packaging and handling of bagged grain, and chemicals to control storage pests. Factors such as topography, soil characteristics, accessibility, orientation and proximity to human dwellings should be considered when locating the warehouse.

When determining the dimensions of the warehouse, the following information is important:

- the specific volume of the principal product to be stored ($m^3$/tonne)
- the maximum tonnage of the product to be stored
- the maximum stack height desired
- the extent to which separation of lots is desired.

Some grain can be conditioned to improve its quality. One way to do this is to pass the grain over an inclined sieve (commonly used for sorting coffee beans). This is operated by one or two people. A sack of grain is emptied onto the sieve. The grain is then moved across the sieve by hand so that broken grain and dust fall through it and collect in a container below the sieve. The grain retained by the sieve can be handpicked to remove discoloured, rotten and diseased grain. The grain is gradually pushed down the sieve into the sack that is suspended at the lower. Instead of using a manual system like this, mechanical grain cleaners are available that can clean up to 20 grain tonne/h. However, to remove discoloured, rotten and diseased grain would still require hand picking. This is laborious and so it is much better that farmers have selected out this grain on farm and that it is not accepted at the Collection Point.

Bagging grain (weighing, filling, stitching)

It will often be necessary to rebag grain. This may be when the customer wants grain put into their own bags showing their name or logo, following the conditioning of grain or during the replacement of torn bags. Grain can be emptied from the old bags into a simple hopper that empties into the new bag. The new bag with grain should be weighed to ensure that it conforms to the required weight. Add or remove grain so that the weight is correct. NEVER fill a bag beyond the weight for which it is designed, the bag may split.

Ideally the bags should be prepared as follows:

- Fill the bag with the correct weight of grain (to ±2kg of the nominal bag capacity)
- Fold the bag mouth inwards by 5 to 10 cm (this strengthens the bag by creating an extra layers to take the stitching and by forming a valve that deflects some of the pressure of the grain away from the stitching when the bag is built into a bag stack)
- Close the bag with about 16 stitches
- Knots should not be made at either end of the string, instead leave a 10 cm extension of the string loose at both ends. The bag can then be opened by making a small cut in the middle of the string and then pulling each piece out from either side. This causes less damage (especially to polypropylene bags) so that they have a longer life.

How and where to build bag stacks It is important that bag stacks are built on pallets, especially in stores where the floor does not include a damp proof membrane. If pallets are not available then bag stacks can be built on a plastic sheet or tarpaulin.

It is important to decide whereabouts in a store the bag stacks should be built. The important principles to remember are - The bag stack should be built at least 1m away from the walls of a store. This allows easy inspection, prevents moisture ingress from contact with the wall and facilitates fumigation treatments since a gas-tight sheet can be placed over all sides of the stack. There should be a gap of at least 1.5m between stacks, and 2m between stacks where this space is the main gangway leading to the doors. The bag stack should be built clear of any pillars, otherwise it will not be possible to place a fumigation sheet over the stack. The bag stack should not be built too high and not closer than 1.5m to the store roof beams so that staff can work on top of stacks. When using jute or sisal bags the bag stack can be built to around 18 to 20 layers, any higher then there is a risk to stability and it is difficult for storage workers. When using polypropylene or plastic bags the stack heights must be lower as they are less stable than jute or sisal. At about the 12th layer, the bags should be moved inwards by one bag width at each layer so that the sides will slope inwards like a pyramid. No bag stack should ever be higher than it is wide, otherwise it will be unstable.

It is important to ensure that stacks are positioned in stores to make good use of the storage space and to facilitate normal storage operations. There is inevitably plenty of activity at the front of the store so there should be some work space left there (Fig. 4.2) It is good practice to mark out the best positions for bag stacks on the floor of the store using paint.

To minimise cross-contamination (e.g. with non-food grade chemicals), insect crossinfestation etc., make sure that: stocks are placed in an orderly manner in a dry and clean store, using clean and repaired pallets grain is stored completely separately from other non-food goods and that materials such as pesticides, fertilizers, cleaning chemicals and cements are not placed in stores that are being used for food any damaged, rotten or spoiled grain should be segregated and stored separately (see Sub-Section 4.9) different commodities, different consignments (new and old) are placed in different stacks, i.e. separated in batches based also on the time of their reception in store, as far as the available space will allow.

Example

Design a flat or standard grain storage godown for storing 5000 tonnes of cereal grains. Draw a layout plan for such a godown giving approximately dimensions including inside stacks, compartment, alleys, etc.

Assuming capacity of a bag of 100 × 60 ×30 cm be 85 kg,

Then number of bags required = $(5000 \times 10^3)/85 = 58823.5 = 58850$ (say)

Assuming that there are 15 layers in stack-A placed in length and 10 bag in width,

Total number of bag = 10 × 10 × 15 = 1500.

Similarly, in stack-B be 15 layers with 10 bags in length, 15 bags in width,

Making total number of bags = 10 × 15 × 15 = 2250.

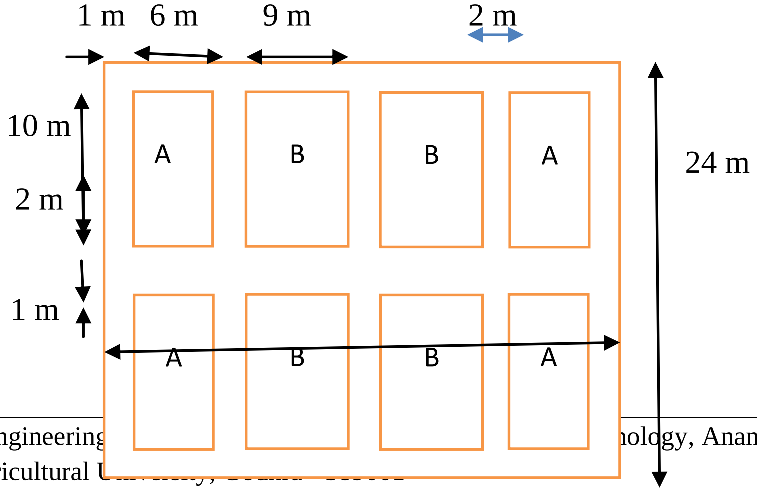
No. of bags per compartment of 4 stacks each of A and B = (4 × 1500) + (4 × 2250) = 15000 bags

Therefore, number of compartments = 58850/15000 = 3.92 ≈ 4 (say)

Layout plan for one compartment (38 × 24 m) is shown in the following figure. Four such compartment could be erected in series/parallel depending upon the land availability.

A, L = 1 ×10 = 10 m
W = 0.6 ×10 = 6 m
h = 0.3 × 15 = 2.5 m

B, L = 1 × 10 = 10 m
W = 0.6 × 15 = 9 m
h = 0.3 × 15 = 2.5 m



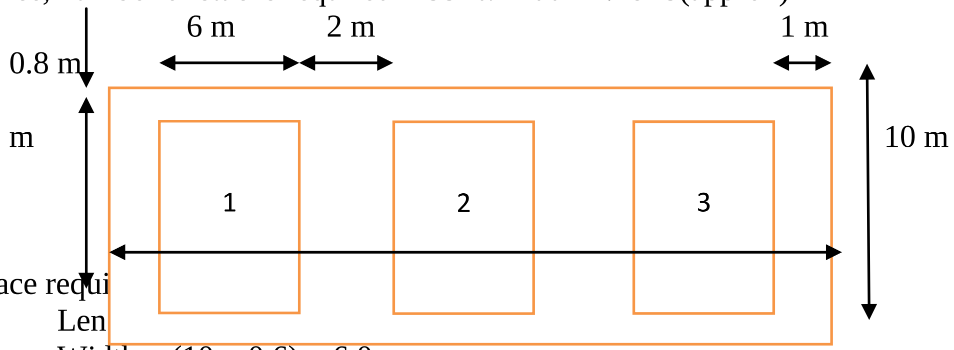
Each compartment should have rolling shutter door (1.83 × 2.45) on both the sides.
About 27% floor space for alleys be provided.
Floor should be made 1.2 m above the ground and rodent proof.
The clear height of 5.4 m should be provided with steel ventilators at top.

**Example**

Design a bag storage structure for storing 250 tonnes of paddy with a stack of 10 bags in length and 10 bags in width. Each bag is 85 cm long, 60 cm wide and 30 cm high. Give the complete floor plan of the structure (godown). Assume other reasonable data wherever necessary, but state them clearly.

**Solution**

Storage capacity required = 250t = 250, 000kg
Assume capacity of bag of 85 × 60 × 30 cm be 75 kg of paddy.
Hence, number of bags required = (250, 000/75) = 3340
Let, there be 10 bags in length and 10 bags in width in a stack. Then,
Number of bags per layer = 10 ×10 = 100
If there are 12 layers in a stack, total no. of bags/stack = 100 × 12=1200
Hence, number of stacks required = 3340/1200= 2.78=3(approx)




Space requi

Len

Width = (10 × 0.6) = 6.0m

Height = (12 × 0.3) = 3.6m

The clear distance between the walls and the end of stack = 0.8m
The clear distance between the stacks = 2.0m
Hence, the length of floor = (3 × 6.0) + (2 × 2.0) + (2 × 0.8) = 23.6m
And, width of floor = (8.5 × 1.0) + (2 × 0.8) = 10.1m
Therefore, the overall dimensions of the godown may be taken as 24 × 10m.
The height of the walls may be kept as 3.0 m above the floor level.

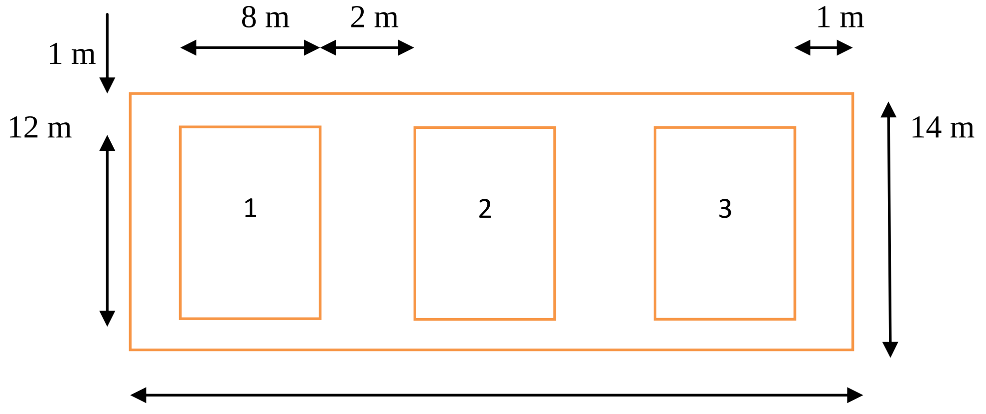
**Example**

300 tonnes of wheat is stored in the warehouse. Show the stacking arrangement of bags.

**Solution**

Capacity of warehouse = 300×1000 = 3, 00,000 kg
Assuming capacity of a bag of 100×60×30 cm be 100 kg, then
Number of bags = (3, 00,000)/100 = 3000
Calculation of number of stacks:
Let the every stack is having 10 bags in length and 10 bags in width and 10bags in height.
Number of bags in each stack = 10×10×10 = 1000bags
Number of stacks = 3000/1000 = 3
Size of stack:
Length = 10×1 = 10m = 12m (say)
Width = 10×0.60 = 6m = 8m (say)
Height = 10×0.30 = 3m = 5m (say)
The clear distance between the walls and the end of stack is 0.8m

The clear distance between the stacks is 2.0m
Length of floor in the warehouse = (3×8.0) + (2×2.0) + (2×0.80)
=29.6 m = 30 m (say)
Width of floor = (1×12) + (2×0.80) = 13.6m = 14 m (say)
Height of the ceiling from the floor may be kept as 5 m.
The floor plan of the warehouse is shown below.



# Practical No. 11

**Objective:** Design and layout of commercial bulk storage facilities

**Theory:**

**Soild-wall bins and silos for bulk storage**

Soild wall bins may be anything from a small plastered basket to large steel or concrete silos holding several thousand tons. The traditional bins used by the African farmers are small with capacity of up to 2-3 tonnes and include gourds, clay pots, mud plastered baskets raised off the ground and mud walled silos. Many of these have limitations, particularly in durability, protection against rodents and insects as well as moisture from ambient air. Solid wall bins or silos should only be used in areas where the produce can be dried sufficiently before storage. Several attempts have been made to improve on the traditional stores to make them more suitable for long term storage.

**Grain bin wall pressure**

The design of bulk storage for grain and oilseeds requires a compromise between the conflicting requirements of structural strength, economical construction and convenience in handling. Frequently bin wall pressure is calculated using Janssen's equation. Experimental determinations of bin wall pressures on models and actual bins have confirmed that Janssen's theory is only applicable to static or filling conditions. Sometimes, pressures are larger than calculated pressure while emptying.

**Janssen theory of static pressure**

Janssen's theory is widely accepted during filling (static) pressure in deep bins. It is very simple in application.

**Grain Pressure Theories**

The grain pressure in bins were first calculated as being a semi liquid of same density as the grains. The lateral pressure was first calculated using the hydrostatic formula.

Where, $P_l = wh$

$P_l$ = lateral pressure exerted by the grain on the bin wall, kg/m$^2$, w= density of grain, kg/m$^3$, h= depth of grain from the top of the bin surface, m

This formula has serious deficiencies because many structures buckled under the vertical load arising from the friction of the grain on the walls. The formula (1) was modified to incorporate a factor 'K ' known as Rankine's earth pressure coefficient. The Rinkine's formula is based on the following principle, the resistance to displacement by sliding along a given plane in a loose granular mass is equal to the normal pressure exerted between the parts of the mass on either side of the plane, multiplied by the specific constant. The formula (1) when multiplied by the factor 'K ' is known as Rankine's earth pressure coefficient.

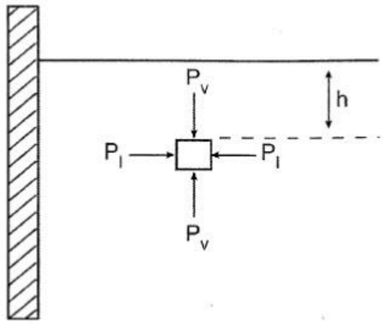
$$P_l = Kwh$$

$$K\ (Rankine's\ coefficient) = \frac{(1 - sin\emptyset)}{(1 + sin\emptyset)}$$

Where, φ = angle of internal friction of grain

$P_l = wh\ \frac{(1-sin\emptyset)}{(1+sin\emptyset)}$

The whole weight of the grain was assumed to be transferred to the bottom of the beam. The Rankine theory with horizontal soil surface behind a vertical wall is shown in Figure. Consider an element of soil at depth '**h**'. The vertical pressure acting on this element $\boldsymbol{P_v}$ and the horizontal pressure $\boldsymbol{P_l}$ is active pressure at failure.




$$P_l = \frac{(1 - sin\emptyset)}{(1 + sin\emptyset)} Pv$$

**Airy's equation**

The scientist Airy developed a theory for pressure induced by granular materials against retaining wall or in shallow bins. The lateral pressure exerted by grains in a shallow bin can be given by following Airy's equation

$$\boldsymbol{P_l = wh\left[\frac{1}{\sqrt{\mu(\mu+\mu'} + \sqrt{1+\mu^2}}\right]^2}$$

**Where,**

w = grain bulk density

h = depth of grain to point under consideration

μ = coefficient of friction of grain on grain

= tan Φ, Φ is angle of internal friction

μ' = tan Φ', Φ' is the angle of wall friction.

**Janssen equation**

The scientist Janssen took into account the friction between the grain and bin wall and, proposed the following formula for 'deep bins'.

$$P_l = \frac{wR}{\mu}\left(1 - e^{\frac{-k\mu h}{R}}\right)$$

Where,

***P<sub></sub>*** $\boldsymbol{P_l}$ = lateral pressure

**R** = hydraulic radius

**w** = grain bulk density (unit weight of grain)

**μ** = coefficient of friction of the grain on the wall

= tan Φ

$$K\ (Rankine's\ coefficient) = \frac{(1 - sin\emptyset)}{(1 + sin\emptyset)}$$

**h** = depth of grain

**Example**

A RCC cylindrical grain storage bin has ID of 5 m and is 20 m deep. It is completely filled with paddy weighing 600 kg/m$^3$. The angle of internal friction for paddy can take as 35° while the angle of friction between paddy and bin wall is 30°. The ratio of horizontal and vertical pressure intensity k is 0.4. Calculate the lateral pressure intensity at 2.0 m interval.

**Solution**

The lateral pressure can be measured by Jansen's equation,

$$P_1 = \frac{w\ R}{\mu}\left[1 - e^{\frac{-\mu k h}{R}}\right]$$

Given, Unit weight of paddy = w = 600 kg/m$^3$; R = D/4 = 5/4 = 1.25 m

Coefficient of friction between paddy and bin wall = μ = tan30° = 0.577

Ratio of horizontal and vertical pressure intensity = k = 0.4

Then,

$$P_1 \text{ at 2.0 m} = \frac{600 \times 1.25}{0.577}\left[1 - e^{\frac{-0.577\times0.4\times2.0}{1.25}}\right] = 401.6 \text{ kg/m}^2$$

$$P_1 \text{ at 4.0 m} = \frac{600\times1.25}{0.577}\left[1 - e^{\frac{-0.577\times0.4\times2.0}{1.25}}\right] = 679.8 \text{ kg/m}^2$$

Similarly, the lateral pressure at different depths can be obtained as given below:

| Depth, m | 6.0 | 8.0 | 10.0 | 12.0 | 14.0 | 16.0 | 18.0 | 20.0 |
|---|---|---|---|---|---|---|---|---|
| $P_1$, kg/m$^2$ | 870.8 | 1003 | 1094.4 | 1158 | 1202 | 1232.2 | 1253 | 1268.6 |

**Example**

The diameter of a circular grain silo is 2 m and its height is 6 m. it is filled with grain having density of 800 kg/m$^3$. It is then compacted to a density of 1000 kg/m$^3$. How much additional space will be created? The true density of grain is 1200 kg/m$^3$.

**Solution**

Volume of silo = ($\prod$/4) × $d^2$ h = (3.14/4) × 2 × 6 = 18.85 m$^3$
Initial weight of grain = 18.85 × 800 = 15080 kg
When compacted to a density of 1000 kg/m$^3$,
The volume is reduced to = 15080/1000 = 15.08 m$^3$
Hence, additional space to be created = 18.85 – 15.08
= 3.77 m$^3$

**Example**

Design a cylindrical hopper bottom steel bin for storing 100 tonnes of paddy at 15% moisture content (wb). Take bulk density of paddy as 750 kg/m$^3$.

**Solution**

Volume of paddy = $\frac{100 * 1000}{750}$ = 133.33 m$^3$

Assuming the depth of cylindrical portion of the hopper to be 2.5 times its diameter and angle of hopper is 45°. The hopper opening is kept 0.5 m.

The volume of bin = $(\frac{\pi}{4} \text{D} \times \text{D} \times 2.5D) + (\frac{\pi}{4} D \times \text{D} \times \frac{D}{2} \times \frac{1}{3}) - (\frac{\pi}{4} 0.5 \times 0.5 \times \frac{0.5}{2} \times \frac{1}{3})$

V = $\frac{16\pi DDD}{24} - 0.0164 = 133.33$ or, D = 4 m and h = 2.5 × 4 = 10 m

Dimeter of bin = 4 m
Height of bin = 10 m
Depth of hopper = 2 m
Hopper opening diameter = 0.5 m.

# Practical No. 12

**Objective: Study of different domestic storage structures**

In India, a large quantity of food grain is stored in villages, in different traditional storage structures and containers. It is estimated that sixty to seventy percent of food grain produced in the country is stored at home level in indigenous storage structures. The storage methods range from mud structures to modern bins. The containers are made from a variety of locally available materials differing in design, shape, size and functions. The materials used include paddy straw, wheat straw, wood, bamboo, reeds, mud, bricks, cow dung etc. Method of storing grains.

Following factors needs to be controlled to minimize the storage losses.

1. Moisture of the stored grain.
2. Temperature in the storage structure.
3. Insect and rodents population in and around storage structure.
4. Quality of the grain before storing the grain
5. Types of storage bin
6. Use of pesticides and fumigants
7. Mechanical loss factors
8. General conditions of location of storage.

There are different ways of storing the produce. 1) Indoor storage 2) Outdoor storage 3) Underground storage.

**Indoor storage of grains**

Kanaja is a grain storage container made out of bamboo. The base is usually round and has a wide opening at the top. The height varies. The Kanaja is plastered with mud and cow dung mixture to prevent spillage and pilferage of grains. The top is also plastered with mud and cow dung mixture or covered with paddy straw or gunny bags. Wooden boxes, also called as Sanduka, are used for storing pulses, seeds and smaller quantities of grains. These boxes have a storage capacity of three to twelve quintals. In some cases, partition is also made inside the box to store two to three types of grains. A big lid on the top with a small opening enables taking out the grains. To protect the grains from moisture, the box is kept 12 inches above the ground level with the help of stands/legs. The box has to be regularly polished for its maintenance. Kothi is used to store paddy and jowar. A room is constructed with a large door for pouring grains. A small outlet is made for taking out the grains. Earthen pots are indoor storage containers for storing small quantity of grains. These are made locally using burnt clay and are of different shapes and sizes. The earthen pots are placed at the floor level. They are arranged one above the other and known as dokal.

**Outdoor storage of grains:**

Bamboo structures are used for storing unthreshed and threshed paddy. Gummi is an outdoor structure used for storing grains. This structure is made with bamboo strips or locally available reeds. It is usually circular or hexagonal in shape and plastered with mud. The base on which the structure is constructed is also made up of reeds or in some cases with stone slabs. The roof of the structure is usually made from loose straw. The structure is placed on a raised platform. Kacheri is a traditional storage structure using paddy or wheat straw, woven as rope. It is made from either paddy straw alone or paddy straw mixed with mud.

**Underground storage of grains:**

Hagevu is an underground structure that is used to store grains. It is a simple pit lined with straw ropes to prevent damage from moisture. In some cases, hagevu is constructed as an indoor structure (with stones). After filling the structure fully, the paddy straw is spread on top as a thick layer and the structure is sealed with mud plaster. In some cases a small square or circular opening is provided at the top. The inlet opening is above the ground level. The advantage of this structure is that fumigation is not required for disinfestation. Grain can be stored for a longer period. This storage method is suitable for dry agro climatic zones. It is not suitable for storing seeds.

Bamboo structures made on a raised timber or stone platform protect grain from rat damage and prevent moisture absorption from the ground. Regular mud plastering is required for a variety of indoor and outdoor storage containers and structures for increasing their life span and ensuring safe storage of grains. The structures made of indigenous material like bamboo, straw and other plant material allow free flow of air. Indigenous storage structures are not suitable for storing grains for very long periods.

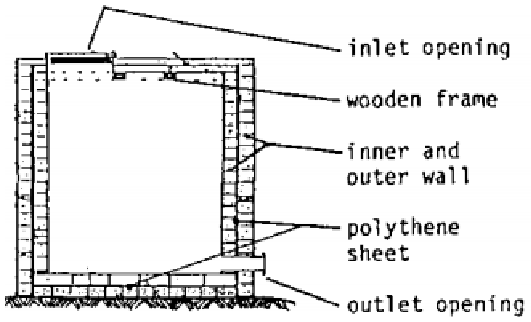
**Comparison of store types for safe storage of grain in smallholder households**

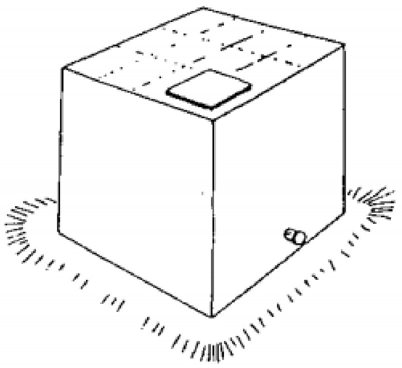
| Store type | Storage period | Pest Control | Weakness | Life span |
|---|---|---|---|---|
| Open weave sacks (Jute, sisal, polypropylene) | 6 months | If >3 months storage then admix insecticide<br>For cowpea an option is to use solarisation if this is not for seed | If used >6 months, grain quality declines more rapidly than in other store types | 3 years |
| Improved mud silos or traditional storage structures | 3-12 months | If >3 months storage then admix insecticide<br>For cowpea an option is to use solarisation if this is not for seed | Shorter life than metal silo, very heavy so can't be moved to new location, takes up fixed space in house whether empty of full | 5 years |
| Metal silos | 3-12 months | Make hermetic then use lighted candle or phosphine fumigation, or Admix insecticide | Extra sealing required to make hermetic, then no access for 2 weeks. | 15 years |
| Polythene bags (1 liner + sack) | 3-12 months | Solarisation if grain not for seed<br>Or Admix insecticide | Best for small quantities, susceptible to sharp objects and rodent attack. | 2 years |
| Metal/ plastic drums | 3-12 months | Hermetic seal kills pests | Drum to be nearly full and no access for first 6 weeks of storage. | 20 years |
| Triple bags (2 liners + 1 sack) | 3-12 months | Hermetic seal kills pests | Susceptible to sharp objects and rodent attack. No access for the first 6 weeks of storage. | 3 years |
| Super Grain bags (1 liner + sack) | 3-12 months | Hermetic seal kills pests | Susceptible to sharp objects and rodent attack. No access for the first 6 weeks of storage. | 2 years |

Some of the traditional indigenous storage structures are described below -

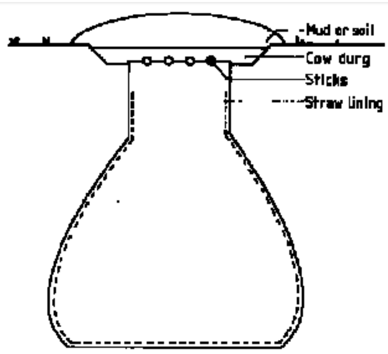
**The Pusa Bin:** It is developed by the Indian Agricultural Research Institute, New Delhi. These silos are made of earth or sun-dried bricks; they are rectangular in shape and have a capacity of 1 to 3 tonnes. A typical "Pusa" bin has a foundation of bricks, compacted earth, or stabilised earth. A polyethylene sheet is laid on this, followed by a concrete slab floor 10 cm thick. An internal wall of the desired height (usually 1.5 to 2 metres) is constructed of bricks or compacted earth, with a sheet of polyethylene wrapped around it. This sheet is heat-sealed to the basal sheet, and the external wall is then erected. During the construction of the wall an outlet pipe is built into its base. The concrete slab roof is supported by a wooden frame and, like the floor, is constructed of two layers separated by a polyethylene sheet. During its construction, a man-hole measuring 60 x 60 cm is built into one corner.

The "Pusa" bin" has been widely adopted in India. It gives good results when loaded with well dried grain.



**Underground Pits:** In India, underground pits are claimed to keep grain without damage for many years. The pits keep grain cool, and some of them are relatively airtight. Grain on top and around the sides can however often be mouldy. There are several types of pits, most of them flask shaped covered with sticks, cow dung and mud, or a large stone embedded in soft mud. The area should be free from termites and relatively dry. Improvements of the pit may include: • Better lining of straw and mats, • Plastic sheets and concrete or ferro-cement • Use of plastic bags in the pit • Improved covering • Surface drainage




**Domestic Hapur Bin:**

The Indian Grain Storage Institute, which is engaged in the development and dissemination of advances in storage technology to users, has developed metal bins for domestic storage of food grains. They are made of galvanised iron and/or aluminium sheets. The bins are available from 200 to 1000 kg capacity and cost Rs 350-1200 per bin.

**Coal Tar Drum Bin:**

This simple device has brought a major change in the storage system at farmer level. Farmers showed little resistance to this technology, mainly due to its low cost and easy availability. It was developed at the Central Institute of Agricultural Engineering (CIAE) and compares very well with other metal structures. Basically, it is a used or empty bitumen drum. After the road construction authority has used the coal tar, the drums are discarded as junk or are sometimes used for protecting roadside plantations. The drum is heated by open fire to remove any excess tar. A layer of tar remains inside, and serves as an insulator as well as a protective coating for the galvanised iron sheet. The local artisan can bring this drum to an attractive shape and can also fabricate a lid and a discharge chute.

# Practical No. 13

**Objective: Visits to commercial handling and storage facilities for grains**

## Details of the visit

| | | | |
|---|---|---|---|
| **1.** | **Date of the visit** | **:** | |
| **2.** | **Time** | **:** | |
| **3.** | **Location** | **:** | |
| **4.** | **Address** | **:** | |
| **5.** | **Phone numbers & email address, if any** | **:** | |
| **6.** | **Name of the contact person** | **:** | |
| **7.** | **Details of staff** | **:** | **Regular -**<br>**Contractual -** |
| **8.** | **Type of storage structures** | **:** | **Bag/bulk storage** |
| **9.** | **Number of storage structure** | **:** | **Shed/Silo** |
| **10.** | **Maximum capacity of the storage structure** | **:** | |
| **11.** | **Details of moisture proofing measures** | | |
| **12.** | **Details of rat proofing measures** | | |
| **13.** | **Details of aeration/ drying method used during storage** | **:** | |
| **14.** | **Name of various equipments used in the plant** | **:** | **1.**<br>**2.**<br>**3.**<br>**4.**<br>**5.**<br>**6.**<br>**7.**<br>**8.** |

| | | | |
|---|---|---|---|
| | | | **9.**<br>**10.** |
| **15.** | **Any other information not stated above** | **:** | |

## Summary of the visit