ADITYA ENGINEERING COLLEGE (A)

UNIT-IV

DRYING

Introduction

- Drying of agricultural products is an important unit operation under post harvest phase. It refers to removal of moisture from grains and other products to a predetermined level, whereas, dehydration means removal of moisture to very low levels usually to bone dry condition.
- Drying makes the food grains and other products suitable for safe storage and protects them against attack of insects, molds and other micro-organisms during storage.
- It has been found by several experiments that harvesting of crops at higher moisture content and subsequent drying to safe moisture levels leads towards saving of grains to about 6 to 7%.

Importance of drying

- Dehydration is the oldest method of food preservation practiced by man. For thousands of years he has dried and/or smoked meat, fish, fruits and vegetables, to sustain him during out of season periods in the year. Today the dehydration section of the food industry is large and extends to all countries of the globe.
- Drying facilities range from simple sun or hot air driers to high capacity, sophisticated spray drying or freeze drying installations. A very large range of dehydrated foods is available and makes a significant contribution to the convenience food market.
- The terms dehydration and drying are used interchangeably to describe the removal of most of the water, normally present in a foodstuff, by evaporation or sublimation, as a result of the application of heat.

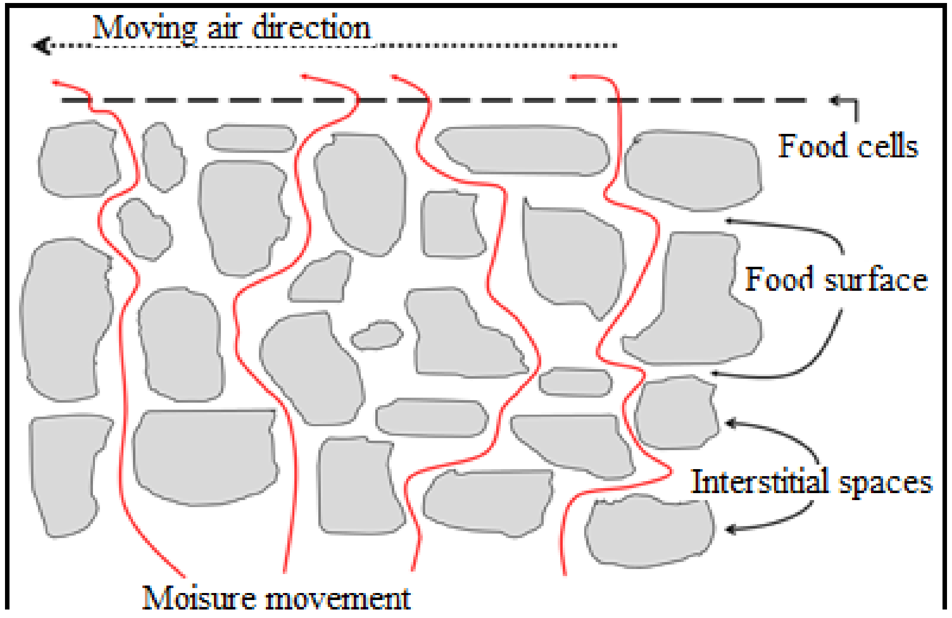
- The main reason for drying a food is to extend its shelf life beyond that of the fresh material, without the need for refrigerated transport and storage.
- This goal is achieved by reducing the available moisture or water activity *to a* level which inhibits the growth and development of spoilage and pathogenic microorganisms, reducing the activity of enzymes and the rate at which undesirable chemical changes occur.

- Appropriate packaging is necessary to maintain the low a_w *during storage and distribution*. Drying also reduces the weight of the food product. Shrinkage, which occurs often during drying, reduces the volume of the product.
- These changes in weight and volume can lead to substantial savings in transport and storage costs and in some cases, the costs of packaging. However, dehydration is an energy intensive process and the cost of supplying this energy can be relatively high, compared to other methods of preservation.

PRINCIPLE OF DRYING

- Drying is a convection process in which moisture from a product is removed.
- The moisture migration into or from a product is dependent on the difference of vapour pressure between atmosphere and product.
    - ❖ Capillary
    - ❖ Diffusion
    - ❖ Concentration difference

- Liquid diffusion : Liquid movement due to difference in moisture concentration
- Capillary flow : Ability of a liquid to flow in narrow spaces without the assistance, or even in opposition to, external forces like gravity. Liquid movement occurs due to surface forces
- Concentration difference : Movement of liquid is caused due to the concentration difference



Factors affecting drying process

- Temperature
- Relative humidity
- Wind speed
- Water vapour pressure difference

Moisture Content and its Measurement

- The moisture content of food grains and other agricultural products plays an important role in maintaining the desirable quality of the product.
- Changes in moisture content of a agricultural material occur during their harvesting, processing and marketing.
- The change in moisture content during successive post harvest stages is dependent upon the initial moisture content of product and atmospheric conditions.

Moisture Content and its Measurement

- The information of moisture content is necessary because it tells us whether the product is suitable for safe storage or for any other processing job.
- For some period, if the moisture content of food grains increases beyond a fixed critical value, under such conditions chances of metabolic reactions inside the grain become higher.
- Due to such reactions, viability of seed reduces.
- Drying of agricultural products become necessary at higher moisture contents.

Moisture Content representation

- The amount of moisture in a product is given on the basis of the weight of water present in the product and is usually expressed in percent.
- Moisture content is designated by two methods.

(1) Wet basis (wb)

(2) Dry basis (db)

- Wet basis: The moisture content in this method is represented by the following expression,

$$\text{Percent moisture content} = \frac{\text{weight of water in product}}{\text{weight of product sample}} \times 100$$

- Dry basis: The dry basis moisture content is determined by the following expression.

$$\text{Percent moisture content} = \frac{\text{weight of water in product}}{\text{weight of dry matter of product sample}} \times 100$$

Note: The value of dry basis moisture content is more than the wet basis moisture content.

- The relationship between dry basis and wet basis moisture content is given by the following expression.

$$\text{Moisture content (db), \%} = \frac{moisture\ content\ (wb)\ in\ decimals}{1 - moisture\ content\ (wb)\ in\ decimals} \times 100$$

Conversion equations:

$$M = \frac{m}{1-m} \quad \text{or} \quad m = \frac{M}{1+M}$$

$$m = \frac{m_w}{m_w + m_d} = \frac{m_w}{m_t}$$

$$M = \frac{m_w}{m_d}$$

where: m = decimal moisture content wet basis (wb)
M = decimal moisture content dry basis (db)
m_d = mass of dry matter in the product
m_w = mass of water in the product
m_t = total mass of the product, water plus dry matter

Problem : 500 kg of paddy at 22% moisture content (wb) is dried to 14% moisture content (wb) for milling. Calculate the amount of moisture removed in drying.

Solution:

1st method, using wet basis moisture content data

Amount of initial water content $= 0.22 \times 500$

$= 110\ kg$

Dry matter in paddy $= 500 - 110 = 390\ kg$

Final moisture content in 14% or 0.14

$$0.14 = \frac{\text{weight of water } (W_w)}{\text{weight of water + dry matter}} = \frac{W_w}{W_w + 390}$$

or

$$W_w = \frac{0.14 \times 390}{0.86}$$

$$= 63.488\ kg$$

Thus amount of water removed $= 110 - 63.49$

$= 46.51$ kg

2nd method, amount of water removed by analysis on dry basis, changing the initial and final moisture content to dry basis, initial mc (db) =

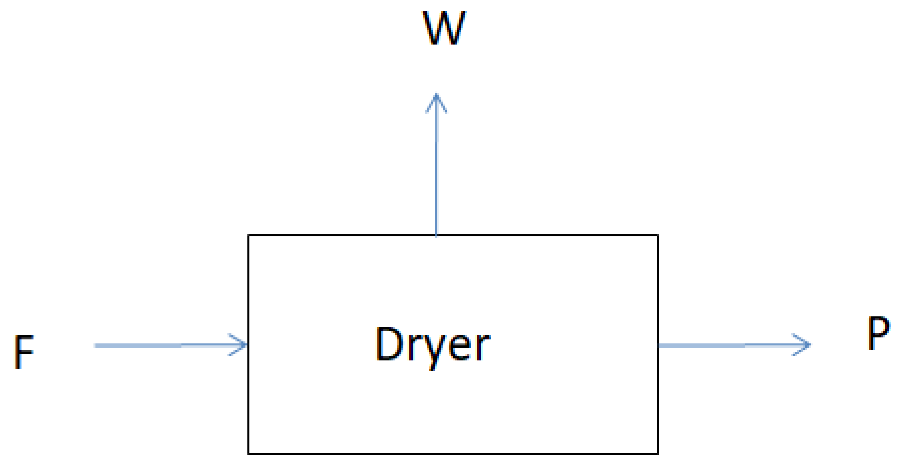
$$\frac{0.22}{1-0.22} \times 100 = 28.20\%$$

$$\text{final } mc\,(\text{db}) = \frac{0.14}{1-0.14} \times 100 = 16.27\%$$

Amount of water removed is equal to the product of initial dry matter and the difference in dry basis moisture content

$$390 \times \frac{28.20 - 16.27}{100} = 46.51\,kg$$

3^{rd} method, Mass and Material balance method



I) $F = W + P$

II) $F \times X_f = W \times X_w + P \times X_p$

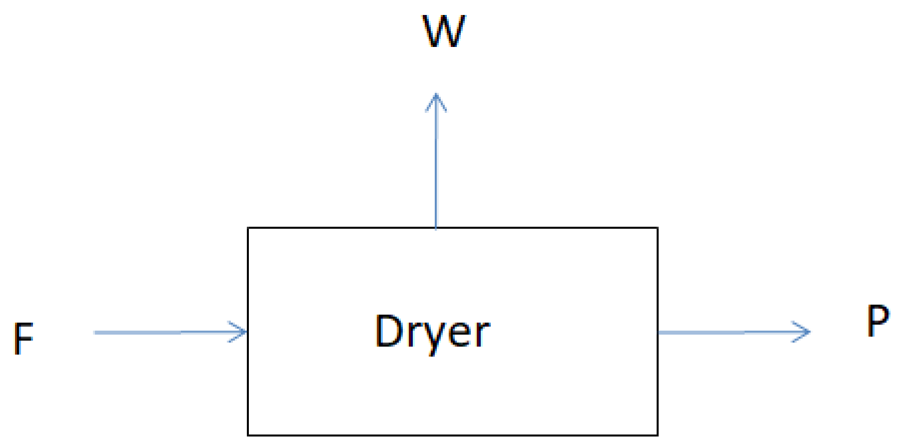
500= W+P, 500-P=W -------(1)

500*(1-0.22) = W*0 + P* (1-0.14) ------(2)

500*0.78 = 0+0.86P, 390 = 0.86P, P= 453.48kg

W= 500-453.48 = 46.52 kg

400 kg of wet pigeonpea at 23% moisture content (wb) is dried to 10% moisture content (wb) for milling. Calculate the amount of moisture evaporated in drying.



I) F= W+P

400 = W+ P

400-P = W -------(1)

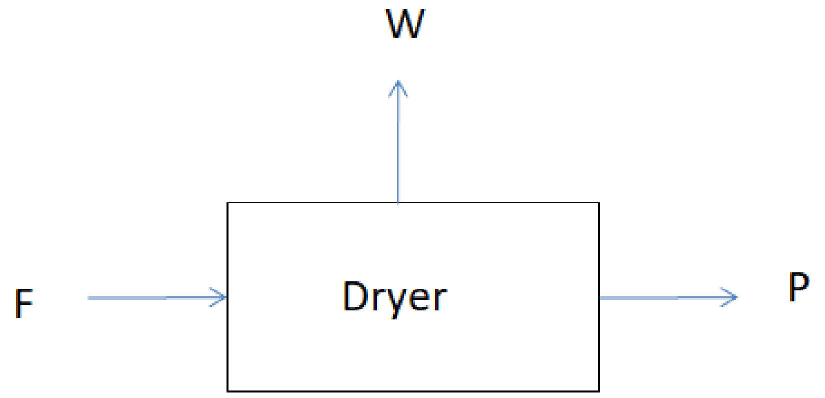
I) $F \times X_f = W \times X_w + P \times X_p$

400* (1-0.23) =W* (0) + P*(1-0.1)

P= 342.23 kg

W= 57.78 kg

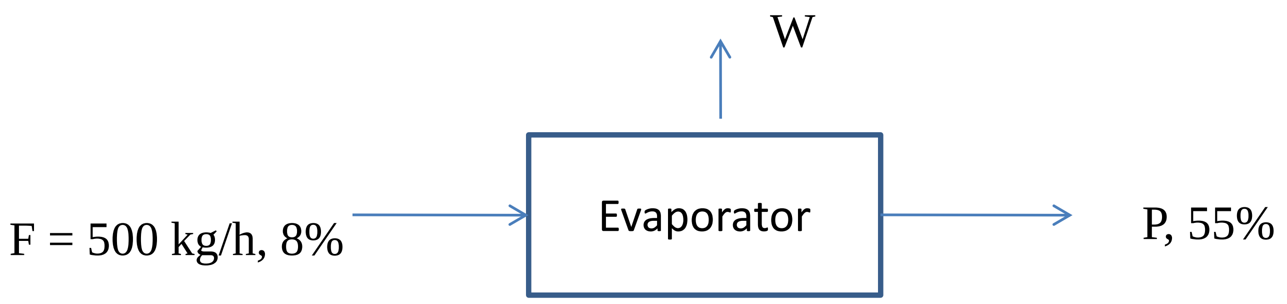
How much water is removed moist food of total mass 100 kg if the moisture content (wet weight basis) is reduced from 12.5% to 8%?



F = W+P
100-P=W ------(1)

100*(0.875) = W*0 + P*0.92
P = 95.1 kg
W= 4.9 kg

Fresh orange juice containing 8% solids is concentrated in an evaporator to 55% solids. If the juice is entering at 500 kg/h, then calculate the amount of water removed and the concentrated juice produced.



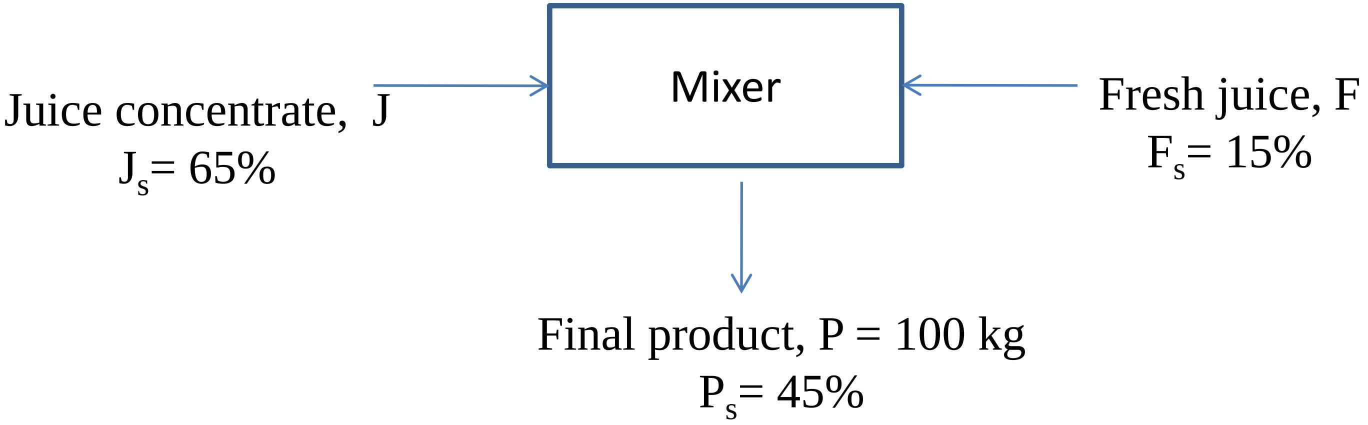
F= W+P ----(1)
P= 72.7 kg
W= 427.28 kg

F= W+P ----(1)
500-P = W

500*0.08 = W*0 + P*0.55
P= 72.7 kg

W= 427.27 kg

It is desired to mix the juice concentrate and fresh juice to maintain flavor in the product. Determine the quantity of juice containing 65% soluble solids and single strength juice containing 15% soluble solids that must be mixed to produce the 100 kg of a concentrated product having 45% soluble solids.



J+F= 100kg ----(1)

$0.65 \times J + 0.15 \times F = 0.45 \times 100$

0.65J + 0.15F = 45 ---- (2)

J = 60 kg   F= 40 kg

Moisture content determination methods

There are several methods for determination of Moisture content of agricultural products. For determination of Moisture content of a particular product, the choice of method depends on many factors, they are:

1) The form in which water is present in the product

2) The relative amount of water present

3) The rapidity of determination

4) Accuracy of method

5) Products nature whether easily oxidised or decomposed

6) The cost of equipment used.

Moisture content is determined only by two methods:

1) Direct or primary

2) Indirect or secondary

- The accuracy of moisture content determination by direct methods is high, hence these methods are used by research workers.
- The moisture content values obtained by direct methods are used to calibrate all the indirect type moisture measuring devices.

- The direct methods of moisture determination are time consuming therefore, such methods are not very much useful for determination of moisture in field, mandi or warehouses.
- Indirect methods are faster and mostly employ the electrical properties of grains.

Direct methods

Air oven method:

In this method the temperature of the oven is set at 130˚C and the samples are kept in oven for 1-2 hours. Afterwards, the samples are taken out and placed in a desiccator to cool down. The drop in the weight of grain is measured based on its initial weight.

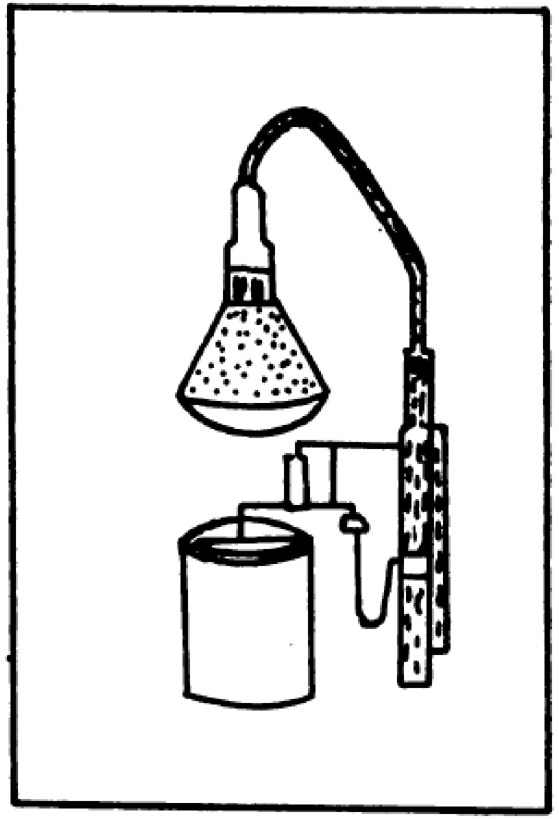
Vacuum-oven method:

In this method, 2-3 grams of representative sample of ground material is placed in vacuum-oven (25 mm vacuum) and dried at 100˚C for 72-96 hours. Afterwards, the samples are taken out and placed in a desiccator to cool down. The drop in the weight of grain is measured based on its initial weight.

- Moisture from the sample is thus evaporated, collected and condensed in a graduated cylinder.
- The millilitre of moisture collected shows the percentage moisture content. The determined moisture content is on wet basis.
- In this method the temperature of mineral oil in flask should reach to 200ºC within 26 minutes. The time required for moisture determination is about 30 minutes.
- If the temperature of the mineral oil reaches to desired temperature within time, the moisture content determination is found to be fairly accurate, when samples of grains are the tune of 1 to 1.5% is possible

Infra-red method:

In this method, grain moisture content is directly measured by evaporation of the water from a sample of grain with an infra-red heating lamp. The instrument consists of a balance, a pan counter balanced by a fixed weight and a variable length of weighing chain. A scale calibrated in percentage moisture content is incorporated in the stem of the instrument. The sample of grains may be unground, but when ground sample is used, the time needed to evaporate the water is reduced.



Indirect methods

Electrical resistance method:

The electrical conductivity or resistance of a product depends upon its moisture content. The universal moisture meter measures the electrical resistance of the grain at a given compaction. It gives fairly accurate readings of moisture content on wet basis.

Dielectric method: These devices measures the dielectric constant of the grains. The grains are filled in chamber. The sides of the chamber is formed by the plates of condenser between which high frequency current is passed to measure the capacitance of the sample. The capacitance varies as per the moisture present in the sample, degree of compaction and the grain temperature .

Chemical method : The removal of water by the strong desiccants ($CaCl_2$) is caused by the vapor pressure gradients. The moisture moves from wet grain to the drying agent since the vapour pressure of the grain in higher than that of the desiccants

- The hydration of salt is accompanied by the evolution of heat, this heat evolution helps in driving water out from the grains.

Equilibrium Moisture Content (EMC)

- Most of the agricultural products, specially the food grains are **hygroscopic** in nature.
- This property of gaining or loosing of moisture as per the atmospheric conditions is known as **Hygroscopicity.**
- The moisture content attained by a grain with respect to a set of atmospheric temperature and relative humidity is called the **Equilibrium moisture content (EMC)** of the grain.

- It is the moisture content at which the product will neither loose nor gain moisture with the atmospheric condition
- It is in equilibrium with atmospheric moisture ie., RH
- The relative humidity of the air surrounding cereal grain in equilibrium with the environment is called the Equilibrium relative humidity (ERH).

Importance of EMC

- It gives an idea weather the material gain or lose moisture
- It gives an idea about the rate of moisture removal
- It helps to determine drying characteristics
- It can be used to predict to which moisture level the product can be dried
- Essential for preservation, drying, storing, packaging and mixing

Factors affecting EMC

- The variation in EMC values is caused by a difference in

  1)The grain variety

  2)The grain maturity

  3)The relative humidity measuring technique

  4) The EMC determination method

Methods of determination of EMC

1. Static method

- Grains left in humid & still air until they attain equilibrium
- H_2SO_4, HCl used to achieve desired RH levels
- Time consuming (3-4 weeks), mold attack, decomposition of grain structure

2. Dynamic method

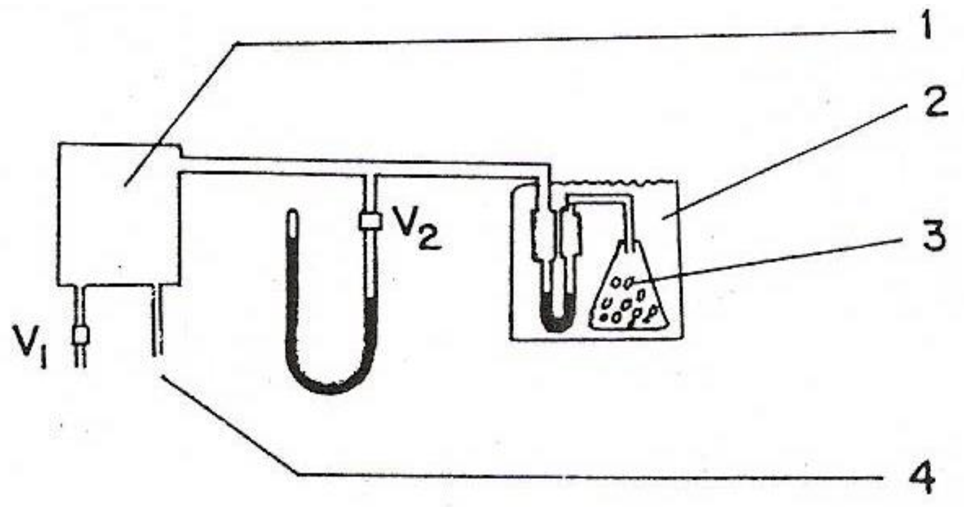
- Humid air is agitated or moved by mechanical means & grains attain equilibrium condition
- Desorption, Isotenoscopic method

Desorption method :

- Property of dry air to absorb moisture from moist grain is used
- Moist grains are put in an air tight container
- RH measured by electric or hair hygrometer

Isotenoscopic method:

- Equipment with U tube filled with liquid of negligible vapor pressure & conical flask
- Grain sample kept in a conical flask
- Vapor pressure exerted by moist grain is measured



1. Vacuum storage jar
2. Water bath
3. Sample flask
4. Vacuum pump

EMC Models

Several theoretical and empirical models have been proposed for calculating the moisture equilibrium of grains.

- *Kelvin equation*
- *Harkins-Jura equation*
- *Chung-Pfost equation*
- *Henderson equation*

Kelvin Equation

- Kelvin (1871) based on the capillary condensation within the pores
- The relationship between the vapour pressure of a liquid in a capillary (P_v) and the saturated vapour pressure at the same temperature (P_{vs}) is the basis of the capillary condensation theory.

$$\ln\left(\frac{Pv}{Pvs}\right) = \left(\frac{2\sigma \text{ V} \cos\alpha}{\text{r RTabs}}\right)$$

Where

P_v - water vapour pressure of the product,

P_{vs} - saturated water vapour pressure,

σ - surface tension of the moisture,

V - volume of the moisture in the liquid form,

α - contact angle between moisture and capillary wall

r - cylindrical capillary radius

R -universal gas constant

T_{abs} – absolute temperature

- The equation is limited to the very high RH range (>95%) where capillary condensation occurs

Harkin –Jura Equation

- Harkin and Jura (1944) proposed the following EMC equation based on the theory of existence a potential field above the surfaces of a solid material
- The total work required to adsorb or desorb a molecule is the sum of the work required for vapour molecule to come on surface and the work necessary for condensation.

$$\ln\left(\frac{P_v}{P_{vs}}\right) = d - \frac{e}{V^2}$$

Where

P_v - water vapour pressure of the product,

P_{vs} - saturated water vapour pressure,

V - volume of the moisture in the liquid form,

d & e –product constant depends on temperature

- It predicts satisfactorily accurate values when RH is more than 30%

Chung Pfost Equation

- This equation is based on the basis of potential field theory
- The Chung equation has the form

$$\ln\left(\frac{P_v}{P_{vs}}\right) = -\frac{A}{RT}\exp(-BM)$$

Where

P_v - water vapour pressure of the product,

P_{vs} - saturated water vapour pressure,

R - universal gas constant

T – absolute temperature

A & B – constant depends on grain temperature

M – moisture content, % (db)

- The above equation gives fairly accurate values of EMC between 20 – 90 % RH values

Henderson Equation

- Henderson (1952) has proposed an equation for predicting the EMC of grains
- Based on Gibb's adsorption equation.
- The equation is for the moisture equilibrium curve of biological products, including grains:

$$1\text{-}rh = e^{-CTM_e^{\,n}}$$

Where

rh – relative humidity , decimal

T – absolute temperature, °K

C & n – constant depends on grain & temperature

Me – equilibrium moisture content, % (db)

Problem : Calculate the equilibrium moisture content of brinjal seed at relative humidity of 10% and temperature of 50°C using Henderson's equation. Given that constants c is 6.5×10^{-6} and n is 1.8.

Solution : Henderson's equation is

$$1 - rh = e^{-CTMe^{n}}$$

Substituting the given values of rh, T and c and n in the above equation, we get

$$1 - 0.1 = e^{-[6.5 \times 10^{-6} \times (50 + 273) Me^{1.8}]}$$

or, $$0.9 = e^{-[6.5 \times 10^{-6} \times 323 Me^{1.8}]}$$

or, $$e^{-0.105} = e^{-[2.1 \times 10^{-3} Me^{1.8}]} \quad (\text{Since } e^{-0.105} = 0.9)$$

or, $$0.105 = 2.1 \times 10^{-3} \; Me^{1.8}$$

or, $$Me^{1.8} = 50$$

$$Me = 8.78\% \text{ (db)}$$

Problem : Determine the values of constants c and n from the Henderson's equation for the following data obtained under two different conditions of EMC studies of sunflower seed.

Condition	Relative humidity, %	Temperature °C	EMC, % (db)
1	50	40	10
2	70	50	13

Solution : Henderson's equation is $1 - rh = e^{-CTMe^n}$

Substituting the values of rh, T, Me in the equation

$$1 - 0.5 = e^{-[C \times (40+273) \times 10^n]}$$

or, $$0.5 = e^{-[C \times 313 \times 10^n]}$$

or, $$e^{-0.693} = e^{-[C \times 313 \times 10^n]} \quad \text{(Since } e^{-0.693} = 0.5)$$

or, $$0.693 = c \times 313 \times 10^n \quad \text{...(i)}$$

Substituting the values of rh, T and Me of condition 2, we get

$$1 - 0.7 = e^{-[C \times (50 + 273) \times 13^n]}$$

or, $$0.3 = e^{-[C \times 323 \times 13^n]}$$

or, $$e^{-1.204} = e^{-[C \times 323 \times 13^n]}$$

or, $$1.204 = c \times 323 \times 13^n$$

Dividing equation (ii) by equation (i), we get

$$\frac{1.204}{0.693} = \frac{C \times 323 \times 13^n}{C \times 313 \times 10^n}$$

or, $$\left(\frac{13}{10}\right)^n = 1.68$$

$\therefore$ $$n = 1.98$$

Substituting the value of n in equation (i)

$$0.693 = c \times 313 \times 101.98$$

or, $$c = 2.32 \times 10^{-5}$$

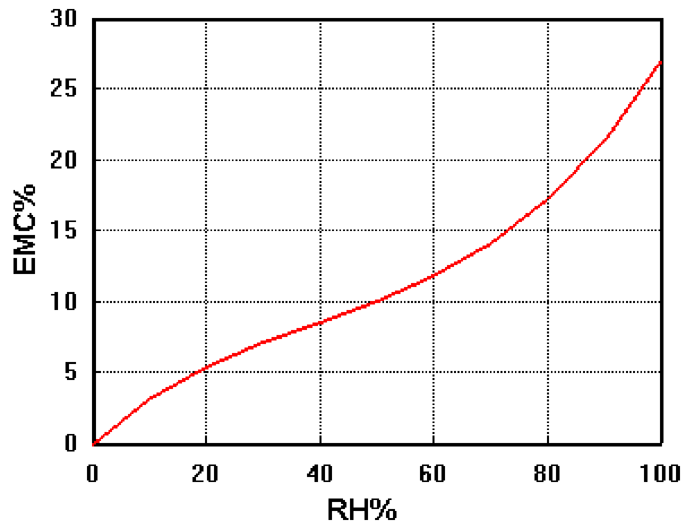
3. Calculate the values of the constants *C* and *n* of Henderson's equation for cauliflower seeds with the help of following data obtained during EMC studies.

Condition	Relative humidity, %	Temperature °C	EMC % (db)
1	70	30	9
2	20	40	5

$$0.3 = e^{-C*(30+273)*9n}$$

EMC Curve

- Plotting the EMC versus relative humidity (holding temperature constant)
- Results in a sigmoid –type (S-shaped) curve that rises sharply above 85% relative humidity.
- The S-shaped curve is characteristic for biological products, including grains.
- EMC curves also called moisture equilibrium isotherms.



Desorption Isotherm:

When some agricultural products in the process of loosing moisture attains equilibrium moisture content with the surroundings, the EMC is known as desorption EMC.

Adsorption/Sorption isotherm:

When a dry product gains moisture from the surroundings and attains EMC, that value of EMC is said to be adsorption EMC.

Hysteresis

- At same RH and Temp level there is a meaningful difference between the desorption and adsorption EMC values. This difference is known as hysteresis effect as shown in Fig.
- Desorption EMC > Adsorption EMC values.

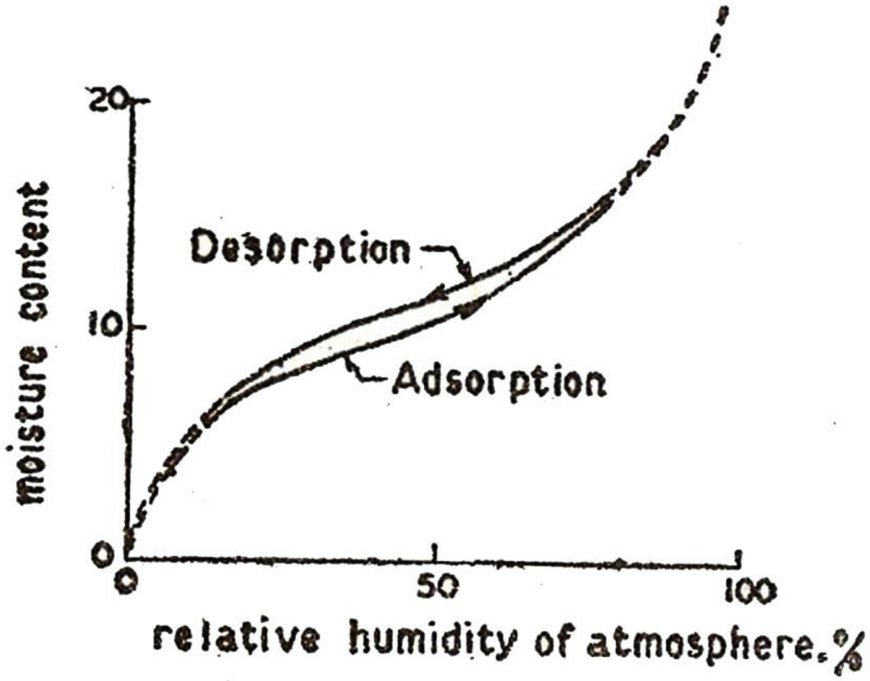


FIG. Relation between equilibrium moisture content of paddy and relative humidity showing hysteresis.

Theory of drying

Free moisture

- Free moisture is the liquid in excess of the equilibrium moisture content at a given temperature and humidity.
- Free moisture can be easily removed by drying by vapor pressure difference between the product and ambient conditions.

Bound moisture

- Bound moisture in a food material is that liquid which is retained in a manner that exerts a vapor pressure less than that of the free liquid at the given temperature.
- Liquid may become bound to the solid by retention in small capillaries, by solution in cells or fiber walls, by homogeneous solution throughout the solid or by chemical or physical adsorption on solid surfaces.

❖ Many food constituents can hold onto water molecules, this water cannot be removed simply and they do not behave like free water. Some properties of bound water are:

1. Bound water cannot act as a solvent for salt, minerals and sugars present in food material

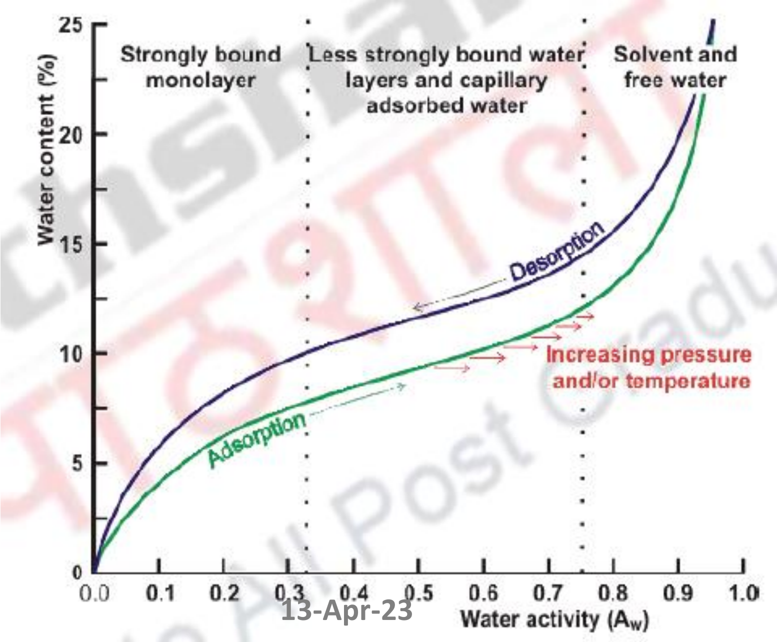
2. Freezing point of bound water is lower than the free water.

3. Bound water exhibits essentially no vapor pressure.

4. The density of bound water is greater than that of free water.

Unbound moisture

- Unbound moisture exerts a vapor pressure equivalent to that of the free liquid. Thus in a non-hygroscopic material, all the liquid is unbound and in a hygroscopic material, the unbound moisture is the liquid in excess of the equilibrium moisture content (EMC), corresponding to saturation humidity.

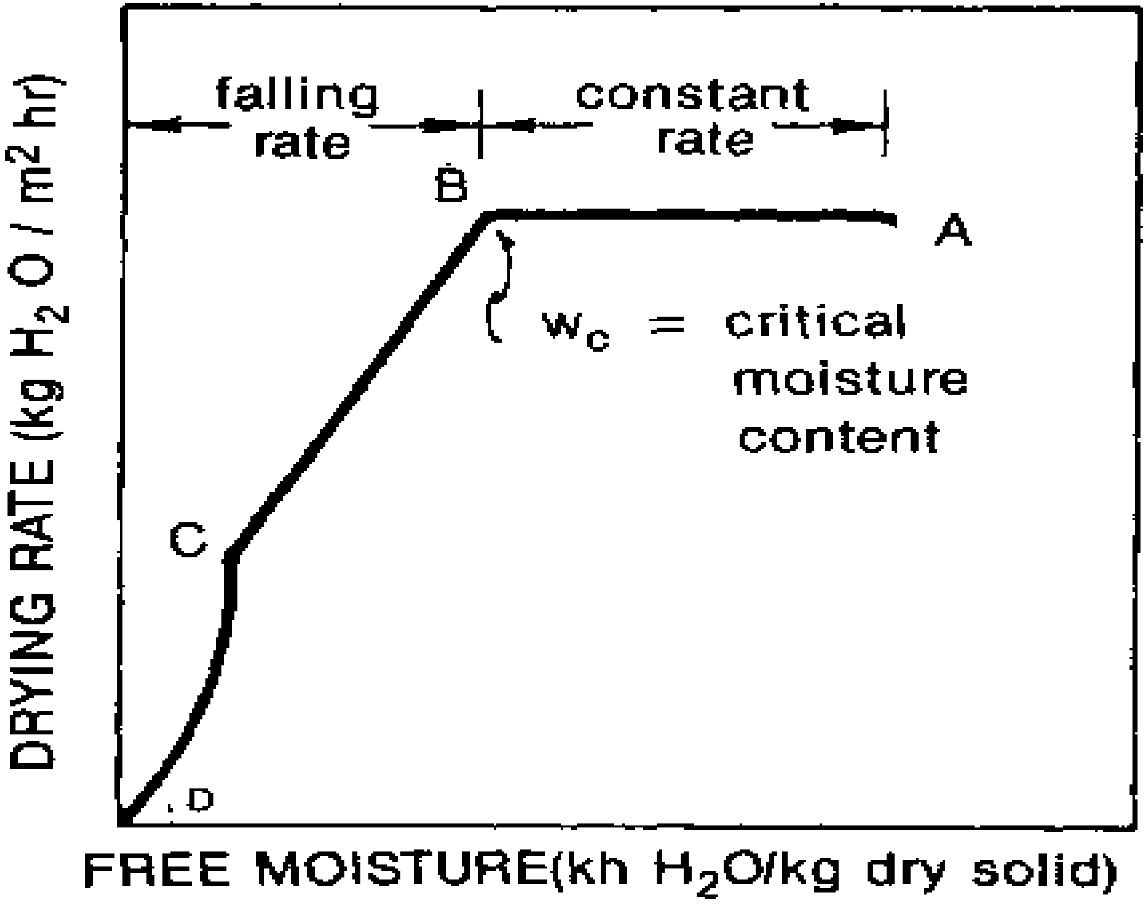


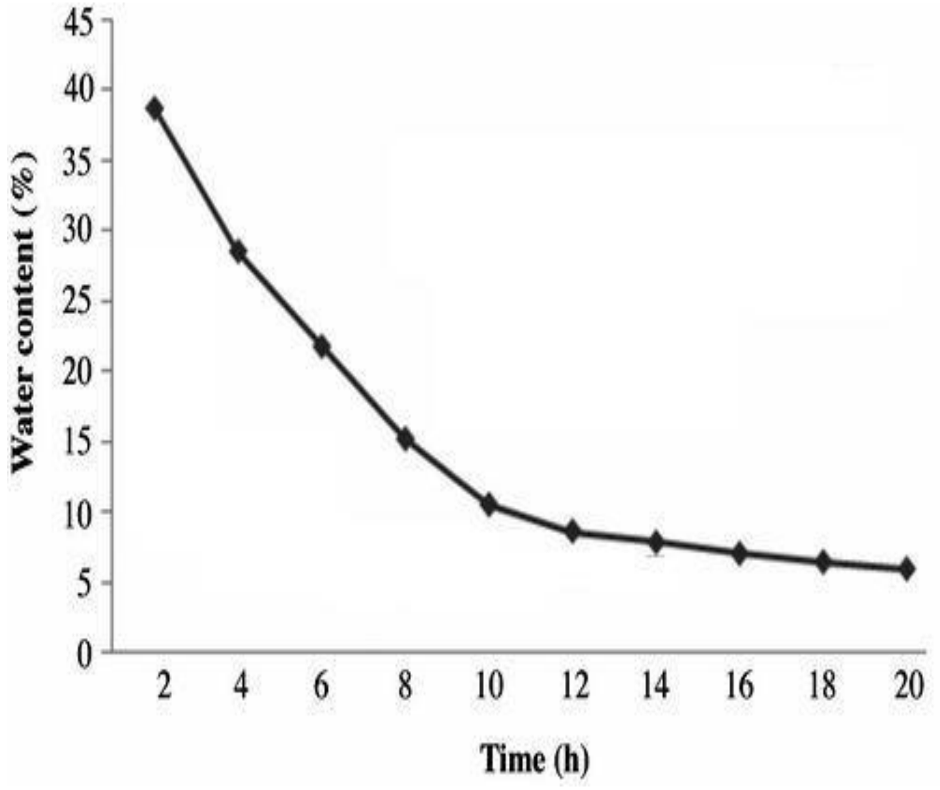
Drying RATE PERIODS

- It is a function of product moisture content

- Convection drying process can be divided into 3 periods
  - Constant rate period
  - Falling rate period
    - 1st Falling rate period
    - 2nd Falling rate period

Drying RATE CURVE





Constant rate period

- In the initial period of drying, the behavior of food materials follows constant rate period and followed by falling rate period.
- In constant rate period (AB), the rate of evaporation under any given set of air conditions is independent of the solid and is essentially the same as the rate of evaporation from a free liquid surface under the same conditions.

The rate of drying during constant rate period is based on the

1. Difference between the temperature of air and temperature of the wetted surface at constant air velocity and relative humidity

Constant rate period

2. Difference in humidity between air stream and wet surface at constant air velocity and temperature

3. Air velocity at constant air temperature and humidity.

- In constant rate period drying takes place by surface evaporation and moisture moves by vapour pressure difference.
- The moisture content at which the drying rate ceases to be constant is known as critical moisture content.
- The critical moisture constant of a product also depends upon the characteristics of a food material such as shape, size and drying conditions.

Falling rate period

- Cereal grains are usually dried entirely under falling rate period.
- The falling rate period enters after the constant drying rate period and corresponds to the drying cycle where all surface is no longer wetted and wetted surface continuously decreases until at the end of this period.
- The cause of falling off in the rate of drying is due to the inability of the moisture to be conveyed from the centre of the body to the surface at a rate comparable with the moisture evaporation from its surface to the surroundings.

Falling rate period

- The falling rate period is characterized by gradual increase in temperature both at the surface and within the food materials.
- The changes in the air velocity have much smaller effect during the constant rate period.
- The movement of moisture within the food material *i.e.*, from the centre to the surface by liquid diffusion and the removal of water content from the surface of the food material to the atmosphere are the two important controlling factor in drying of foods.

Falling rate period

- The falling rate period consists of two stages:

  1. First falling rate

  2. Second falling rate

First falling rate (BC)

The moisture is transported from the inside of the product to the surface and the critical moisture content is reached. However, dry spots appear on the surface and surface area evaporation decreases.

Second falling rate (CD)

In the second falling rate period, there is a slow diffusion of water to the inner surface leading to desorption and diffusion through pores to the surface.

Classification of Drying

- Drying of agriculture products is broadly carried out by two methods

  Thin layer drying

  Deep bed drying

- Thin layer drying : The thin layer drying shows the condition of nearly complete exposure of grains to heated air. The thickness of grains in thin layer drying is **normally up to 20 cm**.
- Deep bed drying : In deep bed drying takes place in a drying zone and the layer of grains is **more than 20 cm**

Thin Layer Drying

- Process in which all grains are fully exposed to the drying air under constant drying conditions i.e. at constant air temp. & humidity.
- Up to 20 cm thickness of grain bed is taken as thin layer.
- All commercial dryers are designed based on thin layer drying principles
- Represented by Newton's law

$$M-M_e/M_o-M_e = e^{-K\theta}$$

Where, M = Moisture content at any time θ, % db

M_e = EMC, % db

M_o = Initial moisture content, % db

K = drying constant

θ = time, hour

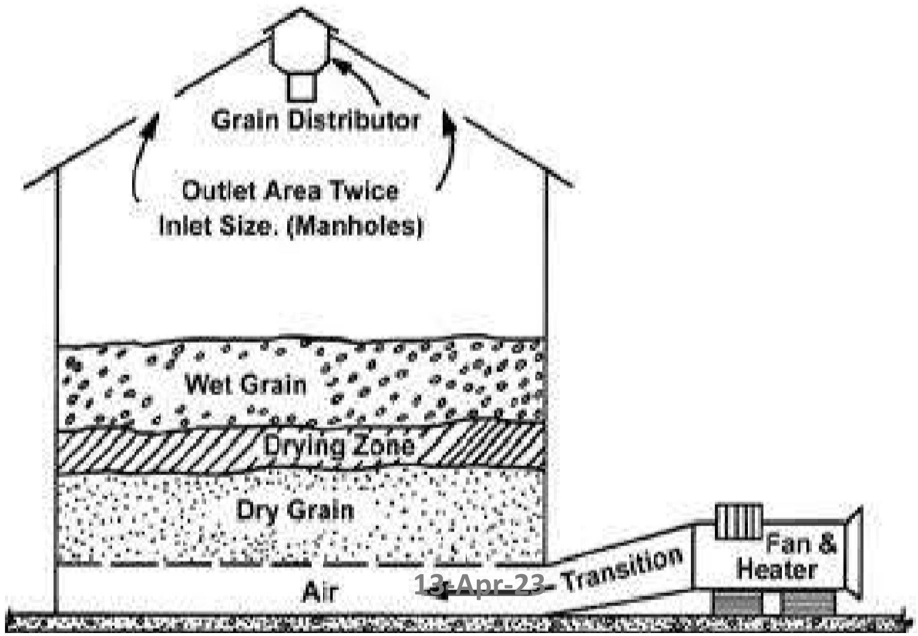
Deep Bed Drying

- The heterogeneous drying of grain in deep layer (more than 20 cm deep). •
- The rate of moisture removal is maximum for the bottom layer and decreased exponentially for subsequent layer.
- Dry air becomes cooler and moister as it moves up in the grain bed.
- It has three zones

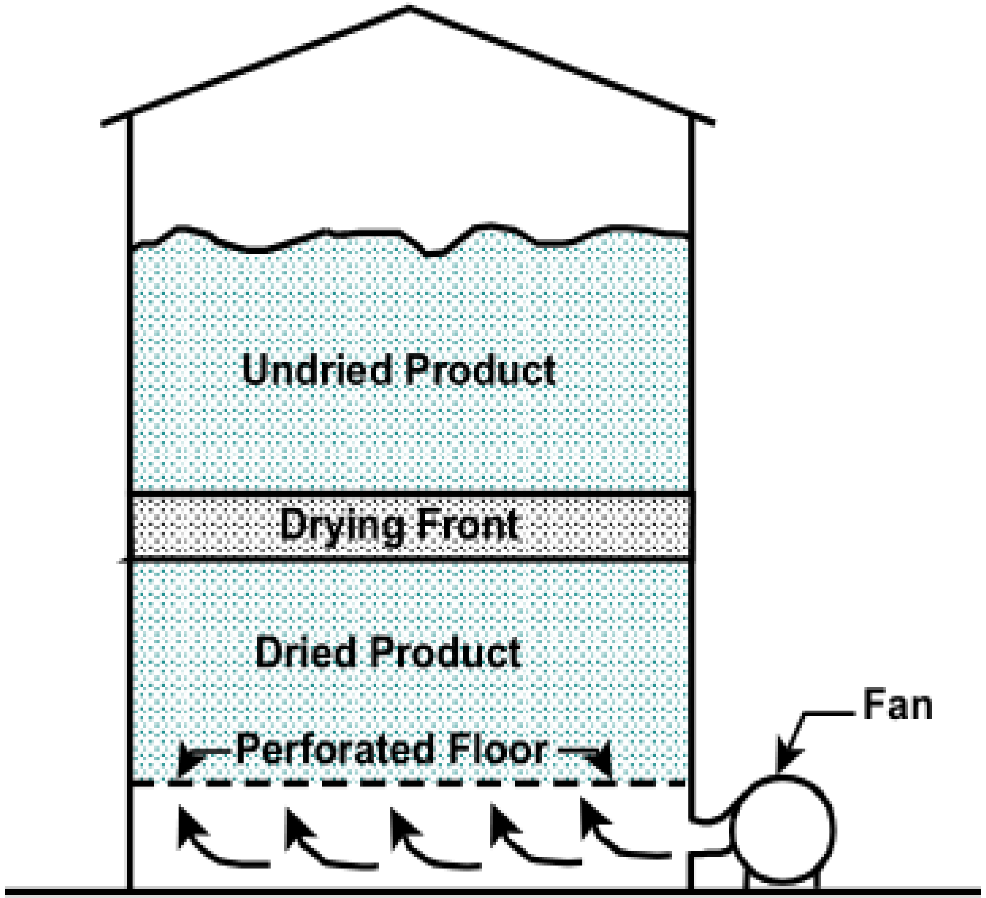
  a. Dried zone

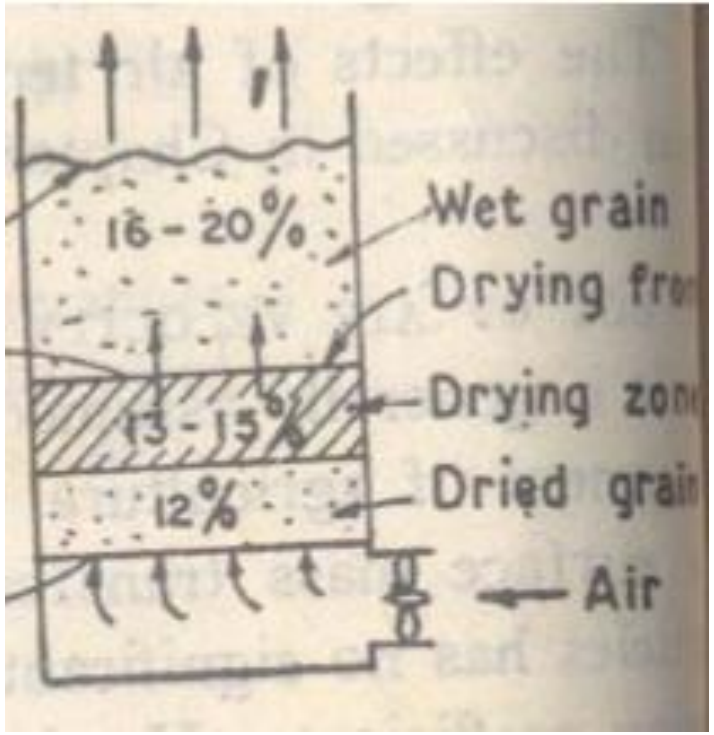
  b. The drying zone

  c. The wet zone



Drying zones in seed bin drying





Important factors affecting the rate of drying are

1. Initial moisture content of the raw material
2. Composition of raw material
3. Initial load of the food kept in drier
4. Size, shape and arrangement of stacking of the raw material
5. Temperature, relative humidity and velocity of air used for drying
6. Rate of heat transfer on the surface of the food
7. Pre-treatment of the raw material prior to drying (peeling, blanching, sulphuring etc.)

Heated Air Dryers

Flat Bed Type Batch Dryer

- This is a static, deep bed, batch dryer. This type of batch dryer is very simple in design and is most popular for on-farm drying in many countries.

Construction

- The rectangular box type batch dryers are shown in Figures.
- The size of the dryer depends on the area of the supporting perforated screen on which the grain is placed.
- The holding capacity of these dryers ranges from 0.25 to 1 tonne/batch only.
- The horse power of the motor for the blower ranges from ¼ to 1.

- For convenience an oil burner can be used but for economy a husk fired furnace should be used for the supply of heat.

Operation: The grain is placed on the supporting screen and the heated air is forced through the deep bed of grain. After drying of grains to the desired moisture level, they are discharged manually. The temperature of the heated air should be limited to 45^0C. The drying rate varies from 20 to 40m^3/min per 1000 kg of raw paddy depending on the initial moisture content.

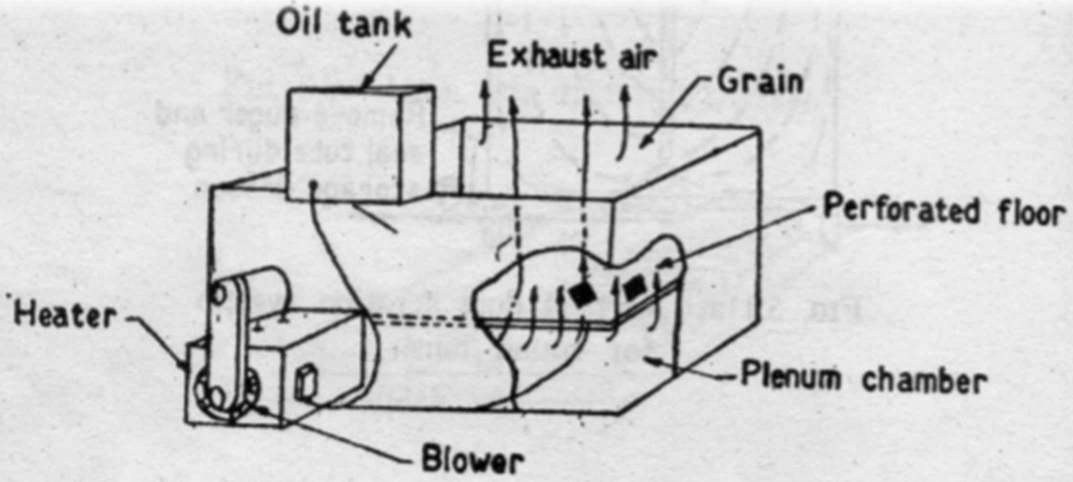


FIG. Rectangular flat bed type batch dryer (Japan).

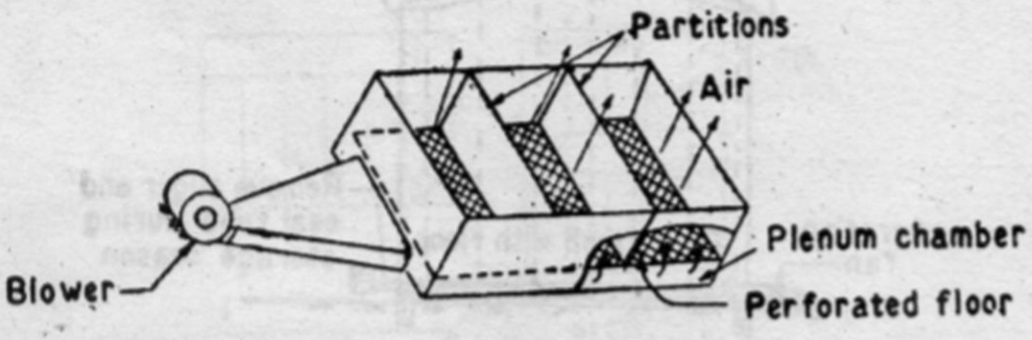


FIG. Rectangular flat bed type batch dryer with partitions.

Advantages:

1) Fairly reasonable price
2) Intermittent drying can also be used
3) Operation is very simple
4) It can be used for seed drying and for storage purpose also after drying
5) It can be manufactured locally using various types of materials like steel sheet, wood piece etc.

Disadvantages:

1) Rate of drying is slow
2) Uneven drying which results in higher percentage of brokens in grains
3) Holding capacity is small compared to flow dryers.

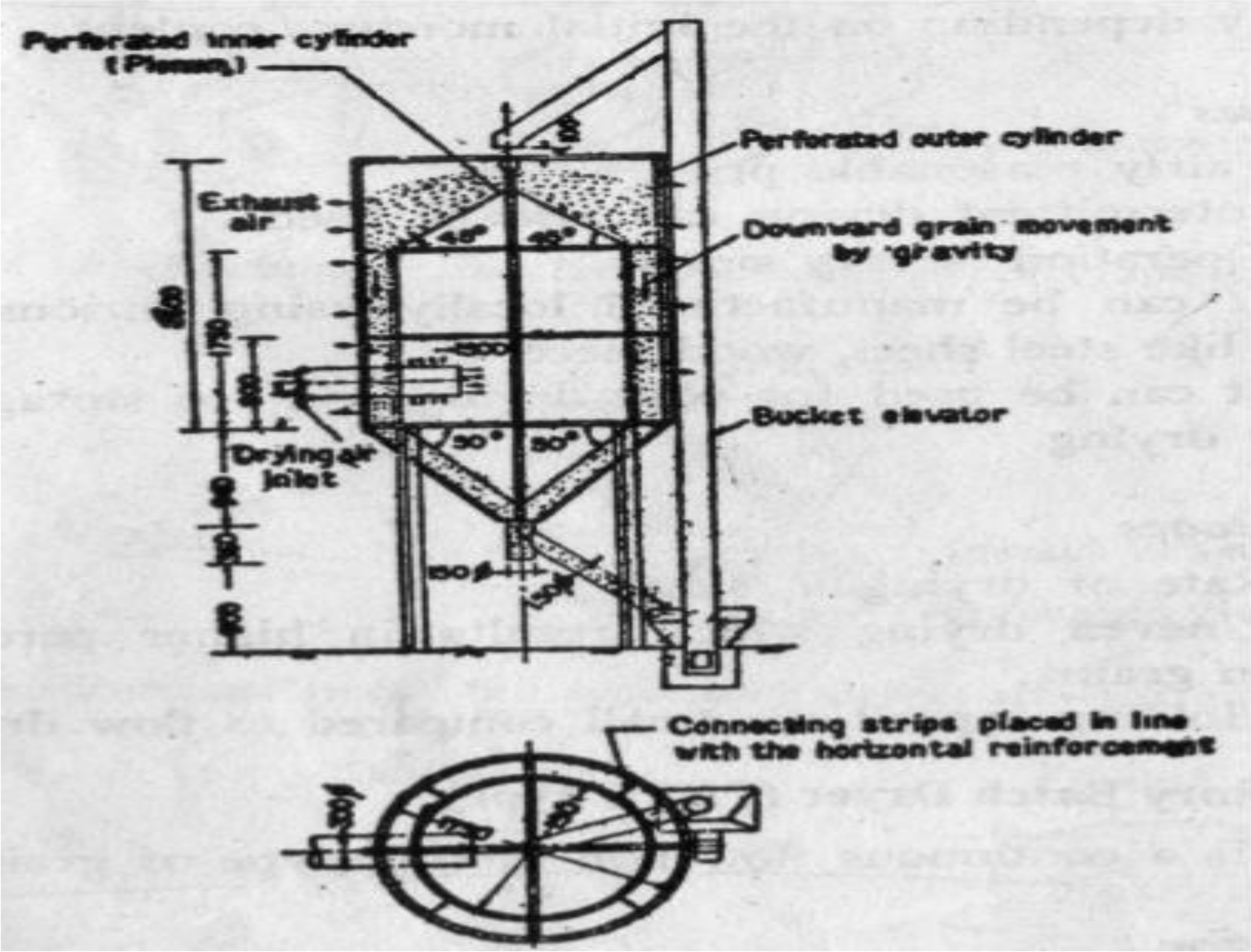
Recirculatory Batch Dryer (PHTC type)

- This is a continuous flow non mixing type of grain dryer.

Construction

- The dryer consists of two concentric circular cylinders made of perforated (2 mm 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 is shown in fig.


Perforated inner cylinder
(Plenum)
Perforated outer cylinder
Exhaust air
Downward grain movement by gravity
Bucket elevator
Drying air inlet
45°
50°
Connecting strips placed in line with the horizontal reinforcement

Operation

- 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.

Advantages:

1. Price is reasonable
2. Simplest design amongst all flow type dryers
3. Easy to operate
4. It can be used on the farm and rice mill as well
5. Operating cost is low with husk fired furnace.

Disadvantages:

1. Drying is not so uniform as compared to mixing type
2. Perforations of the cylinders may be clogged with the parboiled paddy after using it for a long time.

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

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 V ports) 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.
- 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.

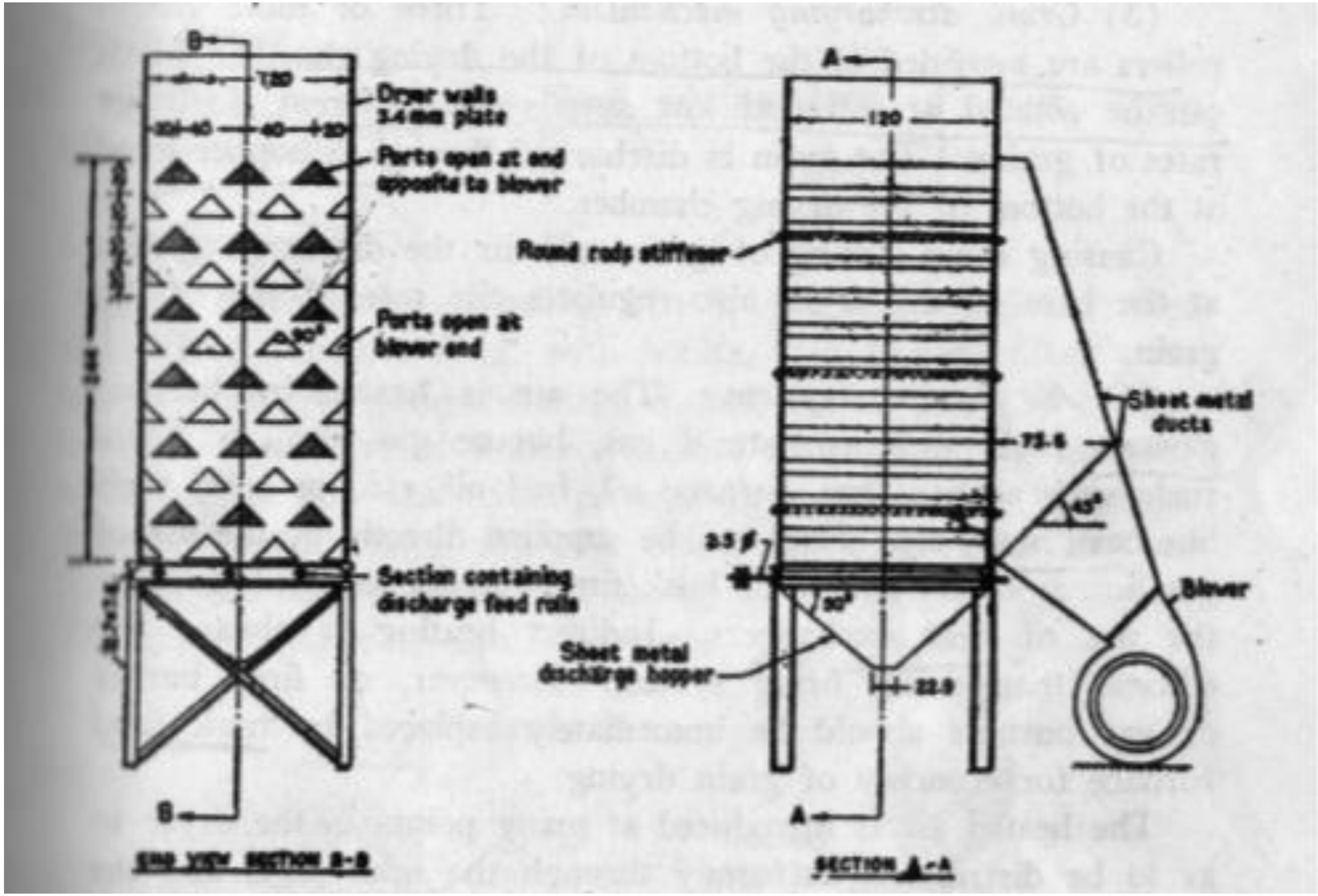
3) Grain discharging mechanism:

- 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 12 tonnes of grain, but sometimes dryers of higher capacities are also installed.
- Recommended air flow rate is 60-70 m^3/min/tonne of parboiled paddy and optimum air temperatures are 60^0C and 85^0C for raw and parboiled paddy respectively.


Dryer walls
3.4 mm plate
Ports open at end
opposite to blower
Ports open at
blower end
Section containing
discharge feed rolls
END VIEW SECTION B-B
Round rods stiffener
Sheet metal
ducts
Blower
Sheet metal
discharge hopper
SECTION A-A

Advantages:

1. Uniformly dried product can be obtained if the dryer is designed properly
2. The dryer can be used for different types of grains.

Disadvantages:

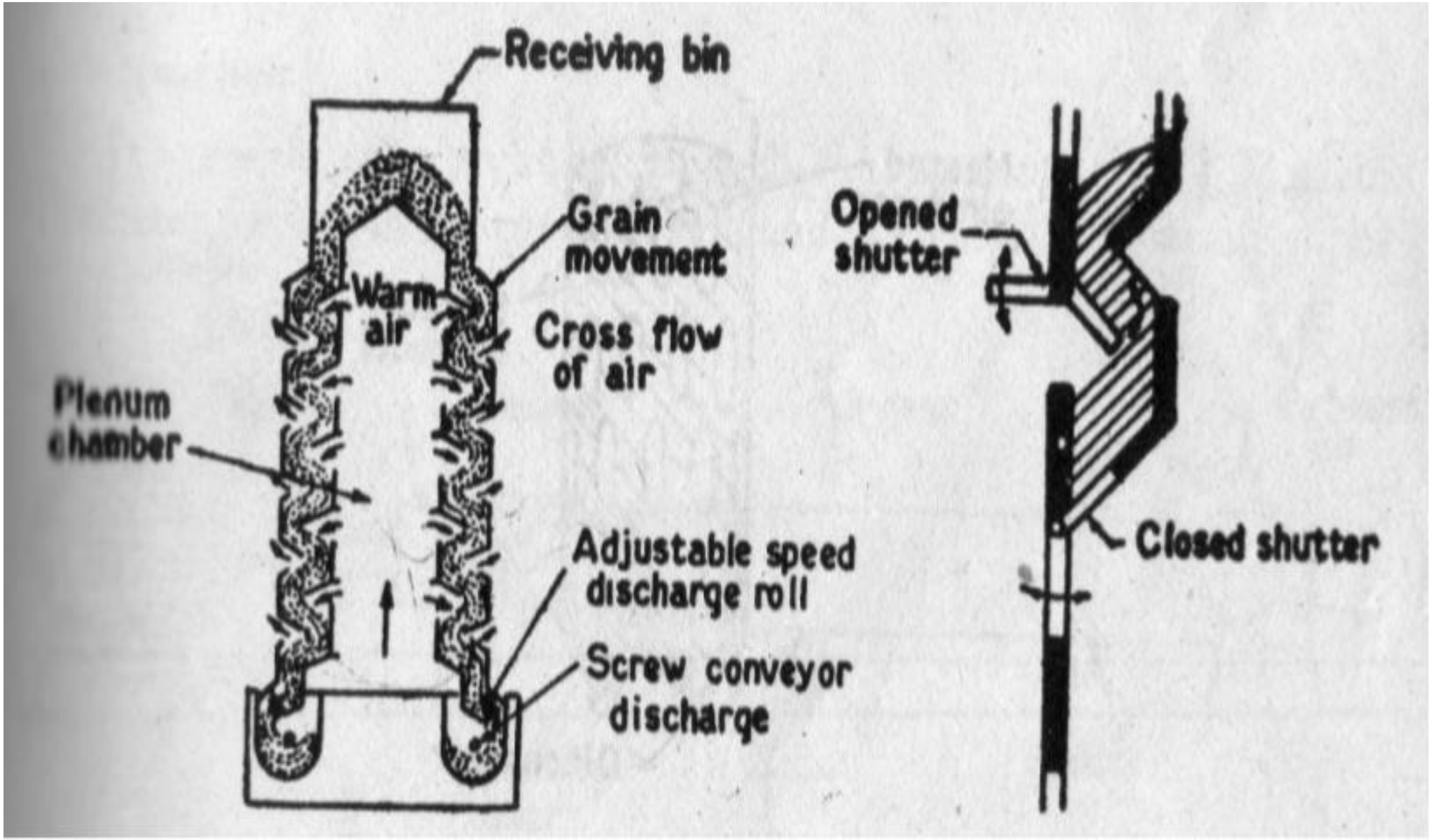
1. High capital investment
2. Cost of drying is very high if oil is used as fuel.

Baffle Dryer

- This is a continuous flow mixing type of grain dryer.

Construction

- The baffle dryer consists of: 1) grain receiving bin, 2) drying chamber fitted with baffles, 3) plenum fitted with hot air inlet, 4) grain discharge control device and 5) hopper bottom.
- A number of baffles are fitted with the drying chamber to divert the flow and effect certain degree of mixing of grain.
- The two baffle plates with the outer and inner sides are set 20cm apart for the passage of the grain in the drying chamber. The dryer is made of mild steel sheet.


Receiving bin
Grain movement
Warm air
Cross flow of air
Plenum chamber
Adjustable speed discharge roll
Screw conveyor discharge
Opened shutter
Closed shutter

Operation:

- Grain is fed at the top of the receiving bin and allowed to move downward in a zigzag path through the drying chamber where it encounters a cross flow of hot air.
- On account of zigzag movement, a certain degree of mixing of grain takes place.
- The particularly dried grain discharged from the hopper bottom is recirculated by a bucket elevator until it is dried to the desired moisture level.
- Some of the dryers are fitted with a large overhead bin at the top which acts as an overhead tempering bin.

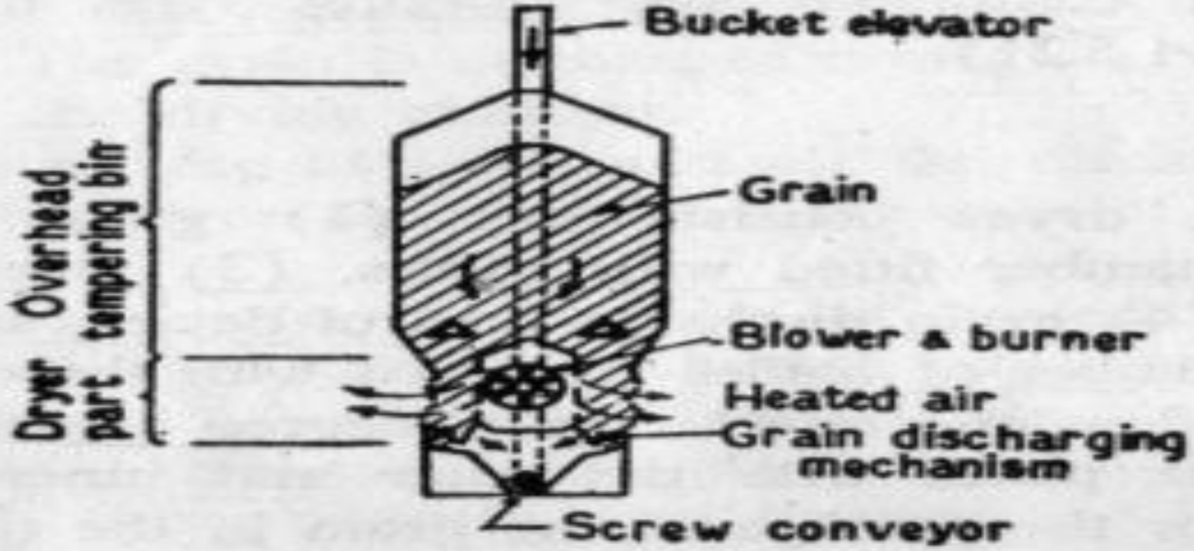
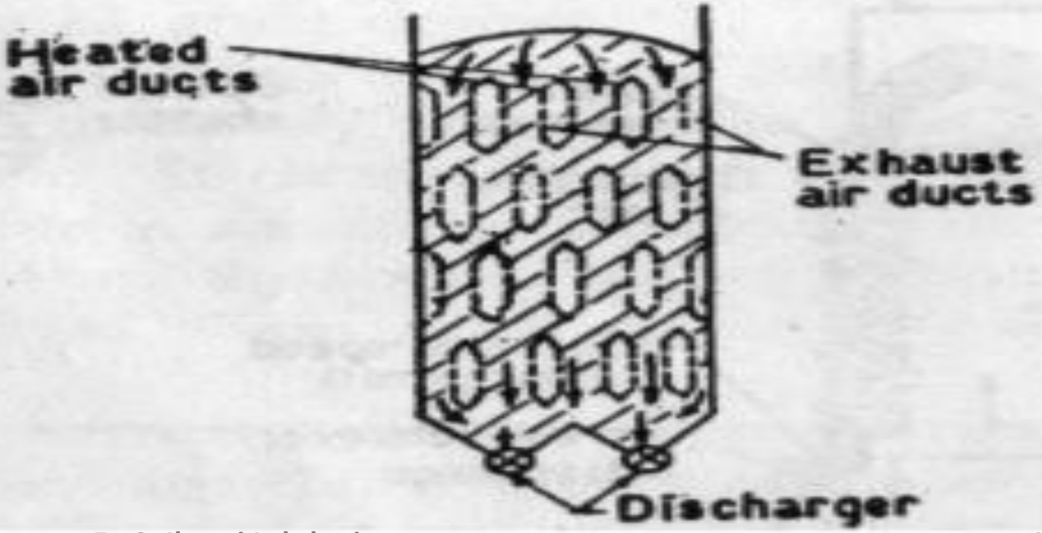


FIG. 5.21. Baffle type tempering dryer.



Advantages:

1. Uniformly dried product is obtained

Disadvantages:

1. Ratio of the volume of plenum to the total volume of the dryer is relatively high.
2. Grains on the baffle plates move slowly than that of other sections.

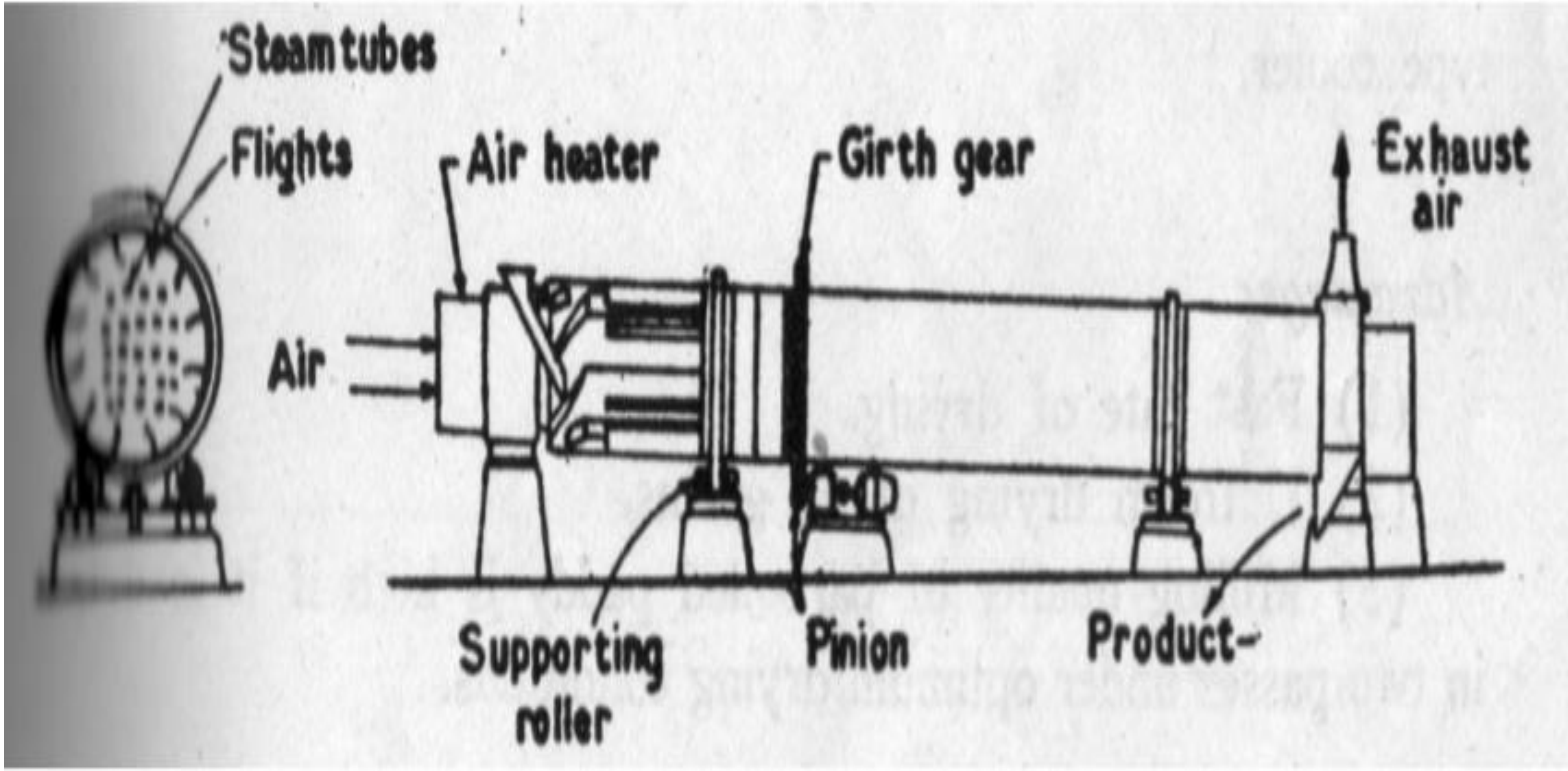
Rotary Dryer

➢ This is continuous dryer 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 110^{0}C.
- In India, the Jadavpur University, Calcutta introduced a rotary dryer of 1 tonne/hr capacity for the drying of parboiled paddy.

Construction

- It consists of a cylindrical shell 9.15 m long and 1.22 m 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.
- 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.


Steam tubes
Flights
Air heater
Girth gear
Exhaust air
Air
Supporting roller
Pinion
Product

Operation

- The soaked and steamed paddy is fed to the dryer by the screw feeder.
- Heated air at about 80^0C 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% 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.

Advantages:

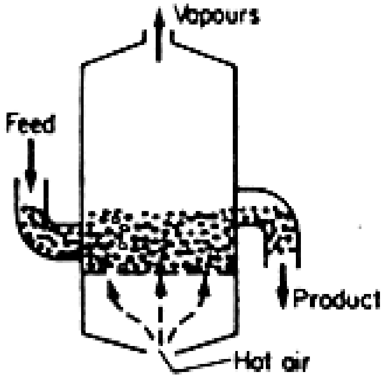
1. Fast rate of drying
2. Uniform drying of all grains
3. Milling quality of parboiled paddy is high if it is dried in two passes under optimum drying conditions.

Disadvantages:

1. Complicated design
2. Needs careful attention
3. Higher capital investment 4. Higher power requirement
5. Operating cost may be high due to higher consumption of electricity and steam.
6. The dryer being horizontal larger floor space is required.
7. Generally only 30 per cent of the dryer volume is utilized.
8. It cannot be used for all types of freshly harvested grains.

Fluidized Bed Dryer

- In a fluidized bed dryer, the food material is maintained suspended against gravity in an upward-flowing air stream.
- There may also be a horizontal air flow helping to convey the food through the dryer. Heat is transferred from the air to the food material, mostly by convection.



FLUIDISED BED DRYER

THANK YOU