Lecture 13

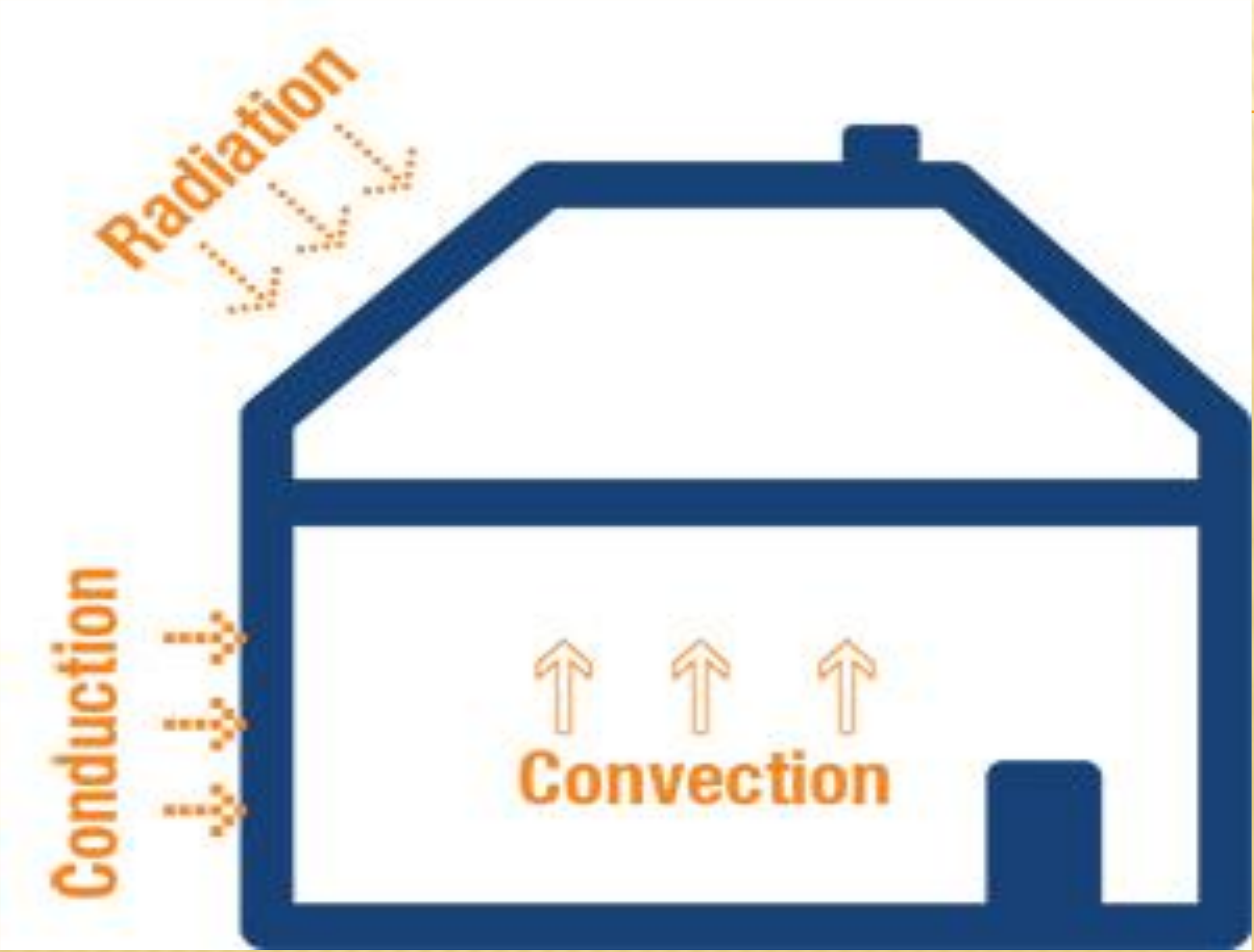
Temperature and moisture changes in storage structures

Drying & Storage Engineering

(PFE-304)

Temperature and moisture changes in storage structures

- Moisture migration in stored grain results from temperature changes.
- Moisture content of grain is *one* of the most important factors influencing its storage life.
- High moisture and a warm climate promote mold growth, insect growth and increase rate of respiration of grains.
- Moisture migration takes place in bin even though the grains are at a moisture level generally considered safe for storage.


Radiation
Conduction
Convection

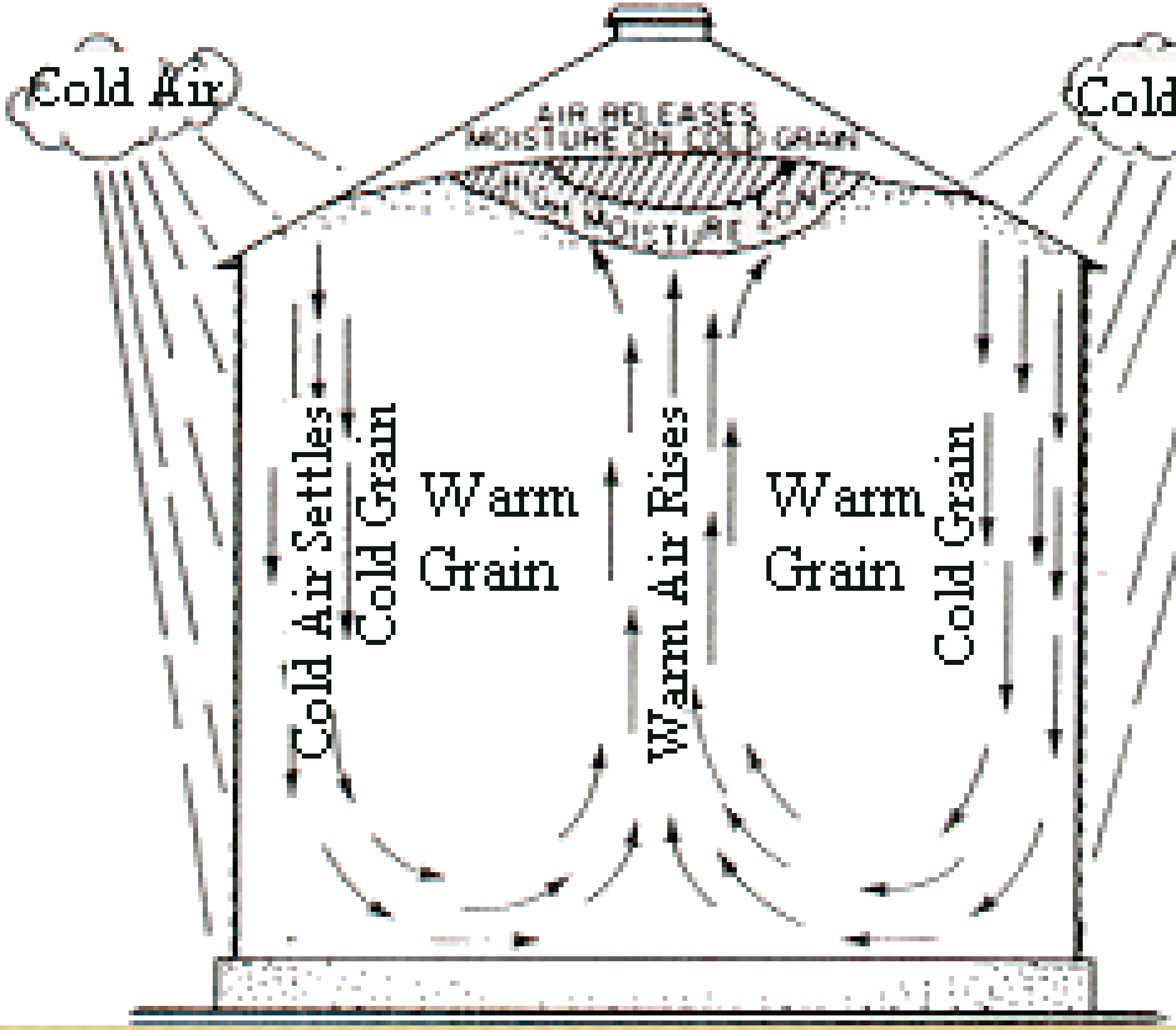
WINTER SEASON

HOT SPOT

- When the winter season grains after harvest are stored in the fall, grains become warm.
- In this condition after passage of time the air at the surface of storage bin *cools*, because the outside temperature is lower than the temperature in the centre of the bin.
- The cool air at inside surface of bin moves down along the edge of the bin across the bottom and then up near the centre of the bin where the air and grain are warm

HOT SPOT

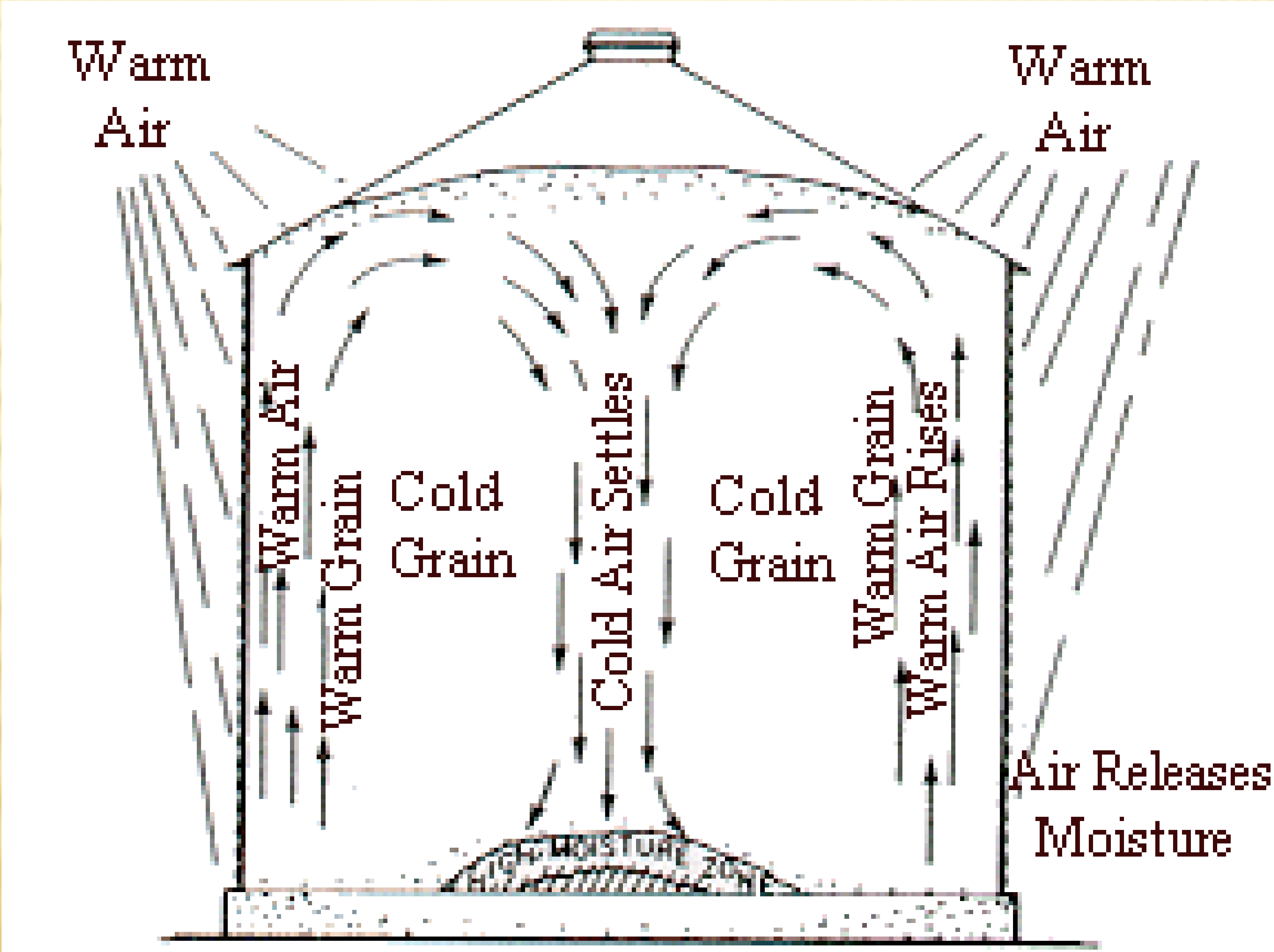
- The air moving through the centre of the bin picks up moisture and moves across the top of the sides.
- At this location the surface of the grain is cold and the moisture condenses on the grain consequently the moisture content of grain is raised.
- Because of increased grain moisture, spoilage takes place at top of the bin.


Cold Air
Cold Air
AIR RELEASES
MOISTURE ON COLD GRAIN
HIGH MOISTURE ZONE
Cold Air Settles
Cold Grain
Warm
Grain
Warm Air Rises
Warm
Grain
Cold Grain

SUMMER SEASON

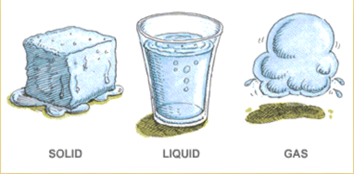
COLD SPOT

- The atmospheric temperature in spring and later on rises, as a result air currents move down through the centre of the bin to its bottom.
- At this spot, moisture condenses on the cold spot.
- The air then moves to the walls and due to higher temperature goes upwards.
- Due to moisture accumulation at the bottom of the bin, spoilage of grain takes place.


Warm Air
Warm Air
Warm Air
Warm Grain
Cold Grain
Cold Air Settles
Cold Grain
Warm Grain
Warm Air Rises
Air Releases Moisture

Characteristics of bulk materials

- The behaviour of food grains and other seeds depends upon their size, shape, density, ease of flow through orifices/chutes, angle of internal friction, moisture content and other physical and mechanical properties.
- The granular materials behave as composite mass having the characteristics of a liquid and a solid.
- They behave as liquid as they can form the shape of the container in which stored, but act as a solid material because of formation of natural angle of repose when dumped on a level horizontal plane.



The grain mass is a numerous small solid particles which can also move around each other and thus becomes a flowing mass.

The laws of hydro-dynamics are not applicable to the flow of granular materials, because

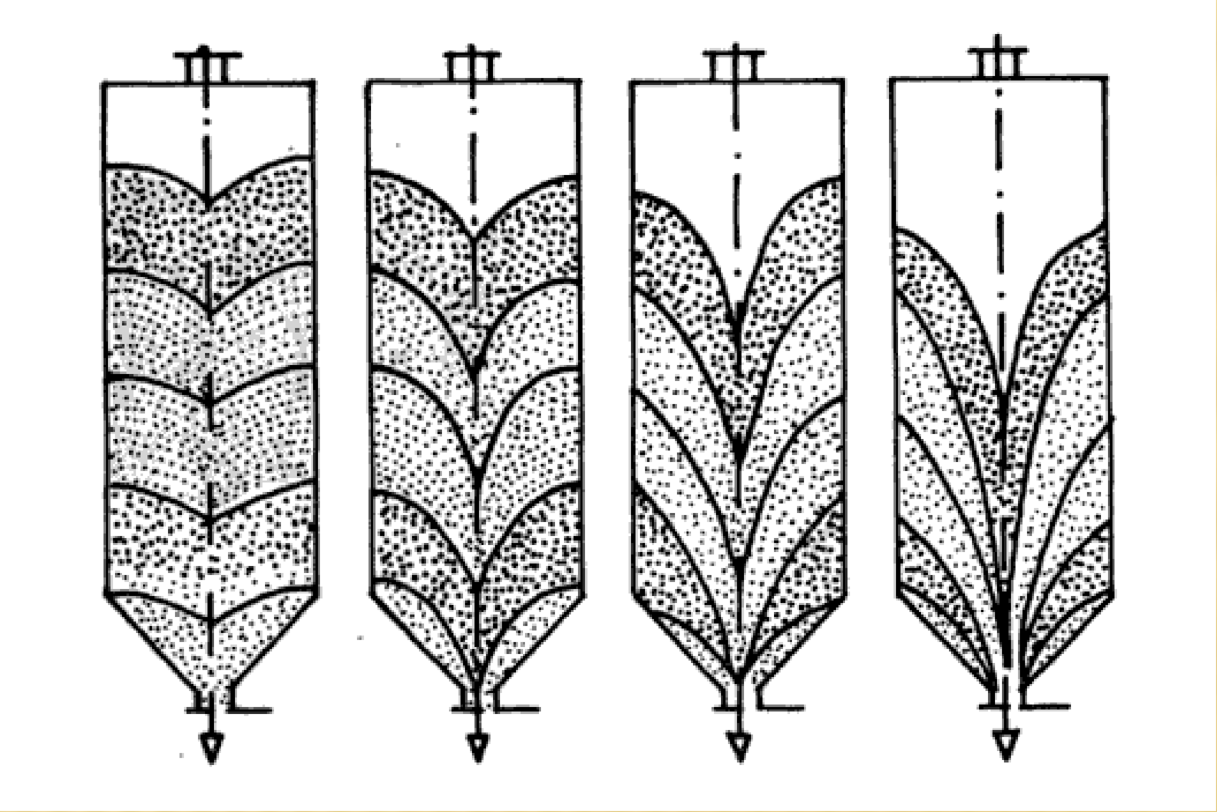
- Pressure is **not uniformly distributed** in all the directions due to development of arches and frictional forces between granular particles.
- The solid grains have **definite shape and size** which govern the rate of flow. Fluids do not have these properties.
- The **rate of *flow* is not proportional to head** except at heads smaller than container diameter

Flow through orifices

- Flow through orifices Information on the flow of grain through openings of various sizes, shapes and orientation is required to determine grain flow and to properly size the opening for flow control during transfer of grain.
- To ensure reliable 'first in first out' flow, laboratory testing of the stored product to determine a number of critical properties such as its unconfined compressive strength after consolidation, internal friction angle, the wall friction angle are required.

Flow through orifices

- Hopper slope angles of 60° or 70° are usually necessary to achieve reliable mass flow.
- With normal hopper slopes of 30°- 40°, pipe flow or funnel flow.



Flow of solid grains

Deming and Mehring applied dimensional analysis technique to study flow of solid particles through funnels and proposed the following relationship.

$$t\,D^{2.5}\,w = f\left(\frac{d}{D}\right)$$

Where, t = time, minutes for flow of 100g material

D = orifice diameter, em

d = equivalent particle diameter, em

w = bulk density, g/cc

They could not establish the actual form of the function, $f\left(\frac{d}{D}\right)$ and proposed that

$$Q = \frac{100\,D^{2.5}\,w}{\tan\phi_r\left[\left(34.6 + 37.4 + 444\sin\frac{\phi_r}{2}\right)\left(\underline{d} + 0.13 - 0.161\tan\phi_r\right)\right]}$$

where, Q = flow rate, g/min

ϕ_r = angle of repose of material

$$\underline{d} = \frac{0.8\left[d_2^5 - d_1^5\right]}{d_2^4 - d_1^4}$$

d_2, d_1 = major and minor dimensions of particle

Flow of solid grains

Ewalt and Buelow (1963) reported that the flow rate of grain through an orifice is independent of the depth of grain above the opening. Beverllooetal (1961) suggested that flow rate varies with the orifice, are times the hydraulic diameter raised to 0.5 power for flow through horizontal openings.

$$Q = 0.75\ A_e \sqrt{g\ De}$$

where, Q = Volume flow rate, m^3/s

g = gravitational acceleration, m/s^2

D_e = effective hydraulic diameter, m

$= D_h - 1.4\ d$

D_h = hydraulic diameter, m

d = average size of particle, m

A_e = effective orifice area calculated from D_e, m^2

Chang et al. (1991) developed an emperical equation for predicting flow of wheat, corn, sorghum and soybean through vertical and horizontal orifices. They reported that the logarithmic plots of volume flow rate per unit orifice area ($m^3/hr/cm^2$) for all orifices shapes versus hydraulic diameter were nearly linear for all tests. They expressed the flow rate as,

$$d = KAD^n$$

where, Q = volume flow rate through the orifice, m^3/hr

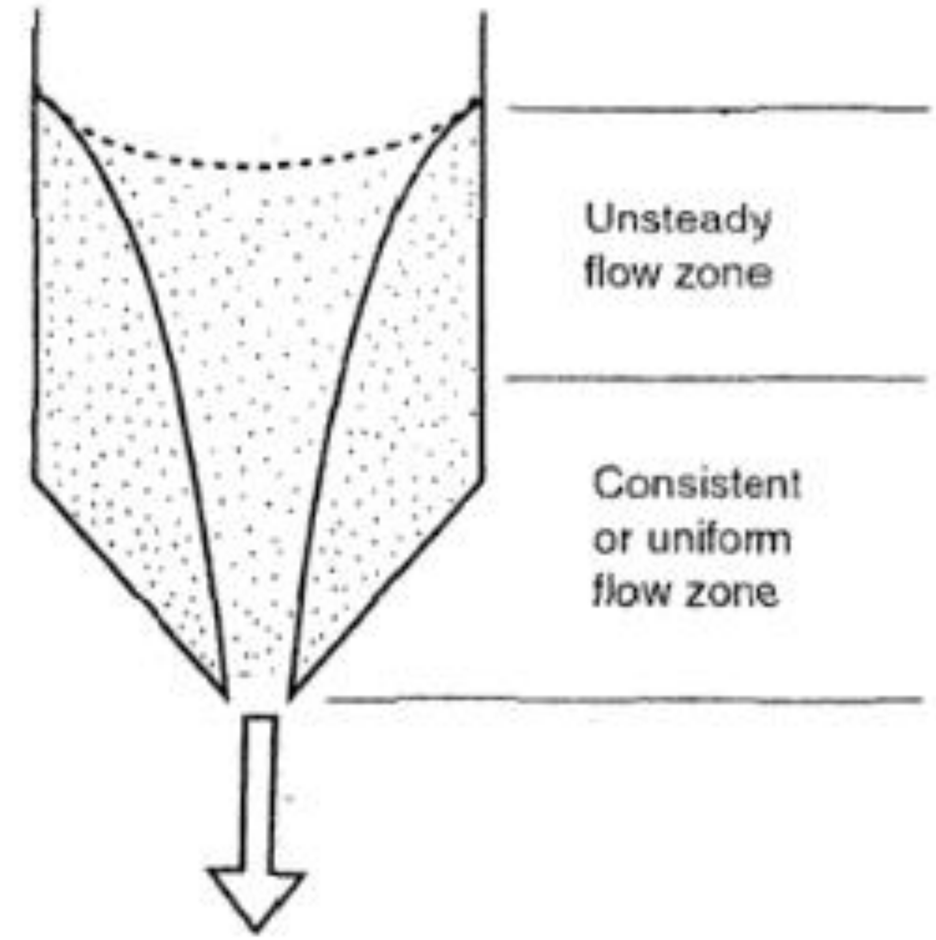
A = Orifice area, cm^2

D = orifice hydraulic diameter, cm

K = coefficient, hr^{-1}

n = coefficient, dimensionless

Flow through circular orifices



PARTICLE SIZE AND SHAPE

- Since the shape of food grains, oilseed and other agricultural granular materials are generally irregular
- The size of grains is represented by their equivalent diameter. It is diameter of a sphere having the same ratio of surface to volume as the actual particle.

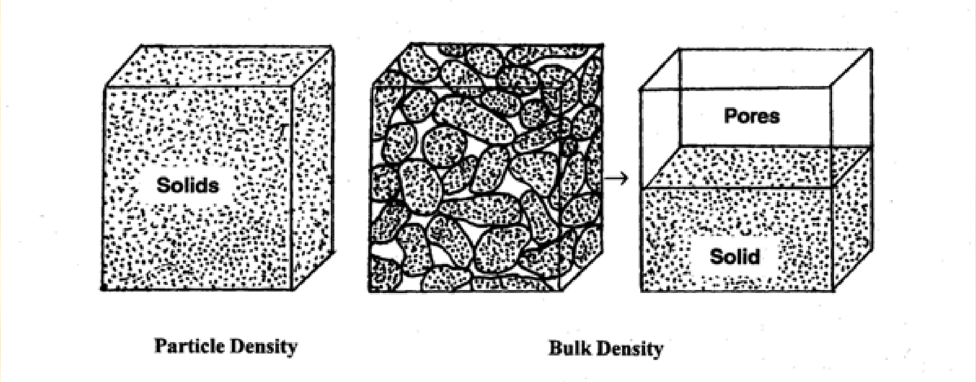
$$Equivalent\ diameter = (a \times b \times c)^{1/3}$$

$$Sphericity = \frac{d_i}{d_c} = \frac{(a \times b \times c)^{1/3}}{a}$$

where, a, b, c are the maximum, intermediate and minimum mutually perpendicular dimensions respectively.

Density

The particle **density** or **true density** of a particulate solid or powder, is the **density** of the particles that make up the powder, in contrast to the bulk **density**, which measures the average **density** of a large volume of the powder in a specific medium (usually air).



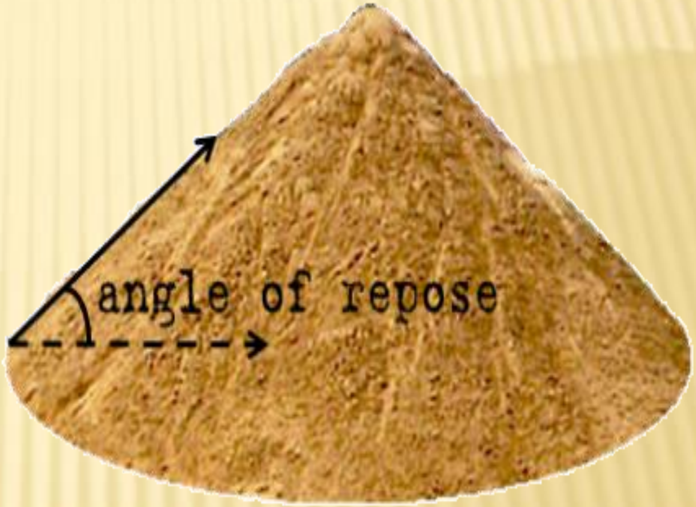
Bulk density is **defined** as the dry weight of soil per unit volume of soil. **Bulk density** considers both the solids and the pore space; whereas, particle **density** considers only the mineral solids.

Density

- **Apparent density** (pb) is the ratio between the **apparent** volume and dry specimen mass of a soil sample. The volume is limited by external specimen forces which include voids.
- The density of compressed mass or bulk is called the 'apparent density'. The value of apparent density is higher by 20% than the normal bulk density.

Angle of repose:

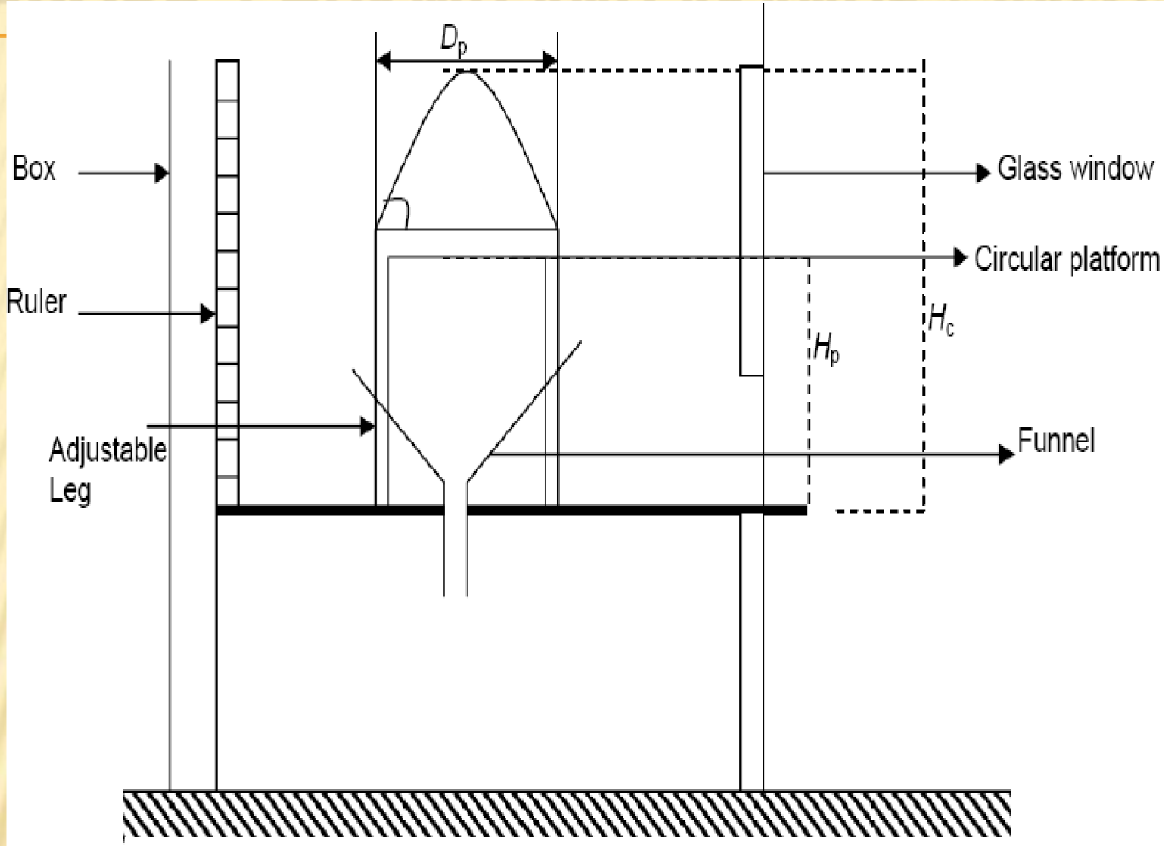
- The steepest angle at which a sloping surface formed of loose material is stable.



Types

1) **Static angle of repose -** granular materials to just slide upon itself
2) **Dynamic angle of repose -** bulk of the grain is in motion like discharge

APPARATUS FOR MEASUREMENT OF THE ANGLE OF REPOSE CHUKWU AND AKANDE *(2007)*



The angle of repose θ_r can be obtained from the geometry of cone from the equation given below:

$$\theta r = \tan^{-1}\left[2\,\frac{(Hc-Hp)}{Dp}\right]$$

Where,

Hc = height of cone from datum.

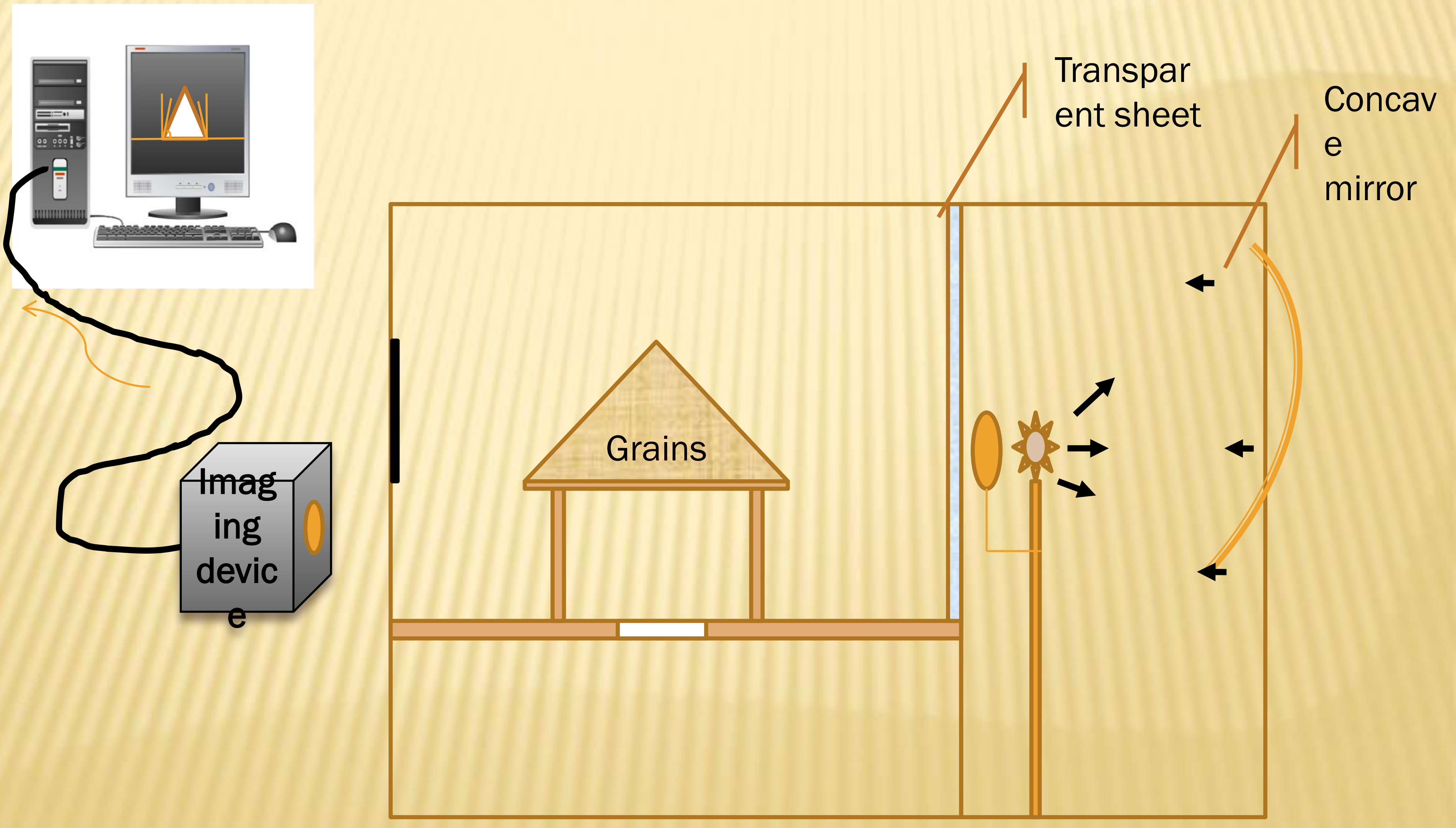
Hp = height of platform.

Hc - Hp = height of cone of solids.

Dp = diameter of circular platform.

θ_r= angle of repose

RAPID ANGLE OF REPOSE APPARATUS



Flow characteristics with respect to angle of repose

Flow characteristics	*Angle of repose, degree*
Very free-flowing	25–30
Free-flowing	30–38
Fair flowing	38–45
Cohesive or non-easy flowing	45–55
Very cohesive	beyond 55

ANGLE OF FRICTIONS

Internal and External Friction In grain conveying systems, two types of friction can be identified,

(1) wall friction or external friction, which is friction between grain mass of kernels and the wall of bin or a surface and

(2) friction of the kernels or grains against each other known as internal friction.

Angle of friction of various silo wall materials

Silo wall material	*Angle of friction, degree*
Oxidised sheet metal	38
Concrete	25
Smooth sheet metal	15
Stainless steel	8

Angle of internal friction of some grains

Grains	*Angle of internal friction, degree*	
	Minimum	*Maximum*
Wheat	24	26
Maize	26	29
Barley	25	29

THANK YOU