AGE 407: Engineering Properties and Processing of Agric. Materials (3 Units)

- Physical and mechanical properties of agricultural materials.
- Thermal properties of agricultural materials.
- Moisture equilibration.
- Air movement.
- Drying theory – thin layer and deep bed drying.
- Design of drying systems.
- Storage principles and practice.
- Principles and applications of the rheology of foods.
- Class project

LECTURER – IN – CHARGE
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Engineering properties and cell

The behaviour of biomaterials are dependent on the cell behaviour. (A brief description of cell structure with diagram is necessary). The cell wall has elastic behaviour. It is capable of expanding and contracting in response to pressure. This is partly responsible for the elastic behaviour of biomaterials. The liquid content of the cytoplasm and the fluid (air content of vacuoles) exhibit the rheological behaviour materials etc.

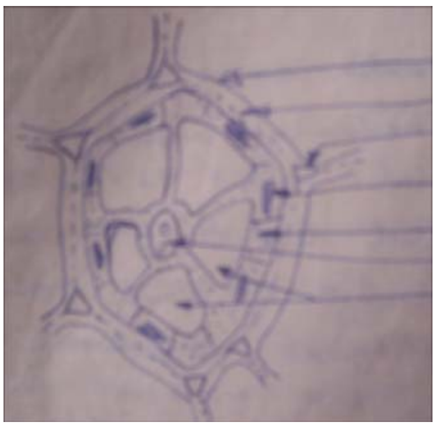


Diagram of any cell with labeling

Basic characteristics of biomaterials

a. Non-homogeneous – Properties vary along a dimension/direction
b. No-isotropic – Properties vary with different directions
c. Moisture dependent – behaviour is dependent on the moisture content
d. Temperature dependent – properties vary with levels of heat applied
e. Time dependent – maturity with time or behaviour differs with time

- **Physical –** Size and Shape – useful in handling, separation and storage
- **Mechanical** – Hardness, friction coefficient – useful in size reduction and conveying operations
- **Thermal** - Thermal Conductivity and diffusivity – useful in heating and cooling operations
- **Electrical** - Conductivity and resistivity - separation and determination of moisture content

Geometric characteristic used in describing different shapes

- Round - approaches circular shape
- Long - longitudinal length greater than the lateral.
- Oblate - flattened stem end
- Oblong - vertical diameter diameter greater than horizontal diameter
- Conic - tapered towards the apex
- Ovate - Egg shaped and broad at tail end
- Regular - Horizontal section approaches a circle

Determination of the physical and mechanical properties

The methods used for are those that have been established in literatures.

Size and Sphericity

Fifty replicate samples of grain/seeds are randomly selected. The three linear dimensions of each seed namely major, intermediate and minor diameters are measured with a micro meter screw gauge, reading to 0.01mm or vernier calliper. The equivalent diameter and sphericity of each seed are determined using the following equation proposed by Mohsenin (1986)

Equivalent Diameter, $D_E = (L \times B \times T)^{1/3}$ ……………….. 1

and Sphericity, $\psi = \frac{(L \times B \times T)^{1/3}}{L}$ …………..………2

where: L = Longest intercept, (Length) in mm; B = Longest intercept normal to 'L' (Breadth) in mm; T= Longest intercept normal to 'L' and 'B'(Thickness) in mm.

Bulk Density:

The bulk density of seed at different moisture content is determined by filling a container of known self-weight and volume to the brim with seeds and weighing to determine the net weight of the seeds. Uniform density is achieved by tapping the container 10 times in the same manner in all measurements. The bulk density is calculated as

$$\text{Bulk Density } (g/cm^3) = \frac{\text{Weight of sample (g)}}{\text{Volume occupied } (cm^3)} \quad \ldots\ldots\ldots\ldots\ldots 3$$

True Density

The true or solid density defined as the ratio of a given mass of sample to its volume is determined by the water displacement method. Accordingly, a known weight (50g) of sample is poured into a $100cm^3$ fractionally graduated cylinder containing $50cm^3$ distilled water. The volume of water displaced by the seeds is observed. The true density s calculated as

$$\text{True Density } (g/cm^3) = \frac{\text{Weight of the sample (g)}}{\text{Volume of distilled water displaced } (cm^3)} \quad \ldots\ldots\ldots\ldots 4$$

The representative values of bulk and true densities are taken as the average of 3 replications.

Porosity

The porosity of an unconsolidated agricultural material can either be determined experimentally using the porosity tank method or theoretically from bulk and true densities of the material. Results from both methods have been found to be in close agreement (Waziri and Mittal, 1983). The porosity of seed determined using the relationship presented by Mohsenin (1986) as follows;

Porosity = (1 – (Bulk Density/ True Density))/100 ………………5

Laboratory Determination of the Porosity of granular materials

Steps

- Fill jar 2 with the product and set up the two jars as shown
- Close valves 2 and 3 and pump air into jar 1until a considerable pressure P1 is recorded. Using the gas law
  $P_1 V_1 = m_1 R_1 T_1$
- Close valve 1 and open 3 with two remaining closed and draw out air from jar two
- Close valve 3 and open 2. The air in jar 1 will be distributed into the two jars. Pressure will drop. Record the pressure as P2
- In jar 1; $P_2 V_1 = m_{1a} R_1 T_1$
- In jar 2; $P_2 V_2 = m_2 R_2 T_2$

But $m_1 = m_{1a} + m_2,$

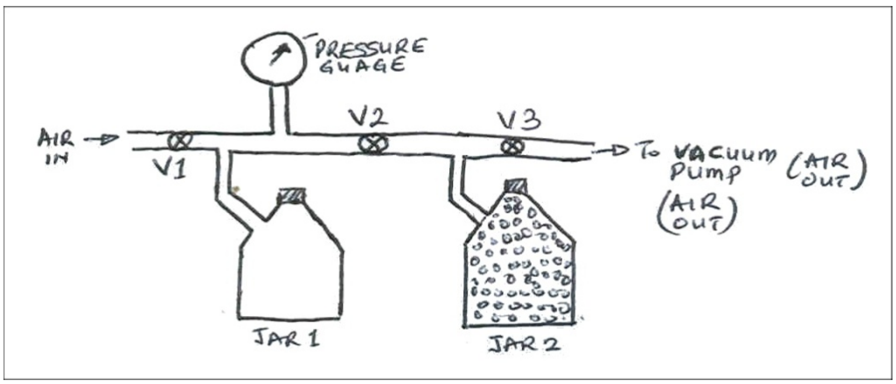
Also since the same gas is used throughout under the same condition;

$R_1 = R_2$ and $T_1 = T_2$

Therefore from Equations 1,2,3 and 4

$$P_1 V_1 = P_2 V_1 + P_2 V_2$$

$\frac{V_2}{V_1} = \frac{P_1 - P_2}{P_2}$ = ratio of void in jar 2 to volume of jar2 (= Vol of jar1)



Thousand Kernel Weight

For small seeds, 1000 kernels are weighed and a parameter known as the thousand-kernel weight (TKW) is determined. An electronic weighing balance having a sensitivity of 0.10g is used.

Coefficient of Friction

The static coefficient of friction was obtained on four structural surfaces namely mildsteel, plywood, concrete and glass. In the case of plywood the direction of movement was parallel to the grain. A tilting table (constructed by the Department of Agricultural Engineering, UNAAB) can be used. The surface to be tested is fixed on the tilting table and the seeds are poured into a cardboard paper ring of diameter 10cm by 2cm deep until the ring is full. Care is taken to raise the ring slightly so that it did not touch the surface. The table is then slowly tilted by a gentle screwing device until movement of the seeds down mounted against the edge of the tilting table. The tangent of the angle of friction is the coefficient of friction

AERODYNAMICS PROPERTIES

The properties include particle diameter, frontal area, terminal velocity and drag coefficients.

Before the introduction of the first set of machines, contaminants were removed from seeds by hand. A mixture of grain and straw was spread in a thin layer on the threshing floor and the large contaminant particles mostly pieces of straw, were removed with a rake. The remaining contaminants larger than the grains were removed with broom or goose wing. Light contaminants were removed by throwing the grain against the wind which lifted the contaminants and ensured partial separation. This manual process is usually time and energy consuming and the efficiency of separation is low. This led to the invention of cleaning machines. The operation of those machines as reported by Adegbulugbe (1983) consist almost solely of separating non-edible impurities such as rubble, lumps, stick, straw, stringe and trapped irons which are obvious. The major characteristics used in separation are size, shape, density, surface texture, terminal velocity, electrical conductivity, colour and resilience (Koya and Adekoya, 1994; Lucas and Olayanju, 2003). These determine what methods of cleaning can be used and their level of efficiency. Most cleaning operations used physical and aerodynamics properties of grain either singly or in some combination. This depends primarily on the grain being cleaned, the quantity of weeds and other contaminants in the mixture and the purity requirements that must be met.

Test Equipment

Terminal velocity of seed, the velocity at which the seed remains in suspension, is measured by using a vertical air tunnel (Figure 1). It consists of the following components: a frame, wind tunnel, plenum chamber, flow straightener, centrifugal blower, electric motor, pitot tubes and inclined manometer filled with coloured water.

The centrifugal fan was mounted on a frame and it provides air current for the equipment. A vertical tunnel which was coupled to the fan is 1200mm long with 100mm x 100mm cross section. An adjustable flap at the top of the fan allows variation of admission of air from the fan into the tunnel. The tunnel was built with mild steel sheet but the front was covered with 2mm thick transparent plastic material for observation. A window was cut at the front of the test section, and below it is a small screen braced to cover the inside of the section. This was to break small eddies behind the vanes and to keep the seed from falling into the chamber (Figure 2).

Air current was monitored in the tunnel with a pitot-static tube mounted inside the tunnel below the product-holding screen. These were two in numbers; the total pressure pitot tube and the static pressure pitot tube. The former is a right-angled bent tube with long arm being 290mm and short arm being 95mm. The static tube is straight with 200mm^2. The diameter of the glass tube is about 10mm.

The out ports of the pilot static tube were connected to the two arms of a -coloured water filled manometer. It is made with a 10mm diameter glass tube inclined at 12^0 to the horizontal. It has a length of 440mm; longer limb 320mm and shorter limb 320mm. The manometer was installed on a – 700mm long, 400mm wide and 12mm thick plywood. Two-holes were drilled at the top of the frame to hold the rubber corks through which manometer limbs passed out. The manometer was connected to the pilot tubes by Ǿ 10mm rubber tubes. A ruler was screwed to the frame below the manometer. This is to aid the reading of the rise of the liquid.

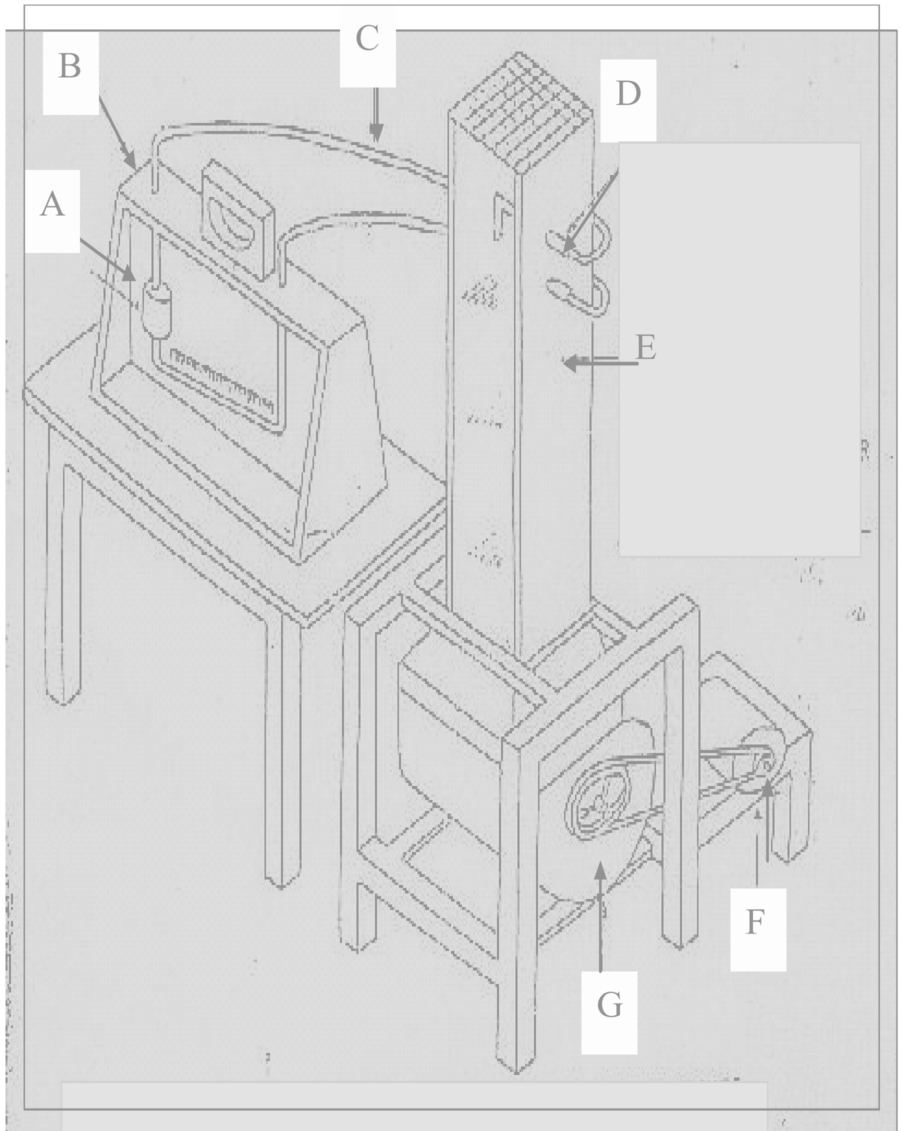


Figure 1: Isometric View of the Terminal Velocity Test Equipment
A – Manometer; B – Manometer Box; C – Rubber Hose;
D – Pitot Tube; E – Wind Duct; F – Electric Motor; G – Blower

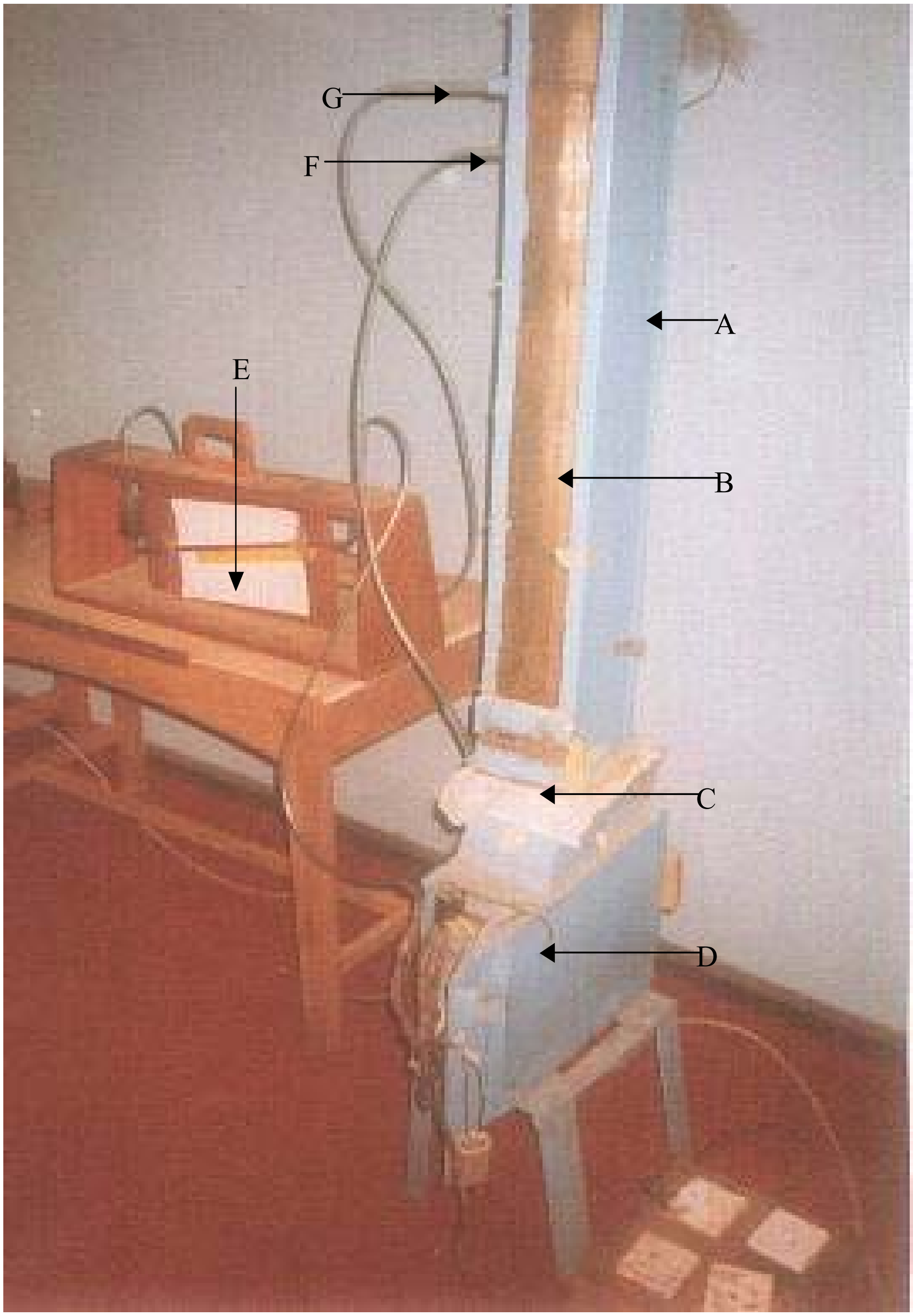


Figure 2: Terminal Velocity Test Equipment
A – Vertical Tunnel; B – Perspex Glass; C – Seed Inlet; D – Centrifugal Blower; E – Manometer; F – Total Pressure Tube; G – Static Pressure Tube

Principle of Operation

From Bernoulli's equation (Douglas et al), at two points 1 and 2 in a flowing fluid (Figure 3):

$$\frac{P_1}{D} + \frac{V_1^2}{2g} + m = \frac{P_2}{D} + \frac{V_2^2}{2g} + h_2$$

where $\frac{P}{D}$ is the pressure head

$\frac{V^2}{2g}$ is the velocity head and h is the elevation head.

D is the density based on gravity.

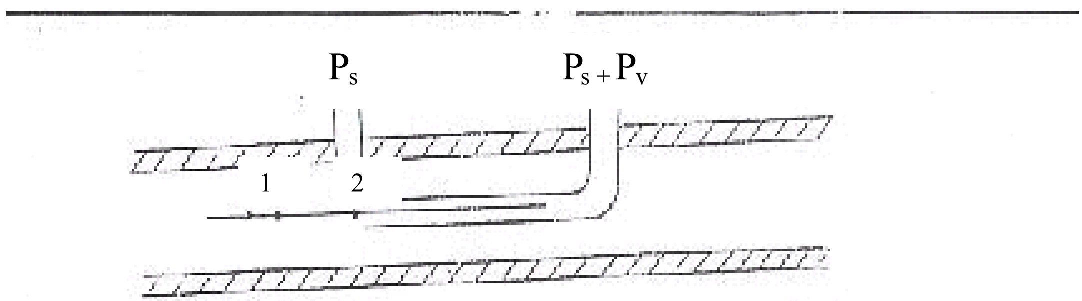


Figure 3: Static and Total Pressure Pitot Tubes

Bernoulli's principle states that in a pipe where fluid flows under steady state conditions without friction, total head is constant; if pressure head is lost, it appears as a Ǿ = 12^0 gain in velocity head. In a flow of fluid through a level pipe as shown above, applying Bernoullis equation to points 1 and 2 gives:

$$\frac{P_1}{D} + \frac{V^2}{2g} = \frac{P_2}{D} + 0$$

The velocity at point 2 is zero as this is a stagnation point where only static pressure is considered to be acting. Therefore,

$$\frac{P_2 - P_1}{D} = \frac{V^2}{2g}$$

The pressure heads measured by the manometer is h. Therefore,

$$V = \sqrt{2gh}$$

where h is the head measured by the manometer after it has been converted into head of working fluid. In this, the range of different air velocities was obtained by adjustable speed motor attached with blower.

Measurements of Terminal Velocity

The test equipment is initially run without any seed while response of the measuring instrument: Pitot – static tube and manometer are observed. The seed sample is placed on a mosquito wire netting within the duct and is blown upwards using a centrifugal blower whose speed is controlled by a variable speed motor. The air velocity at which the seed is lifted off the contacting surface is determined.

Computation of Terminal Velocity using Sphericity Method

The terminal velocity of beniseed was also computed based on its sphericity. According to the equation proposed by Torobin and Ganvin (1960) as reported by Gorial and O'callaghan 1991; the drag coefficient, $C_D = 5.31 - 4.884\ \psi$ for low Reynold's number (with $\pm$ 4% accuracy) where ψ is sphencity of grain with $2000 < Re < 200,000$.

The value of C_D is then used in an equation proposed by Kashayap and Pandya, 1986 for calculation of terminal velocity as:

$$V_t = \sqrt{\frac{2Mg}{A_p S_f C_D}}$$

where:

M = Weight of particle (kg)

A_P = Projected area of seed, LW (m^2)

C_D = Drag Coefficient

δ_f = Density of fluid (air), (kg/m^3) = 1.150

N.B - Density and Viscosity of air were assumed constant at the temp and pressure when the experiment was carried out

g = Acceleration due to gravity, m/s^2 = 9.81

Terminal Velocity

This is the main characteristic employed in the separation process and can be determined by the suspension velocity test which as follows: A duct 1m long with a rectangular section of 0.1m x 0.1m is used to suspend particles in an air stream. Air is supplied by a centifugal fan driven by an electric motor. The fan delivered air through a converging duct. Mmean air velocity is determined as a function of mid velocity, obtained from computation using a pitot tube and manometer of trading up to less than 1m/s.

Suspension tests are carried out on all components or the grain mixture by placing particles of the grain mixture on the duct until the particles, seen through the transparent wall, floated in the central area of the air stream.

Mechanical Behaviour of Beniseed under Compression Loading

Compression tests are performed on seeds/kernels using the Monsanto Universal Testing Machine (National Centre for Agricultural Mechanization, (NCAM) Ilorin, Kwara State). Testing Conditions for the lnstron Machine were loading range: 0 - 500N; chart speed – 50rpm/mm; Crosshead speed – 1.5mm/min. The procedure used by Braga et. al. (1999) is followed.

Each seed is placed between the compression plates of the tensonometer (Plate 3). The seed is compressed at a constant deformation rate of 1.25mm/min. The applied forces at bioyield and oil points and their corresponding deformations for each seed sample is read directly from the force-deformation curve. The mechanical behaviour of seed is expressed in terms of force required for maximum strength of the seed, energy required to deform the seed to initial rupture and seed specific deformation. The rupture force is determined as the force on the digital display when the seed under compression makes a clicking sound. Each process is often completed whenever the break point of the positioned seed is reached.

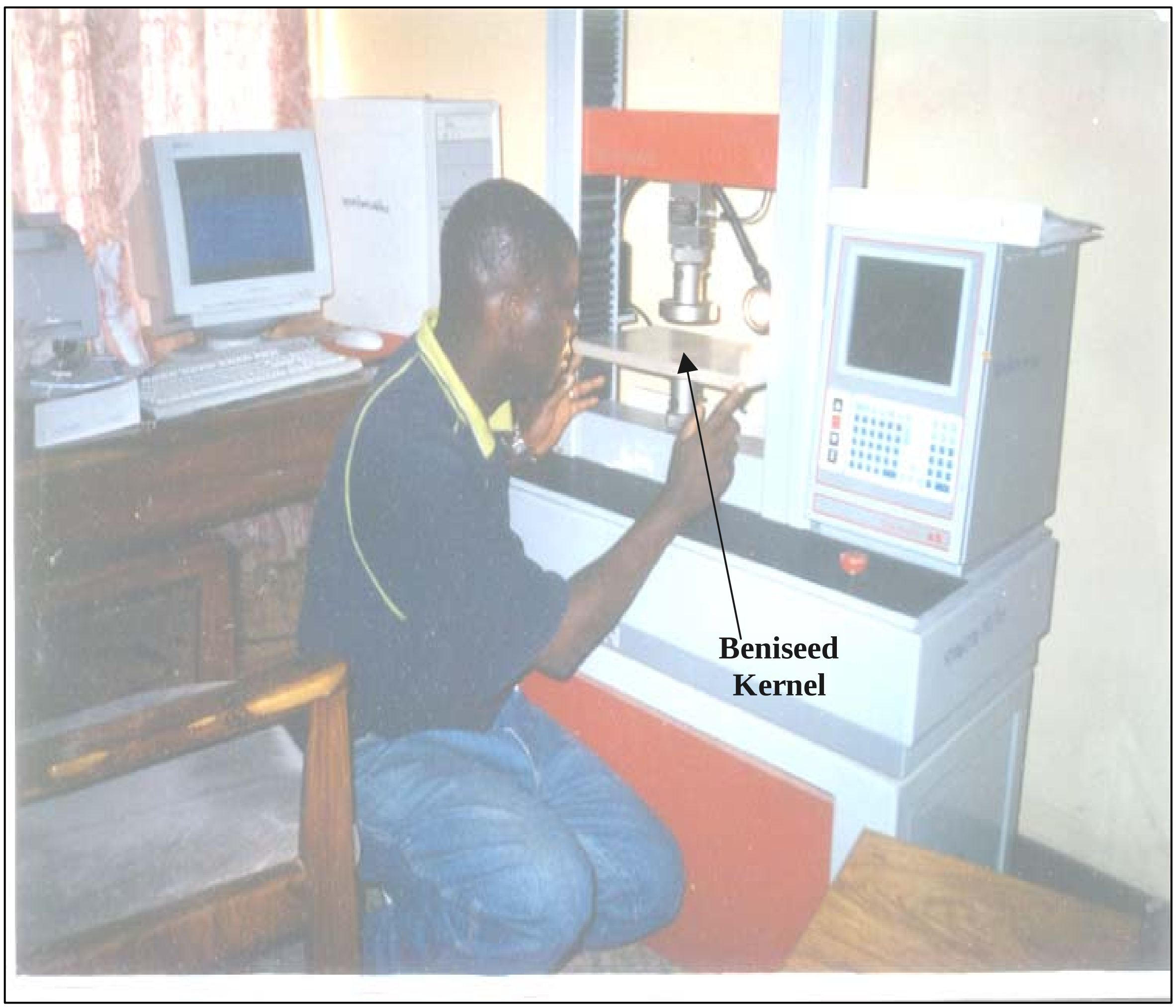


Plate 3: Seed Kernel under Compression Loading

Table 1: Measured Terminal Velocity of Beniseed at the Storage Moisture Content of 5.3% wb Using Vertical Tunnel

Serial No	Inclined length L, 10^{-3}(m)	Actual length $h_w = L\sin\theta$, 10^{-3}(m)	Height of air ha = hwdw/da, 10-3(m)	Terminal velocity Vt = 2/gha, (m/s)
1	1.1	0.23	0.19	1.95
2	1.2	0.25	0.21	2.02
3	1.1	0.23	0.19	1.95
4	1.1	0.23	0.19	1.95
5	1	0.21	0.17	1.84
6	1	0.21	0.17	1.84
7	1.2	0.25	0.21	2.02
8	1.1	0.23	0.19	1.95
9	1.2	0.25	0.21	2.02
10	1	0.21	0.17	1.84
11	1.1	0.23	0.19	1.95
12	1.1	0.23	0.19	1.95
13	1.2	0.25	0.21	2.02
14	1.4	0.29	0.24	2.18
15	1.1	0.23	0.19	1.95
16	1.1	0.23	0.19	1.95
17	1.2	0.25	0.21	2.02
18	1.2	0.25	0.21	2.02
19	1.2	0.25	0.21	2.02
20	1.1	0.23	0.19	1.95
21	1.2	0.25	0.21	2.02
22	1.1	0.23	0.19	1.95
23	1.1	0.23	0.19	1.95
24	1.6	0.33	0.28	2.33
25	1	0.21	0.17	1.84
26	1.1	0.23	0.19	1.95
27	1.2	0.25	0.21	2.02
28	1.2	0.25	0.21	2.02
29	1.4	0.29	0.24	2.18
30	1.2	0.25	0.21	2.02
31	1.4	0.29	0.24	2.18
32	1.1	0.23	0.19	1.95
33	1.5	0.31	0.26	2.26
34	1	0.21	0.17	1.84
35	1.1	0.23	0.19	1.95
36	1.6	0.33	0.28	2.33
37	1.1	0.23	0.19	1.95
38	1.1	0.23	0.19	1.95
39	1.2	0.25	0.21	2.02
40	1.1	0.23	0.19	1.95
41	1	0.21	0.17	1.84
42	1.1	0.23	0.19	1.95
43	1.5	0.31	0.26	2.26
44	1.1	0.23	0.19	1.95
45	1.2	0.25	0.21	2.02
46	1	0.21	0.17	1.84
47	1.1	0.23	0.19	1.95
48	1.1	0.23	0.19	1.95
49	1.6	0.33	0.28	2.33
50	1.1	0.23	0.19	1.95
Mean	1.176	0.2452	0.2036	2.0018
Maximum	1.6	0.33	0.28	2.33
Minimum	1	0.21	0.17	1.84
Std. Deviatio	0.159795788	0.031959158	0.028696867	0.127642517

θ = Manometer's angle of inclination = 12 deg; **δ_w** = Density of manometer's fluid (water) = 1000kg/m^3;
δ_a = Density of air at room temperature = 1.2kg/m^3; **g** = Acceleration due to gravity = 9.81m/s^2

Moisture content
Moisture content is the amount of moisture per unit weight of the product.

Moisture content wet basis and moisture content dry basis.
Mwb is the weight of water in a product per unit weight of the wet material, expressed in percentage.

Mdb is the weight of water in a product per unit weight of the dry matter, expressed in percentage.

The relationship between *Mwb* and *Mdb* is as follows:

$$Mwb = \frac{Mdb(100)}{100 + Mdb}$$

$$Mdb = \frac{Mwb(100)}{100 - Mdb}$$

Mwb is usually used in commerce, *Mdb* in engineering calculations.

EXAMPLES
1a) You are supplied with two bags of maize each weighing 1.0tonne. One bag has maize of 25% dry basis and the other contains maize of 25% wet basis. Which bag contains more dry matter? Show your calculations.

Solution
a) 1tonne of maize = 1000kg

i) $Mwb = Mw/ Mwp$

$Mw/1000 = 0.25$

$Mw = 250kg; \quad Mdm= 750kg$

ii) $Mdb= Mw/(Mwp – Mw)$; $Mw/1000 – Mw) = 0.25$

$Mw = 250 – 0.25M\ Mw; \quad Mdm= 750kg$

$Mw = 200kg; \quad Mdm= 800kg$

The bag of 25% dry basis contains more dry matter:

b) For storage, two bags of maize in (b) are dried to moisture content of 13% wet basis. How much water or moisture will each loose? Show all calculations.

For the first bag, $\frac{Mw}{750 + Mw} = 0.13$

$Mw = 97.5 + 0.13M\ Mw;$

$Mw = 112.07kg$

Water lost = 250 – 112.07 = 137.93kg

For the second bag, $\frac{Mw}{800 + Mw} = 0.13$

$Mw = 104+ 0.13M\ Mw;$

$Mw = 119.54kg$

Water lost = 200 – 119.54 = 80.46kg

(2) A biscuit factory obtained maize from two sources (20 tonnes each), one has 12% moisture content (mc) dry basis and the other 12% mc wet basis. Which one has more dry matter? Justify your answer with calculations.

Both bags have same weight, hence wet weight (original weight) are same

MD = 0.12, MW = 0.12, WW = 20000Kg

Dry Basis	Wet Basis
$MD = \dfrac{WW - DWd}{DWd}$	$MW = \dfrac{WW - DWw}{WW}$
WW = DWd(MD + 1)	WW = $\dfrac{DWw}{1 - MW}$
DWd = $\dfrac{WW}{MD+1}$	DWw = WW(1-MW)
= 20000 $(1.12)^{-1}$	= 20000(0.88)
= 17,860 kg	= 17,600kg

Bag with MC dry basis is heavier in dry matter

(b) In (i) above, the company paid ₦60000.00 per tonne for the maize at 12% mc dry basis. How much should a tonne cost at 12% mc wet basis. If the materials has to be dried to 5% mc dry basis, what quantity of water will be lost from the material from each source per tonne.

Since both will have the same dry matter content i.e. if material in the bag with dry basis was to have been at wet basis

1 Tonne of dry basis costs ₦ 60,000.00

Dry weight for the MD bag = DWd = $\dfrac{WW}{MD+1}$ = $1000((1.12)^{-1}$ = 893kg

The actual wet weight of the MW bag will be WW = $\dfrac{DWw}{1-MW}$ = $893(0.88)^{-1}$ = 1014kg

Therefore 1 Tonne of wet will cost $\dfrac{60{,}000(1000)}{1014}$) = ₦59,171.59

Drying to 5% mc for dry basis ***(This can be done for either 1 or 20 Tonnes)***

WW = DW(MD + 1) = 17860(1.05) = 18753

Weight of water lost = 20,000 – 18753 = 1247kg

Drying to 5% mc for wet basis

WW = $\dfrac{DWw}{1-MW}$ = $17600(1.-0.05)^{-1}$ = 19,555

Weight of water lost = 20,000 – 19555 = 444.44kg

Forms in which water is found in food materials

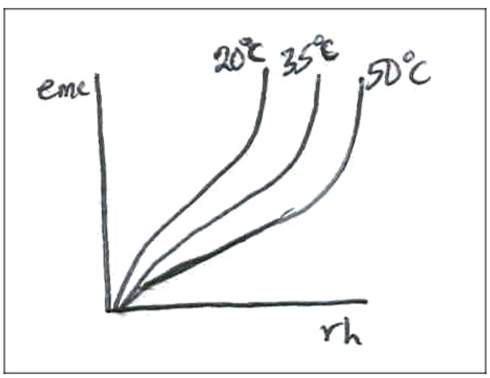
- Pure form as surface water. In this case , it is not part of the product but comes from external source
- Chemically bound to some salts either by its prime valence or as a hydrate. This is not expelled by the common method of food processing.
- Adsorbed as a very thin mono or poly – molecular layer in the internal or external surfaces of product by molecular forces or in fine pores by capillary condensation.
- Adsorbed by colloid substances and remain in a jell as of water of swelling due to its dipolar character.
- Present as a continuous phase, in which 0ther substances may be dispersed molecularly, colloid ally or as an emulsion.

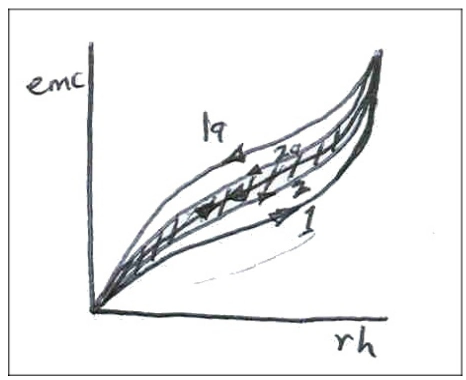
Equilibrium moisture content – moisture content at which the vapour pressure of the moisture present in a product is at equilibrium with the vapour pressure of the environment at constant temperature.

Relative humidity - Ratio of the moisture present in an environment at a given temperature and pressure relative to saturation \

Moisture isotherm - Relationship between the emc and rh at constant temperature.

It is a sigmoidal shaped curve of emc vs rh during sorption and desorption of biomaterials.





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From the diagram, during sorption, the path of the curve is as shown as curve 1. It is expected that the curve will come back through the same path. However this doesn’t happen in practice. Therefore curve 1a represent the desorption curve which shows that there a lagging effect called hysteresis (shaded portion) representing a lost in energy!. This effect is repeated with repeated sorprtion and desorption with the energy lost reducing until the curve closes up and sorption and desorption follows the same path.

Fineness Modulus and Uniformity Index

Fineness modulus is the sum of the weight fractions retained in each of the seven sieves divided by 100. It indicates the average distribution of fines and coarse in a feed.

Uniformity index is a measure of the relative uniformity of of the different sizes of particles in a ground feed sample. It is expressed as a ratio of 3 figures which indicate the proportions of coarse, medium and fine particles in the feed.

Laboratory Determination of Fineness Modulus of a feed

Fineness Modulus is determined in the following way:
Weigh out 250g of ground feed and shake it through 7 sieves of Tyler sieve for 5min by means of ro –tap shaker or similar method. The mesh nos of the 7 sieves are 3/8, 4, 8, 14, 28, 48 and 100 as well as the pan at the bottom. The sieves are designated 1 – 7 starting from the smallest to the biggesti.e from 100 to 3/8 while the pan is designated as 0. Calculate the percentage of material on each screen and multiply it by the designated no. add up all and divide by 100. The result is known as F.M. of the feed.

EXAMPLES

(i) Below is a result of a sieve experiment using poultry feed.

Sieve Mesh	% of Material on each Screen
$^3/_8$	2
4	1.5
8	7.0
14	20.0
28	31.5
48	26.5
100	11.5
Pan	0

From this result, calculate the Uniformity Index. How can you describe the feed?

Coarse = (2 + 1.5 + 7.0)/10 = 1.05; approximately 1

Medium = (20 + 31.5)/10 = 5.15; approximately 5

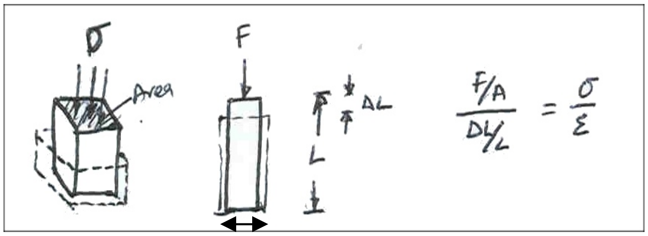
Fine = (26.5 + 11.5 + 0)/10 = 3.8; approximately 4

Uniformity index = 1:5:4

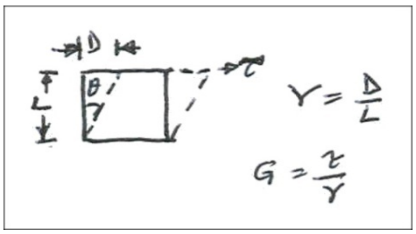
From the above, the feed is between medium and fine.

RHEOLOGY

Young's modulus – E = $\dfrac{Normal\ stress(\sigma)}{Normal\ strain\,(\varepsilon)}$

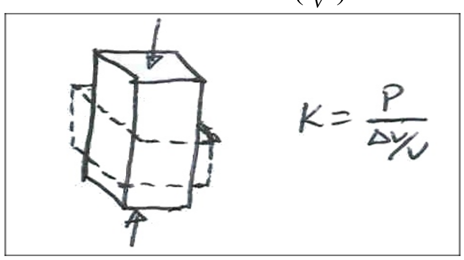


Modulus of rigidity – G = $\dfrac{Shear\ stress\,(\tau)}{Shear\ strain\,(\gamma)}$



w+Δw

Bulk modulus - K = $\dfrac{Pressure\,(P)}{Volumetric\ strain\,(\frac{\Delta V}{V})}$ Poisson's ratio - $\mu = \dfrac{\frac{\Delta L}{L}}{\frac{\Delta W}{W}}$



E = Elastic Modulus, G = Modulus of rigidity, K = Bulk Modulus, μ = Poisson ratio

$$\frac{1}{E} = \frac{1}{3G} + \frac{1}{9K}, \qquad E = 3K(1-2\mu), \qquad E = 2G(1-\mu)$$

Liquid is not compressible, hence G = 0

From Eqn 3, E = 2x0(1-μ) = 0

Liquid doesn't support shear stress, this implies K = ∞ In Eqn 2, $\dfrac{E}{3\infty} = 0$ for E = 0 or K = ∞

Hence 1- 2μ = 0

Therefore μ = $\dfrac{1}{2}$

VISCOSITY

Newtonian and Non-Newtonian Fluids

Viscosity is that property of a fluid that gives rise to forces that resist the relative movement of adjacent layers in the fluid. Viscous forces are of the same character as shear forces in solids and they arise from forces that exist between the molecules.

If two parallel plane elements in a fluid are moving relative to one another, it is found that a steady force must be applied to maintain a constant relative speed. This force is called the viscous drag because it arises from the action of viscous forces.
Consider the system shown in Fig 1.

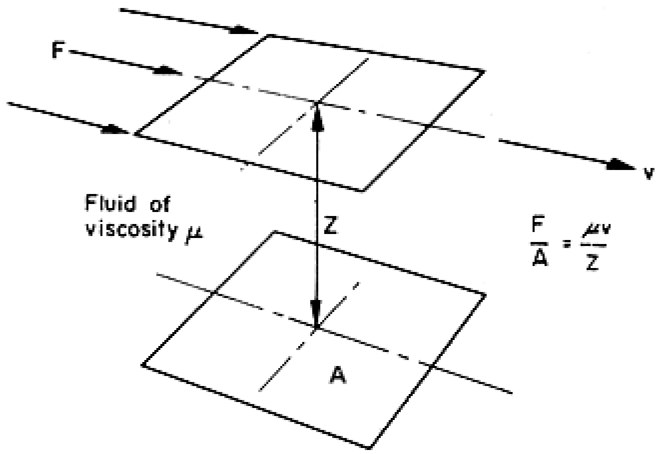


Figure 1. Viscous forces in a fluid.

If the plane elements are at a distance Z apart, and if their relative velocity is v, then the force F required to maintain the motion has been found, experimentally, to be proportional to v and inversely proportional to Z for many fluids. The coefficient of proportionality is called the viscosity of the fluid, and it is denoted by the symbol m (mu).

From the definition of viscosity we can write F/A = mv/Z
(3.14) where F is the force applied, A is the area over which force is applied, Z is the distance between planes, v is the velocity of the planes relative to one another, and m is the viscosity.
By rearranging the eqn. (3.14), the dimensions of viscosity can be found.

$$[m] = \frac{FZ}{Av} = \frac{[F][L][t]}{[L^2][L]} = \frac{[F][t]}{[L]^2} = [M][L]^{-1}[t]^{-1}$$

There is some ambivalence about the writing and the naming of the unit of viscosity; there is no doubt about the unit itself which is the N s m-2, which is also the Pascal second, Pa s, and it can be converted to mass units using the basic mass/force equation. The older units, the poise and its sub-unit the centipoise, seem to be obsolete, although the conversion is simple with 10 poises or 1000 centipoises being equal to 1 N s m^{-2}, and to 1 Pa s.
The new unit is rather large for many liquids, the viscosity of water at room temperature being around 1 x 10-3 N s m-2 and for comparison, at the same temperature, the approximate viscosities of other liquids are acetone, 0.3 x 10-3 N s m-2; a tomato pulp, 3 x 10-3; olive oil, 100 x 10-3; and molasses 7000 N s $m^{-2.}$

Viscosity is very dependent on temperature decreasing sharply as the temperature rises. For example, the viscosity of golden syrup is about 100 N s m-2 at 16°C, 40 at 22°C and 20 at 25°C. Care should be taken not to confuse viscosity m as defined in eqn. (3.14) which strictly is called the dynamic or absolute viscosity, with m/r which is called the kinematic viscosity and given another symbol. In technical literature, viscosities are often given in terms of units that are derived from the equipment used to measure the viscosities experimentally. The fluid is passed through some form of capillary tube or constriction and the time for a given quantity to pass through is taken and can be related to the viscosity of the fluid. Tables are available to convert these arbitrary units, such as "Saybolt Seconds" or "Redwood Seconds", to poises.

The viscous properties of many of the fluids and plastic materials that must be handled in food processing operations are more complex than can be expressed in terms of one simple number such as a coefficient of viscosity.

Newtonian and Non-Newtonian Fluids

From the fundamental definition of viscosity in eqn. (3.14) we can write:

F/A = mv /Z = m (dv/dz) = t

where t (tau) is called the shear stress in the fluid. This is an equation originally proposed by Newton and which is obeyed by fluids such as water. However, for many of the actual fluids encountered in the food industry, measurements show deviations from this simple relationship, and lead towards a more general equation:

t = k(dv/dz)n (3.15)

which can be called the power-law equation, and where k is a constant of proportionality.

Where n = 1 the fluids are called Newtonian because they conform to Newton's equation (3.14) and k = m; and all other fluids may therefore be called non-Newtonian. Non-Newtonian fluids are varied and are studied under the heading of rheology, which is a substantial subject in itself and the subject of many books. Broadly, the non-Newtonian fluids can be divided into:

(1) Those in which n < 1. As shown in Fig. 3.6 these produce a concave downward curve and for them the viscosity is apparently high under low shear forces decreasing as the shear force increases. Such fluids are called pseudoplastic, an example being tomato puree. In more extreme cases where the shear forces are low there may be no flow at all until a yield stress is reached after which flow occurs, and these fluids are called thixotropic.

(2) Those in which n > 1. With a low apparent viscosity under low shear stresses, they become more viscous as the shear rate rises. This is called dilatancy and examples are gritty slurries such as crystallized sugar solutions. Again there is a more extreme condition with a zero apparent viscosity under low shear and such materials are called rheopectic. Bingham fluids have to exceed a particular shear stress level (a yield stress) before they start to move.

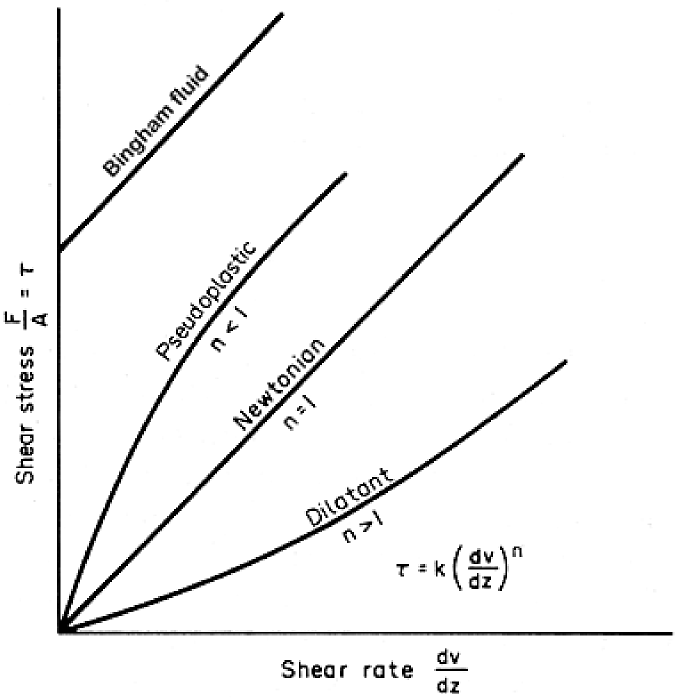


Figure 3.6. Shear stress/shear rate relationships in liquids.

In many instances in practice non-Newtonian characteristics are important, and they become obvious when materials that it is thought ought to pump quite easily just do not. They get stuck in the pipes, or overload the pumps, or need specially designed fittings before they can be moved. Sometimes it is sufficient just to be aware of the general classes of behaviour of such materials. In other cases it may be necessary to determine experimentally the rheological properties of the material so that equipment and processes can be adequately designed.

VISCOCITY

- Dilatant - Dynamic viscosity increases as the rate of shear increases (shear thickening -)
- Pseudoplastic - Dynamic viscosity decreases as the rate of shear increases (shear thining - milk)
- Rheopexy - Shear stress increases with time of shear at a given shear rate – starch
- Thixotropix - Shear stress decreases with time of shear at a given shear rate – honey, bread dough

Non-newtonian fluid

The relationship in a non-newtonian fluid between shear stress (τ) and velocity to diameter ratio (V/D) is given as $\frac{\Delta P.D}{4L} = \tau = K\left(\frac{8V}{D}\right)^n$. We can determine, graphically, the viscous coefficient and the velocity index using a capillary viscometer?

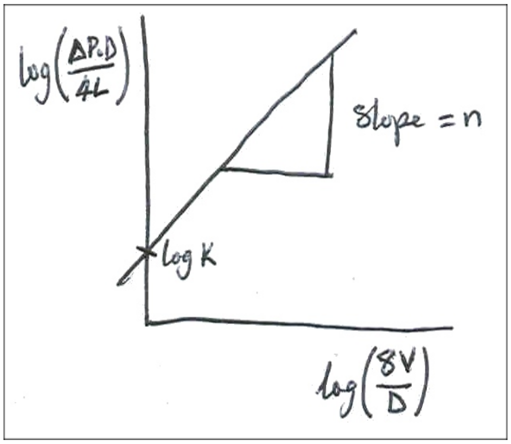
$$\frac{\Delta P.D}{4L} = \tau = K\left(\frac{8V}{D}\right)^n$$

Taking log of both sides

$$\log\left(\frac{\Delta P.D}{4L}\right) = \log K + n\log\left(\frac{8V}{D}\right)$$

$$\log\left(\frac{\Delta P.D}{4L}\right) = n\log\left(\frac{8V}{D}\right) \quad + \log K$$

This implies y = m x + c



Diagram

In a viscometer, varying the velocity and noting the pressure difference results in a record useful for plotting a curve as shown below

From the graph

logK = the intercept on the y axis, hence

K = log^{-1}(intercept on y-axis) = Viscous coefficient

n = the slope of the graph = velocity index

Useful in solving a flow problem in a food processing industry

An idea of the K and n obtainable by experimentation using a viscometer can assist in determining the appropriate pipe diameter or pipe length for a particular type of pipe which gives the K and n that will cope with the speed of operation required. A knowledge of the K is also useful in determining the power requirement for lifting or pumping the fluid hence the selection of appropriate pump for the factory operations.

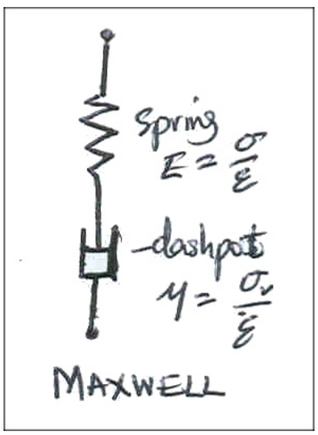
Behaviour of agricultural/food materials under stress

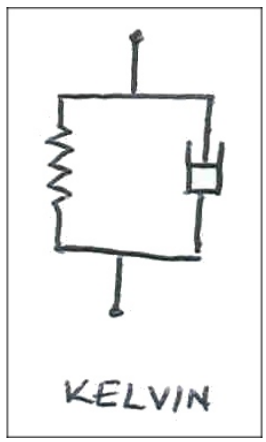
The behaviour of agricultural materials under stress can be represented by any of these three models

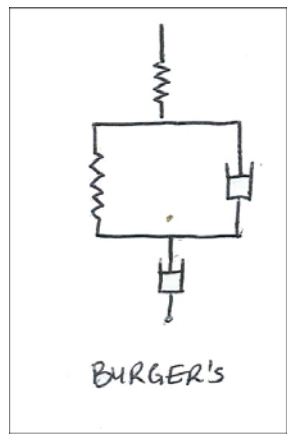
Maxwell model - States that the behaviour of agricultural materials under stress can be represented by a spring (representing elastic behaviour) and a dashpot (representing viscous behaviour) in series.

Kelvin model - States that the behaviour of agricultural materials under stress can be represented by a spring (representing elastic behaviour) and a dashpot (representing viscous behaviour) in parallel.

Burger's model - States that the behaviour of agricultural materials under stress can be represented by a spring (representing elastic behaviour) in series with a dashpot and a combined spring and a dashpot (representing viscous behaviour) in parallel.

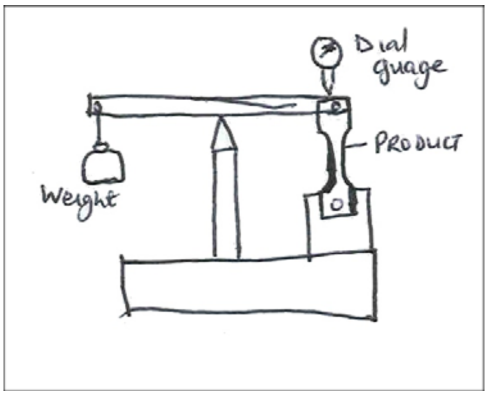




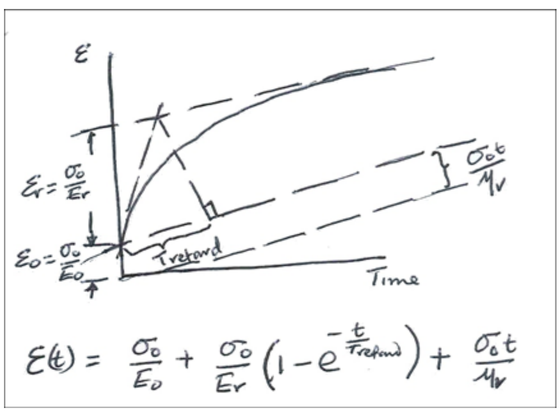


Laboratory method for determining creep in 4 element Burgers model.

The apparatus for use is as shown in figure a below. The product is mounted and the load hang as shown. The deformation from time 0 is monitored on the dial guage for time t. The deformation is then plotted against time and the parameters read as shown in figure b and e(t) computed as in equation beneath figure b. etc



a.



b.

Drying of agricultural materials

- **Grain drying** is a process of simultaneous heat and moisture transfer.
- The study of relationships between air and its associated water is called **psychrometry.**
- The ***relative humidity*** (*RH*) of air is the ratio of the vapor pressure of the water molecules in the air to the saturated vapor pressure at the same temperature. The relative humidity usually is expressed as a percentage.
- The ***specific volume*** (*v*) of moist air is the volume per unit mass of dry air and is expressed in cubic meters per kilogram of dry air. The power required by the fan on a drying system is affected by the specific volume of the drying air.
- The ***enthalpy*** (*h*) of moist air is the energy content per unit mass of dry air above a certain reference temperature (usually 0±C). It is denoted in kilojoules per kilogram of dry air.

Material factors affecting the choice of a drying method

i) **Temperature tolerance**: High temp may reduce germination of grains for seeding and may partially cook the product or change its chemical and physical characteristics.
ii) **Humidity response**: There are materials like tobacco and prunes which undergo physiological change during drying. These products will have to be dried with air of specific RH.
iii) **Compressive strength**: Fruits, vegetables and other soft products which cannot sustain pressure in deep bed drying must be dried in thin layers while tobacco must be suspended.
iv) **Fluidity**: Poor flowing materials cannot be dried in continuous flow driers.

Categories of drying processes

i) **Air and Contact** Drying under Atmospheric pressure: Heat is transferred through the foodstuff either from heated air or from heated surfaces. The water vapour is removed with the air.
ii) **Vacuum Drying**: Advantage is taken of the fact that evaporation of water occurs more readily at lower pressures than at higher ones. Heat transfer in vacuum drying is generally by conduction sometimes by radiation.
iii) **Freeze Drying:** The water vapour is sublimed off frozen food. The food structure is better maintained under these conditions. Suitable temperatures and pressures must be established in the dryer to ensure that sublimation occurs.

EXAMPLE 1. Heat energy in air drying
A food containing 80% water is to be dried at 100oC down to moisture content of 10%. If the initial temperature of the food is 21oC, calculate the quantity of heat energy required per unit weight of the original material, for drying under atmospheric pressure. The latent heat of vaporization of water at 100oC and at standard atmospheric pressure is 2257kJ/kg. The specific heat capacity of the food is 3.8kJ/kg/oC and of water is 4.186kJ/kg/oC. Find also, the energy requirement/kg water removed.

Calculating for 1kg food
Initial moisture = 80%
800g moisture are associated with 200g dry matter

Final moisture = 10%
100g moisture are associated with 900g dry matter
Therefore, 100/900 X 200g = 22.2g moisture are associated with 200g dry matter 1kg of original matter must loose (800 – 22)g moisture = 778g = 0.778kg moisture

Heat energy required for 1kg original material =
heat energy to raise temperature to 100oC + latent heat to remove water = mct + ml =
(1 x3.8 x (100 - 21) + 0.778 x 2257 = 300.2 + 1755.9 = 2056kJ

Energy/kg water removed, as 2056kJ is required to remove 0.778 kg of water =
2056/0.778 = 2543kJ

EXAMPLE 2. Heat energy in vacuum drying
Using the same material as in Example 7.1, if vacuum drying is to be carried out at 60°C under the corresponding saturation pressure of 20 kPa abs. (or a vacuum of 81.4 kPa), calculate the heat energy required to remove the moisture per unit weight of raw material.

Heat energy required per kg raw material
= heat energy to raise temperature to 60°C + latent heat of vaporization at 20 kPa abs.
= (60 - 21) x 3.8 + 0.778 x 2358
= 148.2 + 1834.5
= 1983 kJ.

In freeze drying the latent heat of sublimation must be supplied. Pressure has little effect on the latent heat of sublimation, which can be taken as 2838 kJ kg-1.

EXAMPLE 3. Heat energy in freeze drying
If the foodstuff in the two previous examples were to be freeze dried at 0°C, how much energy would be required per kg of raw material, starting from frozen food at 0°C?

Heat energy required per kilogram of raw material= latent heat of sublimation
= 0.778 x 2838
= 2208 kJ.

Constant rate and falling rate in drying

Constant rate drying occurs at the beginning of drying of a wet product in which the rate of moisture removal is constant.

$$\frac{dM}{dt} = F_v A(P_s - P_a) = \frac{K_f A}{h}(T_a - T_s)$$

Falling rate drying is the process in which the rate of moisture removal decreases with time. This occurs after the constant rate and the moisture content at which the constant rate changes to falling rate is known as critical moisture content

$$\frac{dM}{dt} = \alpha (M - M_e)$$

EXAMPLE

1. If the wet-bulb temperature in a particular room is measured and found to be 20°C in air whose dry-bulb temperature is 25°C (that is the wet-bulb depression is 5°C) estimate the relative humidity, the enthalpy and the specific volume of the air in the room using the Psychometric chart in Figure 1

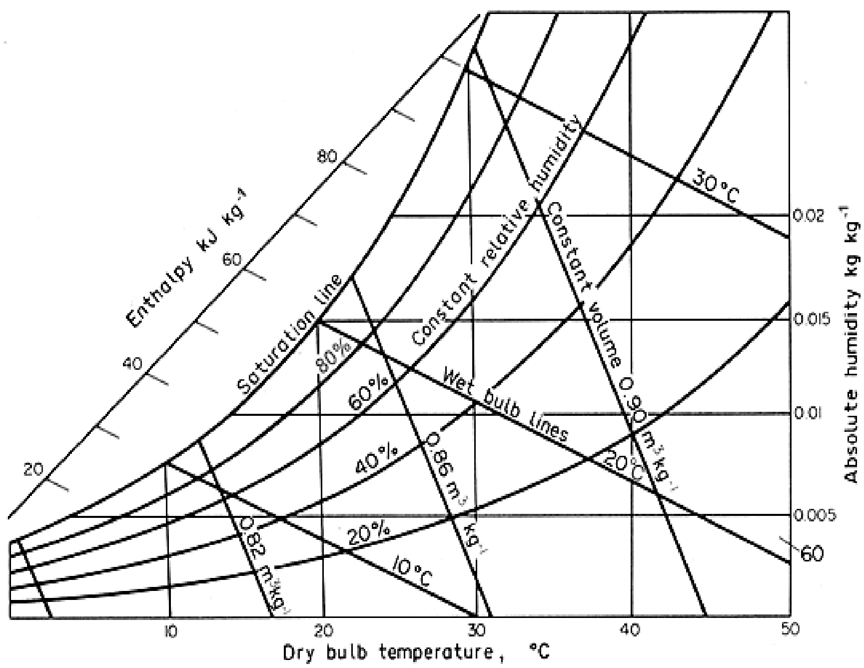


Fig. 1 Psychometric chart

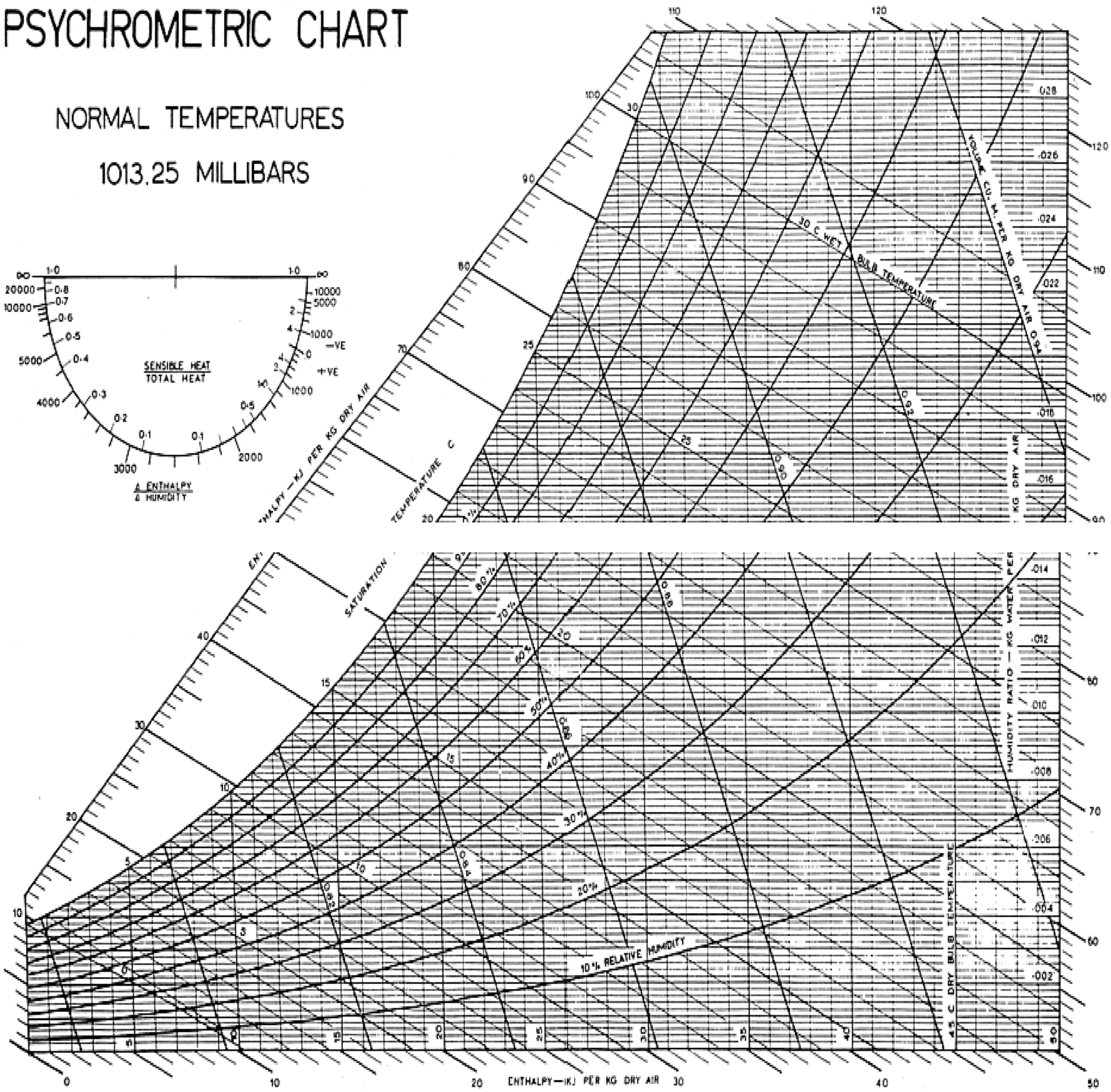
On the Psychometric chart (Figure 1) follow down the wet-bulb line for a temperature of 20°C until it meets the dry-bulb temperature line for 25°C. Examining the location of this point of intersection with reference to the lines of constant relative humidity, it lies between 60% and 70% RH and about 4/10 of the way between them but nearer to the 60% line.

Therefore the RH is estimated to be 64%.
Similar examination of the enthalpy lines gives an estimated enthalpy of 57 kJ kg^{-1}, and from the volume lines a specific volume of 0.862 m^3 kg^{-1}.

PSYCHROMETRIC CHART

NORMAL TEMPERATURES

1013.25 MILLIBARS



LABORATORY 1.

TITLE: Physical Properties of Agricultural Products 1 - Size and shape
OBJECTIVES: At the end of this laboratory you will be able to do the following:

1. Measure the principal dimensions of some fruits and vegetables
2. Determine the roundness and sphericity of the products
3. Determine surface area of the products
4. Determine the overall shape of the products

NOTES: Physical characteristics of agricultural products are very important in handling the products and in the design of machinery for drying, handling, processing and storage.

Procedure

A. Roundness

You are supplied with

a. Garden egg
b. Tomato
c. Orange
d. Any other product

1. Draw the projection of each of the product in the natural rest position.
2. Draw the smallest circumscribing circle on the projection drawn in I
3. Calculate Roundness using the relationship A_p/A_c
4. Repeat procedure A 1 draw an inscribed circle and calculate roundness using the relationship E_t / NR as given in class
5. Repeat procedure A1, and calculate roundness using the relationship r/R as given in class.
6. Compare the three results for all the products.

B. Sphericity

1. Measure the three major diameter, a b and c (as given in class) of all the products given $(abc)^{1/3}/a$
2. Determine sphericity using the relationship
3. Draw the projections of the products in their natural rest position.
4. Draw the largest inscribed circle and the smallest circumscribed circle.
5. Determine sphericity with the relationship d_1/d_2 (as in class)
6. Compare your results in 2 and 5
7. Why do you think roundness and sphericity are important in handling and processing?
8. Which is easier to handle – a large sized product or a small product? Why?
9. Describe the shape of each product.

LABORATORY 2:
TITLE: Physical Properties of Agric Products II – Volume, Density and Surface area
OBJECTIVES: At the end of this laboratory, you will be able to do the following:

1. Determine the volume and density of product that is heavier than water
2. Determine the volume and density of product that is lighter than water
3. Determine the surface areas of some products.

REQUIREMENTS: Fruits, vegetables, graph paper, scale, container sinker and water.
NOTES: Volume, density and surface area are important parameters in the design of soils and storage bins, separation of products from undesirable materials, mechanical compression of material, grading and sorting.

PROCEDURE

A. Volume and Density of heavy product.

You are supplied with 4 agricultural products that will readily sink in water, for all four products

1. Determine the weight of product in air – W_a
2. Determine wt of container + water – W_w
3. Determine weight of container + water – product – W_r
4. Find volume of product. Also find density and specific gravity of product.

B. Volume and density of light product

You are supplied with 3 products that are lighter than water

1. Determine weight of product in air – W_{pa}
2. Determine weight of product in water W_{pw}
3. Determine weight of sinker + product inair – W_{aa}
4. Determine weight of sinker + product in water – W_{aw}
5. Find the wt. of water supplied, volume of solid and density of solid

C. Surface area

You are supplied with 3 kinds of leaves

1. Project the surface area on paper
2. Find the area of the leaves using graph paper

D. Questions

1. In what area do you think surface area of objects is particularly useful?
2. How do you suppose you can find the volume of products that will dissolve in water?

LABORATORY 3

TITLE: Physical Properties of Agricultural Products III – Angle of Repose and Angle of Internal Friction

OBJECTIVES: At the end of this laboratory, you will be able to:

1. Determine the Dynamic angle of repose of an agricultural produce
2. Determine the station co-efficient of friction for agricultural produce

Note: frictional characteristic of agricultural crops play a big role in the design of handling and processing equipment. Angle of repose and static coefficient of friction are two indices that can be used to indicate frictional properties of crops and their definitions have been given in the class. Revise these definitions in order to get a clear distinction between these two properties.

PROCEDURE

A. DYNAMIC ANGLE OF REPOSE

a) You are supplied with two types of agricultural crops. Follow the instructions of the laboratory supervisor and use the funnel system to determine the angle of repose.

ii) You are also supplied with an emptying angle box. Use this method in obtaining the angle of repose.

iii) Compare your results. Which of these values for these crops?

B. STATIC COEFFICIENT OF FRICTION

(i) You are supplied with an inclined plane method apparatus. Following the instructions of the laboratory supervisor, determine the static coefficient of friction on

(a) plywood (along the grain)
(b) plywood (across the grain)
(c) galvanized iron sheet

C. ANSWER THE FOLLOWING QUESTIONS:

(i) Under what real-life situations would you think angle of repose and angle of internal friction are useful?

(ii) Under what situations do you think:

(a) a high angle of repose is an advantage?
(b) A high angle of repose is a disadvantage?

LABORATORY 4

TITLE: The Planimeter

OBJECTIVES: At the end of this laboratory, each student will be able to do the following:

a. Identify the various parts of planimeter

b. Test the planimeter for reliability

c. Use the planimeter to determine area of given shapes

APPARATUS: Planimeter, plain paper, pencil and ruler

NOTES: A planimeter is an instrument for measuring the area of all shapes of plane figure. The area is obtained by tracing their perimeters. Area of plans and maps to any scale, sectional areas of machine drawings as well as the mean heights of line diagrams can also be otained with the panimeter.

PROCEDURE

A. GETTING FAMILIAR WITH THE PLANIMETER

The laboratory instructor will explain to you how the panimeter isused

1. Sketch and label the various parts of the planimeter
2. Explain in your own words how the planimeter is set up and used.

B. TEST-RUNNING THE PLANIMETER

1. Attach the test rule as described to you. Set the planimeter as directed and determine the area described inmm2
2. Find the percent difference between your measurement and the area of the square.
3. Draw a square of 1 x 1cm and use the planimeter to determine the area of the square. Repeat for a circle of 1cm diameter.
4 Find the percentage error.

C. ANSWER THE FOLLOWING QUESTIONS

1. What are the advantages and disadvantages of using a planimeter for area determinations
2. In what disciplines do you think the planimeter can be very useful

LABORATORY 5

TITLE: Using the Planimeter for Area Measurements.
OBJECTIVES: At the end of this laboratory, you will be able to do the following:

1. Use the planimeter to measure the projected area of some crops
2. Use the planimeter to measure the surface area of leaves.
3. Compare the effectiveness of planimeter to graph sheet method

APPARATUS: Planimeter, graph paper, pencil, fruits and leaves.
NOTES: Roundness and surface area of crops and leaves are often needed. The planimeter is one instrument that can be used to quickly determine these characteristics especially where there are no other means of measurement. However, the use of the planimeter requires care because a small error of judgement can result in a large error of measurement.

PROCEDURES

A. AREAS OF LEAVES

You are supplied with three kinds of leaves with different surface areas

1. Trace the areas of the leaves on graph paper
2. Use the planimeter to determine the area of each leaf
3. Use the graph paper to determine the area of each leaf.
4. Compare your results.

ROUNDNESS

You are supplied with three fruits.

2. On a graph paper, draw the projection of each fruit in the natural rest position.
3. Draw the smallest circumscribing circle on the projection drawn in (1)
4. Use both planimeter and graph sheet method to determine the projected area Ap and the circumscribing circle A_2
5. Determine Roundness (Ap / Ac) with both methods
6. Compare your answers for the three products

B. SURFACE AREA OF FRUITS

Your are supplied with two kinds of fruits/seeds

1. Coat each fruit/seed with the ink supplied
2. Cover the entire fruit/seed with graph paper (You may fold the graph paper)
3. Use the graph paper squares to determine the surface area of each fruit/seed.
4. Use the planimeter to determine the surface area of the fruit/seed.
5. Compare your results.

D. Answer the following questions:

1. What specific advantages to do you think
(a) the planimeter has over the graph paper method?
(b) the graph paper method has over the planimeter?
2. Which method will you choose and why if:
(a) you are in the field
(b) you are in the office.

LABORATORY 6

TITLE: Determination of Fineness Modulus and Modulus of Uniformity for feed.

OBJECTIVES: At the end of this laboratory, students will be able to:

1. Identify a set of Tyler's sieve and a Ro-tap machine
2. Determine the Fineness modulus of a given ground feed
3. Determine the Modulus of Uniformity of ground feed.

NOTE: Screening is a method used for classifying small grains or granular materials. Tyler's sieve's which are commonly used originated in the United states in 1910, Sieve sizes (size of opening) vary from 3.75mm to 0.07mm with a pan at the bottom. However, a standard set of seven sleeves is used to classify ground feed.

Fineness modulus and modulus of uniformity are two indices that are used to classify ground feed. These indices have been explained to you in the classroom.

PROCEDURE:

A. SCREENING

You have been supplied with two samples

(i) Grains
(ii) Ground feed

(I) Weigh 250g of each sample
(II) Arrange the seven standard sieves (3/8" 4, 8, 14, 28, 48, 100) and the pan on the Ro-tap, pour the sample from the top and vibrate for 5 minutes.
(III) Find the percentage on each sieve

B. CALCULATIONS

(i) Using an appropriate table, calculate the fineness modulus (f_m)
(ii) Calculate the average size of grain (D) in inches.
$D = 0.0041 \times 2^{fm}$
(iiI) Determine the modulus of elasticity

iv) Draw a graph of screen opening versus percent finer than screen.

C. ANSWER THE FOLLOWING QUESTIONS

i) In what category will you place your two samples in terms of course, medium and finer in relation to;

(a) Fineness Modulus
(b) Modulus of uniformity

ii) What do you think about this statement?

"The bigger the animal, the coarser the feed should be"

Describe how a complete Tyler's sieve set look like (with the aid of diagrams).

]

LABORATORY 7

Storage methods

Objective: To familiarize students with different methods of storage available both on – farm and off –farm

Facility: 1. University Seed processing and storage unig

2. Strategic Reserve in Ibadan

Procedure: Students are taken on a study tour of the seed processing and storage unit to identify various storage units and machinery.

Students are taken to one of the Nation's strategic Reserve Location in Ibadan to identify and specify the storage systems and processes

Result: Students to submit a study tour report to include

1. Estblishment (s) visited
2. Process lines
3. Storage units and Processing machinery
4. Comparism of Industrial storage/off-farm and on-farm storage structures

UNIVERSITY OF AGRICULTURE, ABEOKUTA

DEPARTMENT OF AGRICULTURAL ENGINEERING

First Semester B.SC. Examination 2010/2011 Session

AGE 407: Engineering Properties and Processing of Agricultural Materials (3 Units)

INSTRUCTION: ANSWER **QUESTION ONE** **AND ANY OTHER TWO**

TIME: $2^1/_2$HOURS

QUESTION ONE (30 marks)

a. Define the following terms with respect to drying of agricultural materials:
(i) Grain Drying (ii) Psychometric (iii) Relative Humidity (iv) Specific volume and (v) Enthalpy

(b) What are the materials factors that affect the choice of a drying method?

(c). Mention and explain briefly, three categories in which drying processes can be classified.

(d) What do you understand by constant rate and falling rate in drying? Give the governing equations.

(e) A food containing 80% water is to be dried at 100oC down to moisture content of 10%. If the initial temperature of the food is 21oC, calculate the quantity of heat energy required per unit weight of the original material, for drying under atmospheric pressure. The latent heat of vaporization of water at 100oC and at standard atmospheric pressure is 2257kJ/kg. The specific heat capacity of the food is 3.8kJ/kg/oC and of water is 4.186kJ/kg/oC. Find also, the energy requirement/kg water removed.

QUESTION TWO (20 marks)

(i) A biscuit factory obtained maize from two sources (20 tonnes each), one has 12% moisture content (mc) dry basis and the other 12% mc wet basis. Which one has more dry matter? Justify your answer with calculations.

(ii) In (i) above, the company paid ₦60000.00 per tonne for the maize at 12% mc dry basis. How much should a tonne cost at 12% mc wet basis. If the materials has to be dried to 5% mc dry basis, what quantity of water will be lost from the material from each source per tonne.

QUESTION THREE (20 marks)

(i) What do you understand by Fineness Modulus and Uniformity Index?

(ii) Describe how to determine the Fineness Modulus of a feed in the laboratory.

(iii) Below is a result of a sieve experiment using poultry feed.

Sieve Mesh	% of Material on each Screen
$^{3}/_{8}$	2
4	1.5
8	7.0
14	20.0
28	31.5
48	26.5
100	11.5
Pan	0

From this result, calculate the Uniformity Index. How can you describe the feed?

QUESTION FOUR (20 marks)

(i) What are the five forms in which water is found in food materials?

(ii) Give a brief description of any five geometric characteristic used in describing the shape of fruits and vegetables.

(iii) Describe how the Terminal Velocity of an agricultural material can be obtained in the laboratory.

QUESTION FIVE (20 marks)

(i) Briefly explain (using models) how the behaviour of agricultural/food materials under stress are represented (sketch where necessary).

(ii) Give a detailed description (with equations and sketches where necessary) of the laboratory method for determining creep in 4 element Burgers model.