

ENGINEERING PROPERTIES OF FOOD AND BIOMATERIALS

This course covers the concept of engineering properties based on various physical properties of food and biological materials.

At the end of the course, students will be able to:

1. Identify engineering properties of food and biomaterial
2. Explain related measurement methods
3. Relate engineering properties of food and biological material to process design and quality control

Contents

1. Introduction

Lecture: 1 hour

Practical work: 2 hours

Aims and objectives, basic categories of food and agricultural materials engineering properties, the importance of engineering properties of food and agricultural materials to food processing

2. Physical and chemical properties

Lecture: 1 hour

Practical work: 2 hours

Physical characteristics of food and agricultural materials: size, shape, volume, density, porosity, surface area

Chemical properties: compositions of food and agricultural materials, sources of carbohydrates

3. Mechanical properties

Lecture: 2 hours

Practical work: 4 hours

Deformation of solid, apparent modulus of elasticity, testing methods, measurement equipment

4. Rheological properties

Lecture: 2 hours

Practical work: 4 hours

Newtonian and Non-Newtonian flow, textural profile of food analysis

5. Frictional, Aerodynamic and Hydrodynamic properties

Lecture: 1 hour

Practical work: 2 hours

Angle of repose, angle of internal friction, flow pattern, forces in bin, drag coefficient and terminal velocity

6. Thermal properties

Lecture: 2 hours

Practical work: 4 hours

Thermal conductivity, specific heat, thermal diffusivity, heat amount transferred

7. Electromagnetic properties

Lecture: 1 hour

Practical work: 2 hours

Electromagnetic, Dielectric constant and loss factor properties, Its application in design and operation of equipment processing

Total lecture hours: 10 hours

Practical works: 20 hours

References:

1. Sahin, S., & Summu, S.G. (2006). Physical properties of foods. New York: Springer
2. Singh, R.P and Heldman, D.R., (2014). Introduction to Food Engineering (5th Edition). Academic Press
3. Rao, M.A., Rizvi S.S.H., Datta, A.K & Ahmed, J., (Eds.). (2014). Engineering properties of food (4th Edition). Boca Raton: CRC Press

ENGINEERING PROPERTIES OF FOOD AND AGRICULTURAL MATERIALS

Lecturer :

Associate Prof. Dr. SITI MAZLINA MUSTAPA KAMAL

Address:

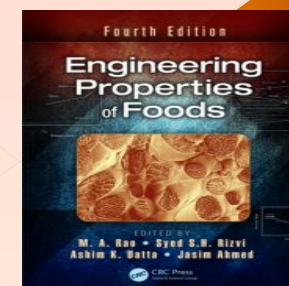
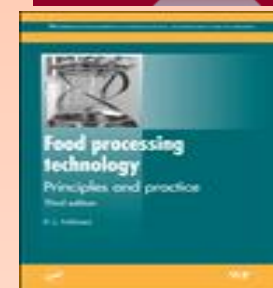
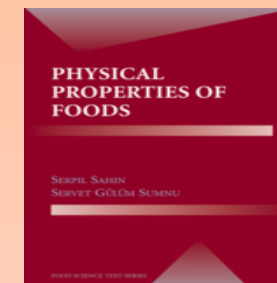
**Department of Process and Food Engineering,
Faculty of Engineering, Universiti Putra Malaysia,
Serdang, 43400, Selangor, MALAYSIA**

Email :

smazlina@upm.edu.my

REFERENCES

1. Sahin, S. & Sumnu, S.G. (2009). *Physical Properties of Foods*. New York: Springer (eBook)
2. Singh, R.P & Heldman, D.R. (2014). *Introduction to Food Engineering*. (5th. Edition). Academic Press
3. Fellows, P. (2009). *Food Processing Technology: Principles and Practice (3rd Edition)*. Abington: Woodhead Publishing Ltd.
4. Stroshine, R. (1998). *Physical Properties of Agricultural Materials and food products*. Purdue University (eBook)
5. Rao, M.A., Rizvi S.S.H. & Datta, A.K. (Eds.) (2014). *Engineering Properties of Food (4rd Edition)*. Boca Raton: CRC Press.



COURSE OBJECTIVES

- To learn the physical and thermophysical properties of food and agricultural materials.
- Understand the science and engineering concepts for characterizing the physical and thermophysical behaviours of food and agricultural materials.
- To learn the requirement of engineering properties of materials for analysis and design of agricultural, food and biological systems.

LEARNING OUTCOMES

At the end of the course, students should be able to

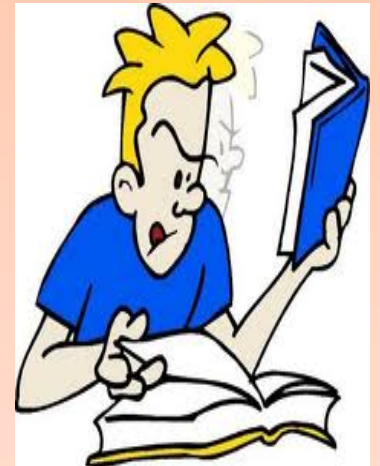
- 1) identify engineering properties of food and agricultural materials**
- 2) explain related measurement methods**
- 3) relate engineering properties of food and agricultural materials to process design and quality control**

TOPICS

1. Physical properties
2. Chemical properties
3. Mechanical properties
4. Rheological properties
5. Frictional properties
6. Aerodynamic and Hydrodynamic properties
7. Thermal properties
8. Electromagnetic properties

Why are you taking this course?

- Raw food materials are biological and have certain unique characteristics.
- Food and feed undergo various unit operations from pre-harvest to post harvest processing, formulation, preservation, packaging, storage distribution, domestic storage and finally consumption.
- During all those processes, the properties of biological (food and agricultural) material will be changed.
- An understanding of the engineering properties of biological material are important in order to solve problems while designing and selecting the modes of preservation, packaging, processing, storage, marketing and consumption.



Engineering Properties

Introduction

Any attribute affecting the processing or handling of a biological material can be defined as an engineering property

- They are divided into the following categories:

- Physical properties (Structural and Geometric Properties)

- Chemical properties

- Mechanical properties (Strength properties)

- Rheological properties

- Frictional properties

- Aerodynamic and hydrodynamic properties

- Thermal properties

- Electromagnetic properties

-Various food processing methods can potential alter those properties and cause desirable or sometimes not so desirable changes in nutrient profiles, texture, color, taste, aroma and other quality attributes.

1. Physical properties

- Shape, size, volume, surface area, density and porosity
- Knowledge on some of physical properties is necessary for the design of various separating, handling, storing and drying systems.

2. Chemical properties

- Focus on chemical compositions and moisture content
- Knowledge on the composition of biomaterials is useful for estimating densities and thermal properties.

3. Mechanical properties

- Focus on strength properties and testing such as compressive strength and deformation

4. Rheological properties

- Focus on food texture and rheological characterization
- Knowledge of rheological properties of various food systems is important in the design of flow processes for quality control, in predicting storage, and in understanding and designing texture.

5. Frictional properties

- Coefficient of friction, angle of internal friction and angle of repose
- Angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures.
- Angle of internal friction between seed and wall in the prediction of seed pressure on walls.
- Coefficient of friction is also important in designing storage bins, hoppers, chutes, screw conveyors, forage harvesters, and threshers.

6. Thermal properties

- These properties are involved in almost every food processing operation.
- Such as specific heat, thermal conductivity and thermal diffusivity
- Knowledge of these properties helps in designing thermal process and calculating thermal load for canning, sterilization, pasteurization, cooking and many other processes.

7. Aerodynamic and Hydrodynamic properties

- Terminal velocity and drag coefficient of agricultural products are important in designing of air/hydro conveying systems and separation equipment.
- Air is often used as a carrier for transport or for separating the desirable products, therefore terminal velocity and drag coefficient are needed for air conveying and pneumatic separation of materials.

8. Electromagnetic properties

- Dielectric constant, dielectric loss factor and penetration depth
- Dielectric properties is important in determining the interaction between the food material being processed and the electromagnetic energy.
- Useful in designing and controlling thermal processing and moisture content determination.

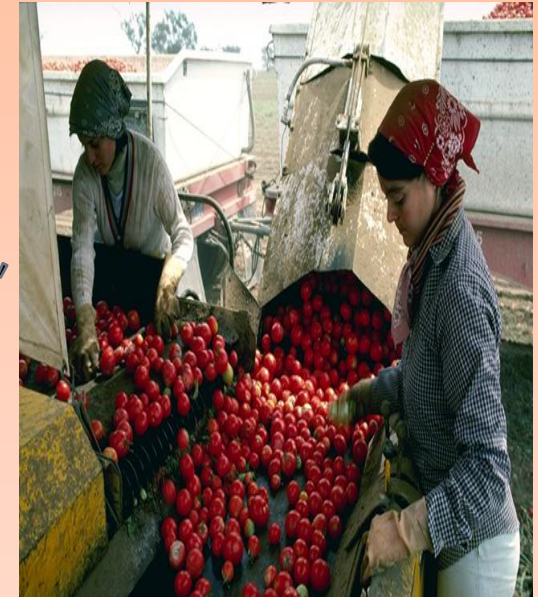
Applications

- Understand the way biological food materials respond to physical + chemical treatment to allow for optimum design of food equipment + processes to ensure food quality + safety
- Knowledge of an engineering properties of biological/food material is necessary:
 - 1) Defining quantifying a description of the biological / food materials.
 - 2) Providing basic data for food processing + unit operation
 - 3) Predicting behaviour of new food material.

The relation of engineering properties of biological material to food processing

Example : post harvest

- 1) Handling and transportation
 - Materials harvest different size, shape, density
 - Sorting + grading operations can aid by removing oversize, undersize, and over quality.
 - * How to distinguish it?
 - * Why required to sort it?



- During handling – can kernel damage could happen? How to control ?
Proper equipment design
- How to maintain the quality of food during transportaion?
- Storage + market value of the material?
Need to know moisture content + protein

How to measure it?

- Seed planting – one kind of seed or many kinds of seed
- Need to know the size + shape for plate design



Transformations to food product

- a) Wheat to flour
Need to know the kernel hardness
for grinding
How to measure it?
- b) Baking
The process – deformation of
characteristics of dough and
finished loaf



Proofer



Baking

c) Food processing into juice
Juice yield as compression time.

d) Fruit juice/ puree
- juice is Newtonian
- puree is non-Newtonian

Info need to
determine
flowrate through
pumping
equipment



Tentative course schedule

- ◉ Week 1: 3 Nov. – 7 Nov. 2015

(Tuesday to Friday)

- Lecture

8 Nov. 2015 (Saturday)

- Exam 1

- ◉ Week 2: 9 Nov. – 11 Nov. 2015

(Monday to Wednesday)

- Lecture

12 Nov. 2015 (Thursday)

- Exam 2

13 Nov. 2015 (Friday)

- Final Lecture + Summary of assessment

TENTATIVE PLANNING FOR COURSE GRADING

Exam 1: 40%

Exam 2 : 50%

**Attendance and contributions
in the class: 10%**

**Total:
100%**



Physical Properties

(Structural and geometrical properties)

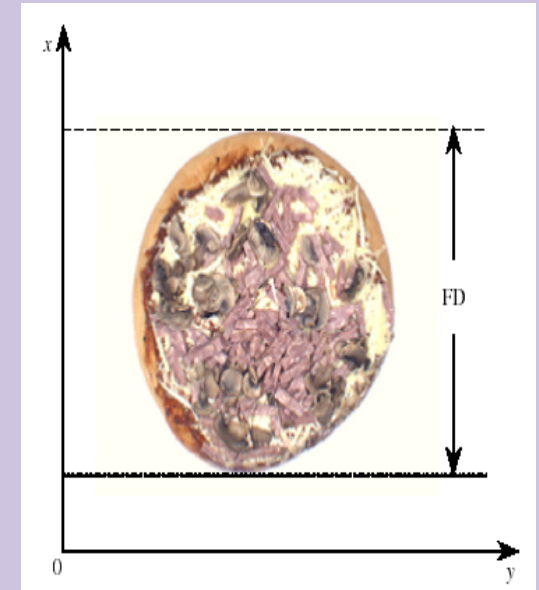
Objectives:

To study physical properties of foods and agricultural products, and to explore the significance of these properties with respect to the following applications:

-
- Design of equipment, e.g., line sorting machines, pumping requirements, etc.
 - Development of sensors, e.g., colour and weight sensors in line sorters, ultrasonic fat detection etc.
 - Process design, e.g., thermal treatments

Introduction

- Physical attributes: Size, Shape, Sphericity, Volume, Surface area, Density and Porosity
- Rapid and accurate determinations of physical properties are needed in processing agricultural materials.
- It is important to investigate the physical of foods/ agricultural materials to gain insights on how they affect the quality attributes.
- Physical properties are normally important in many food materials handling and processing operations.



Application of physical properties

- Size, shape and density: Fruits and vegetables grading, Food materials quality evaluation



- Bulk density: For storage and transportation



Shape factor and surface area: Heating and cooling process- to predict the freezing and thawing rate



Skeleton
length

Porosity: For shrinking mechanism – during drying

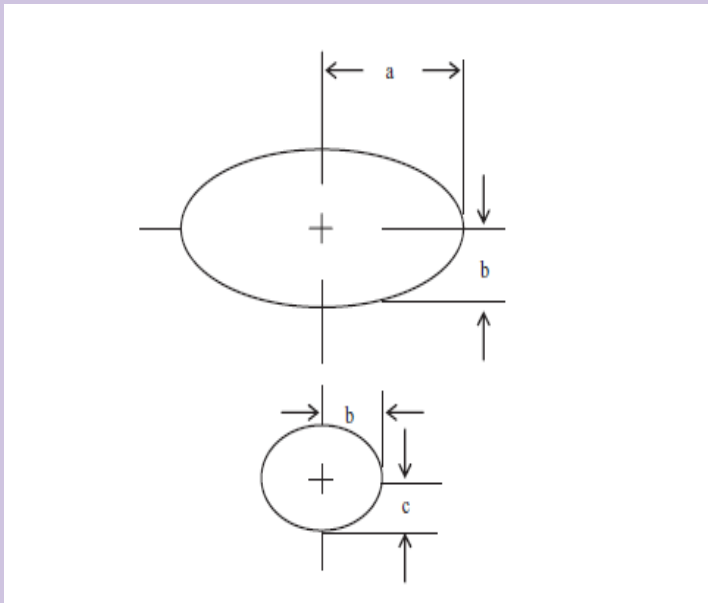


Fundamental of physical properties

Size

- Easy to specify size for regular particles, but for irregular particles the term size must be arbitrarily specified.
- Size can be determined using the projected area method.
 - three characteristic dimensions are defined:
 - 1. Major diameter, which is the longest dimension of the maximum projected area;
 - 2. Intermediate diameter, which is the minimum diameter of the maximum projected area or the maximum diameter of the minimum projected area; and
 - 3. Minor diameter, which is the shortest dimension of the minimum projected area.
- Length, width, and thickness terms are commonly used that correspond to major, intermediate, and minor diameters, respectively.

Triaxial ellipsoid: D_{\max} , D_{inter} and D_{\min} ,



In a triaxial ellipsoid, all three perpendicular sections are ellipses, then;

$$D_{\max} = 2a$$

$$D_{\text{inter}} = 2b$$

$$D_{\min} = 2c$$



Measurement equipment :
Micrometer

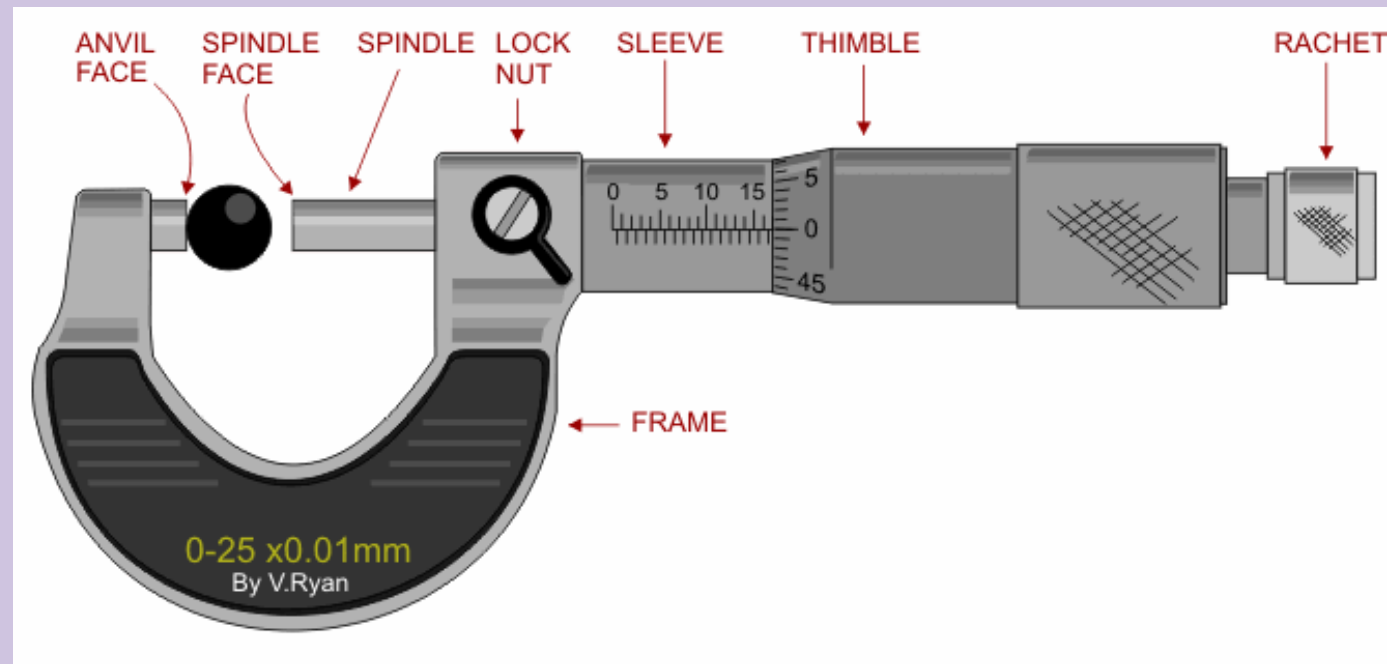


Table 2.1 Dimensions of Grains, Fruits and Vegetables.

Product	Major Diameter (mm)		Intermediate Diameter (mm)		Minor Diameter (mm)	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Grains^a:						
Corn	12.01	1.52	8.15	0.71	5.18	1.00
Wheat	6.02	0.41	2.79	0.37	2.54	0.08
Soybeans	7.29	0.66	6.43	0.51	5.38	0.20
Oats	10.84	1.65	2.67	0.37	2.03	0.33
Barley	8.76	1.19	3.15	0.38	2.51	0.38
Rye	6.65	0.69	2.21	0.25	2.11	0.25
Fruits and Vegetables^b						
Apples (Gldn. Delicious)	70.1	-	67.6	-	56.4	-
Apples (Red Delicious)	76.7	-	71.6	-	63.5	-
Blueberry	11.7	-	11.4	-	8.6	-
Cherry (Napolean) ^c	22.6	0.864	22.5	1.19	19.8	0.864
Peach (Red Haven)	58.2	-	57.2	-	54.9	-
Pear (Maxine)	83.6	-	73.2	-	68.1	-
Plum	46.0	-	44.7	-	40.9	-
Potato (Norchip) ^d	70	-	62	-	53	-
Tomato	63.8	-	59.2	-	47.2	-

^a Edison and Brogan (1972). Numbers shown are the averages for 10 varieties with 100 measurements averaged on each variety.

^b Data are from Mohsenin (1987) Table A-8 with exceptions noted.

^c Tennes et al. (1969) Table 1, data for fresh sweet cherries.

^d McClure and Morrow (1987) Table 2. Values for bags 1, 2, and 3 averaged by multiplying the number of potatoes in each bag by their average density, then summing the values for all three bags, and dividing by the total number of potatoes in the three bags.

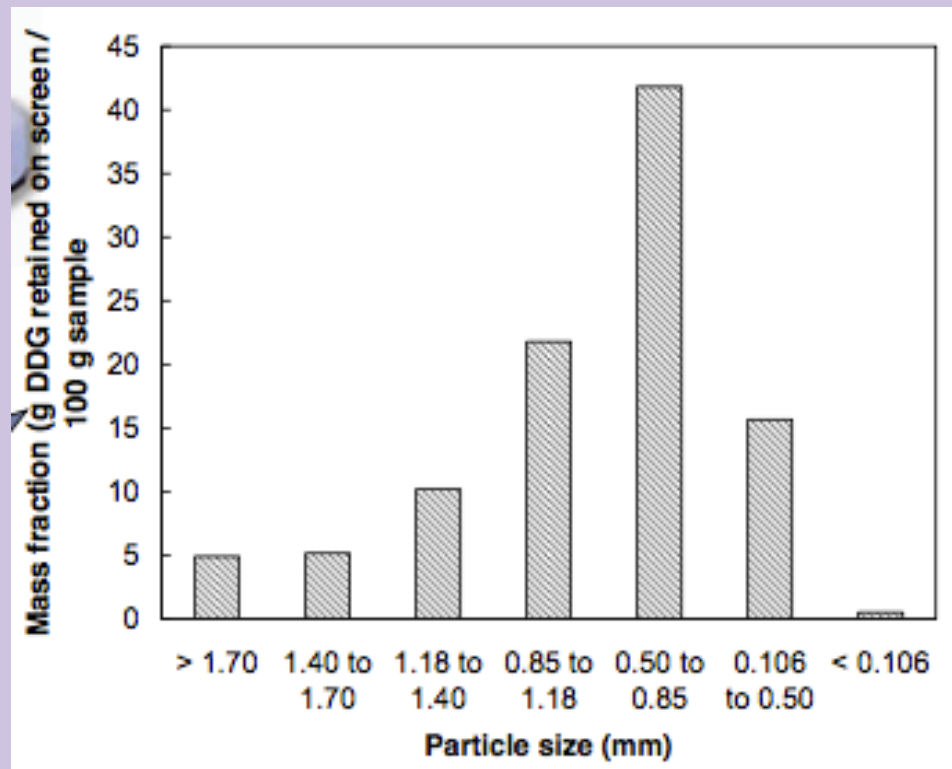
Source data from
Stroshine , R.
(1998). Physical
Properties of
Agricultural
Materials and food
products. Purdue
University

Particle Size Distribution

- Examples : Powder, sugar, salt and other fine particles
- Particle sizes are expressed in different units depending on the size range involved.
- Coarse particles are measured in millimeters, fine particles in terms of screen size, and very fine particles in micrometers or nanometers.
- Particle size of particulate foods - sieve analysis



A set of sieves with different opening sizes are used and opening sizes of sieves decreases from the top to the bottom



Approximate ranges of the median sizes of some common food powders

<u>Commodity</u>	<u>Microns</u>
<i>Rice and barley grains</i>	2,800 – 2000
<i>Granulated sugar</i>	500 - 355
<i>Table salt</i>	300 -210
<i>Cocoa</i>	75 - 53
<i>Icing sugar</i>	45

Shape

To characterize food's shape: roundness and sphericity

- Roundness is a measure of the sharpness of the corners of a solid

$$\text{Roundness} = \frac{A_p}{A_c}$$

where

A_p = largest projected area of object in natural rest position (m^2),

A_c = Area of the smallest circumscribing circle as defined in Fig. 1.4a (m^2).

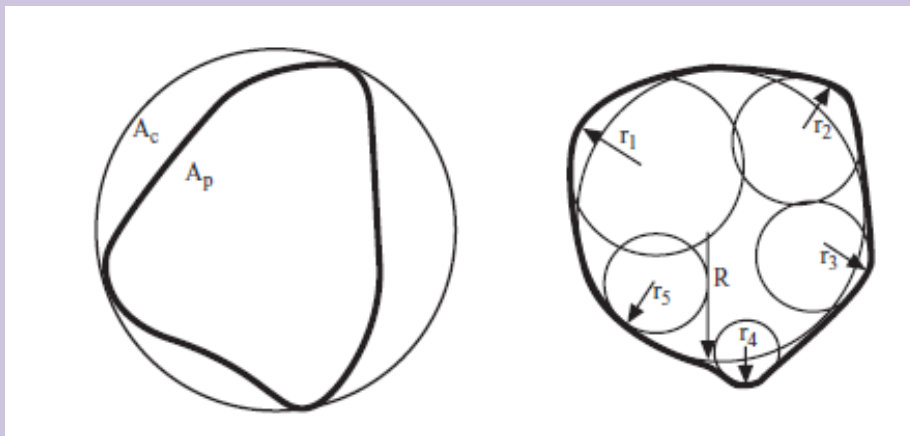
OR

$$\text{Roundness} = \frac{\sum_{i=1}^N r}{NR}$$

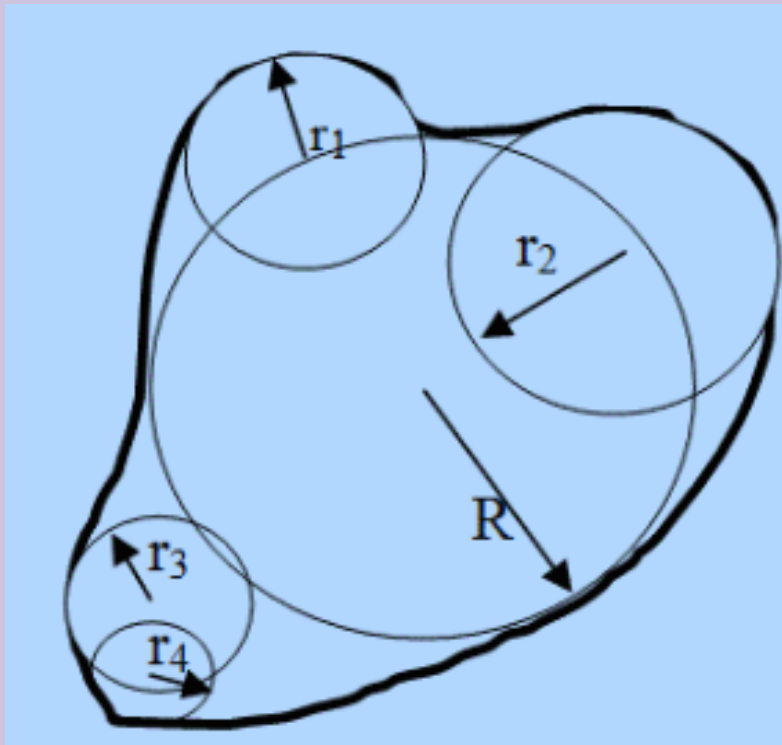
Where, r = radius of curvature

R = radius of the maximum inscribed circle (m)

N = total number of corners summed in numerator



- The shape of a food material is usually expressed in terms of its sphericity and aspect ratio.
- Sphericity or shape factor is the degree to which an object resembles a sphere. It is defined as the ratio of the volume of triaxial ellipsoid to the volume of sphere with $D = D_{\max}$ with a power of one third.



$$\text{Sphericity} = \left(\frac{\text{Volume of solid sample}}{\text{Volume of circumscribed sphere}} \right)^{1/3}$$

Assuming that the volume of the solid sample is equal to the volume of the triaxial ellipsoid with diameters equal to major, minor and intermediate diameter

$$\phi = \left(\frac{V_e}{V_c} \right)^{1/3}$$

where

ϕ = sphericity,

V_e = volume of the triaxial ellipsoid with equivalent diameters (m^3),

V_c = volume of the circumscribed sphere (m^3).

- Volume of the triaxial ellipsoid :

$$V_e = \frac{4}{3} \pi abc$$

Then, sphericity is:

$$\phi = \frac{(abc)^{1/3}}{a}$$

Particle size depends on particle shape, which is rarely spherical.
Particle (grain, seed) maybe compact, plate-like or needle like

Shape and description of various agro commodities

Shape	Description	Examples
Round	Approaching Spheroid	Cherry tomato, pea
Oblate	Flattened at the stem end and apex	Orange, pumpkin
Oblong	Vertical diameter greater than horizontal	Some apple varieties, capsicum, brinjal, rice, wheat
Conic	Tapered toward the apex	Ladies finger, carrot, reddish
Ovate	Egg shaped & broad at stem end	Brinjal, apple and guava
Oblique	Axis connecting stem and apex slanted	Some apple varieties, tomato
Obovate	Inverted ovate-broad at apex	Mango, papaya
Elliptical	Approaching ellipsoid	Rice, wheat, pointed guard
Truncate	Having both ends squared or flattened	Capsicum
Unequal	One half larger than the other	Mango
Ribbed	In cross section, sides are more or less angular	Ladies finger
Regular	Horizontal section approaches a circle	Orange, apple, guava
Irregular	Horizontal section deviates materially from a circle	Mango, ladies finger, capsicum

Volume

- SI unit of volume is m^3
- The most common definitions of volume:
 - Solid volume/True volume (V_s) – volume of the solid material (including water) excluding any interior pores that are filled with air.
 - Apparent volume (V_{app})– Volume of a substance including all pores within the material (internal pores).
 - Bulk volume (V_{bulk}) – is the volume of a material when packed or stacked in bulk.
- Volume of solids can be determined experimentally by liquid, gas or solid displacement

Density

- *Density = Mass/Volume = m/V*
SI unit: kg/m^3
- Density can be expressed in different forms.
- Solid density (ρ_s) - mass per unit volume of the solid material and **excludes** any interior pores that are filled with air.

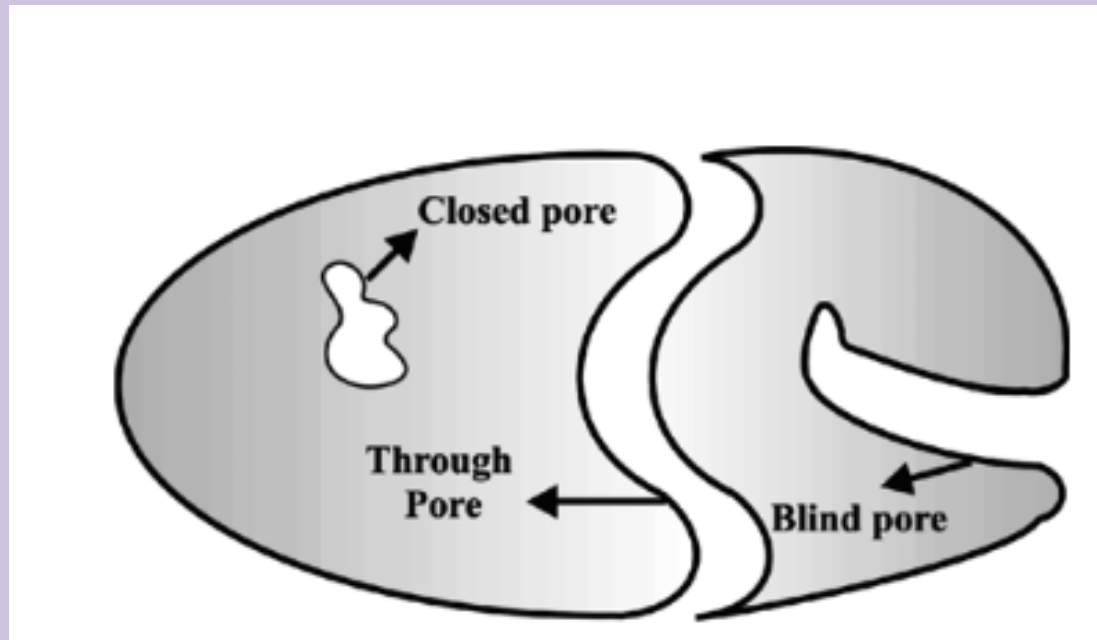
$$\rho_s = \frac{1}{\sum_{i=1}^n \frac{m_i}{\rho_i}}$$

Where ρ_i - density of the i -th component
 m_i - mass fraction of the i -th component

- Particle density (ρ_p) - mass of a particle to its actual volume. **Internal pores are included.**
- Bulk density (ρ_{bulk}) - the mass per total volume occupied by a large quantity of particles. **Pores space among particles are included.**
If the volume of the internal pores is negligible, there is

Solid density = Bulk density

Pore within the food materials (internal pores) :
(1) closed pore, (2) through pore and (3) blind pore



- Density of solids and liquids change moderately with changes in temperature and pressure.
- The density of food materials depends on temperature, and also depends on the major food components (pure water, carbohydrate, protein, fat, ash and ice);

$$\rho_{\text{water}} = 997.18 + 3.1439 \times 10^{-3}T - 3.7574 \times 10^{-3}T^2$$

$$\rho_{\text{CHO}} = 1599.1 - 0.31046T$$

$$\rho_{\text{protein}} = 1330 - 0.5184T$$

$$\rho_{\text{fat}} = 925.59 - 0.41757T$$

$$\rho_{\text{ash}} = 2423.8 - 0.28063T$$

$$\rho_{\text{ice}} = 916.89 - 0.1307T$$

- where; densities (ρ) are in kg/m³ and temperature(T) are in °C and varies between -40 and 150°C. (Ref; Based on Choi and Okos (1986))
- The density can be determined by using a pycnometer, etc.

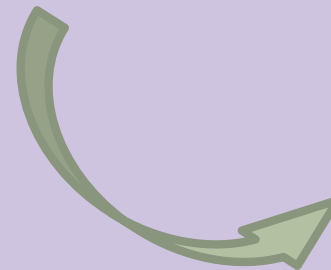


Table 1.6 Solid Densities of Major Ingredients of Foods

Ingredient	kg/m³	Ingredient	kg/m³
Glucose	1560	Fat	900–950
Sucrose	1590	Salt	2160
Starch	1500	Citric acid	1540
Cellulose	1270–1610	Water	1000
Protein (globular)	~1400		
<i>Source: Peleg (1983)</i>			

Table 1.7 Bulk Density of Selected Food Materials

Material	Bulk density (kg/m ³)
Beans, cocoa	1073
Beans, soy, whole	800
Coconut, shredded	320–352
Coffee beans, green	673
Coffee, ground	400
Coffee, roasted beans	368
Corn, ear	448
Corn, shelled	720
Milk, whole dried	320
Mustard seed	720
Peanuts, hulled	480–720
Peas, dried	800
Rapeseed	770
Rice, clean	770
Rice, hulled	320
Sugar, granulated	800
Wheat	770

Porosity

- It is the measure of void space between the materials.
- Porosity (ϵ) is the percentage of the total volume occupied by the air

Total volume = Volume occupied by particle/sample + Volume occupied by air

$$\begin{aligned}\text{Porosity (\%)} &= \frac{\text{Total volume} - \text{particle volume}}{\text{Particle volume}} \times 100\% \\ &= \frac{\frac{\text{mass}}{\text{Bulk density}} - \frac{\text{mass}}{\text{Particle density}}}{\frac{\text{mass}}{\text{Bulk density}}} \times 100\% = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100\%\end{aligned}$$

- Method to determine porosity:
 - Direct method – porosity is determined from the difference of bulk volume of a piece of porous material and its volume after destruction of all voids means of compression.
 - Optical method – porosity is determined from microscopic view of a section of the porous medium.

Shrinkage

- Shrinkage is the reduction in volume or geometric dimensions during processing.
- Isotropic – the uniform shrinkage of the materials under all geometric dimensions
- Anisotropic (non-uniform) – develops in different geometric dimensions

How it occurs? Moisture loss, during freezing, drying, frying etc.

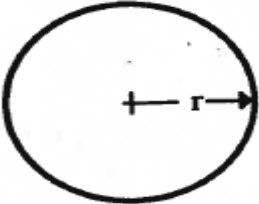

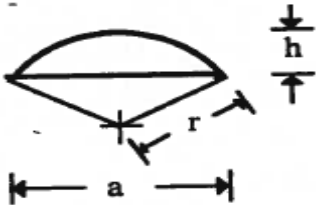
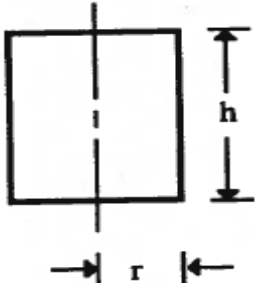


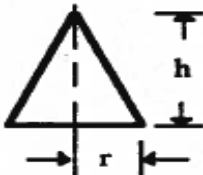
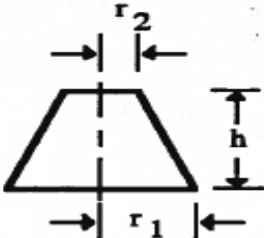
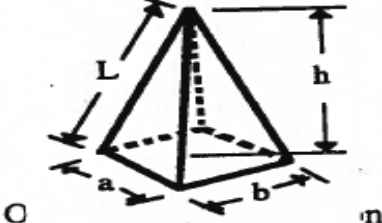
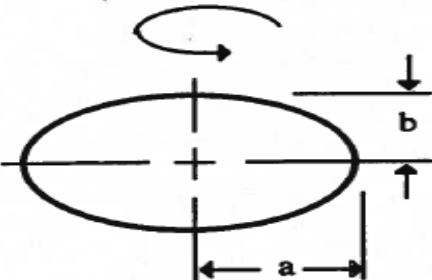
Source data for the following table is from –
Stroshine , R. (1998). Physical Properties of Agricultural
Materials and food products. Purdue University

Table 2.3. Equations for the bulk density (D) of several types of grain as a function of the wet basis moisture content (M) expressed as a decimal value. The equations are valid for a wet basis moisture range of 10 to 40 %. Source: Brusewitz (1975).

Grain	Bulk Density kg/m ³	Grain	Bulk Density Kg/m ³
Barley	$D = 705.4 - 1142 M + 1950 M^2$	Soybeans	$D = 734.5 - 219 M - 70 M^2$
Corn (shelled)	$D = 1086.3 - 2971 M + 4810 M^2$	Sorghum (grain)	$D = 829.1 - 643 M + 660 M^2$
Oats	$D = 773.0 - 2311 M + 3630 M^2$	Wheat	$D = 885.3 - 1631 M + 2640 M^2$
Rye	$D = 974.8 - 2052 M + 2850 M^2$	Wheat	

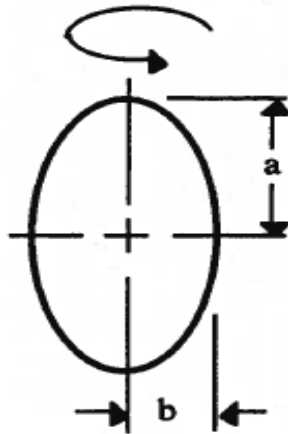
Appendix C **Formulas for Surface Areas and Volumes of Geometric Solids**

SHAPE	SURFACE AREA	VOLUME
<p>Sphere</p> 	$S = 4 \pi r^2$	$V = \frac{4}{3} \pi r^3$
<p>Hemisphere</p> 	$S = 3 \pi r^2$ (not including circular bottom)	$V = \frac{2}{3} \pi r^3$
<p>Spherical Segment</p> 	$S = 2 \pi r h$ (not including circular bottom)	$V = \frac{1}{3} \pi h^2 (3r - h)$ where $r = \frac{h}{2} + \frac{a^2}{8h}$
<p>Right Circular Cylinder:</p> 	$S = 2 \pi r (h + r)$ (including circular bottom and top)	$V = \pi r^2 h$

SHAPE	SURFACE AREA	VOLUME
<p>Right Circular Cone</p> 	$S = \pi r \sqrt{r^2 + h^2}$ <p>(not including circular bottom)</p>	$V = \frac{1}{3} \pi r^2 h$
<p>Truncated Right Circular Cone</p> 	<p>Area of curved surface (top and bottom excluded)</p> $S = \pi (r_1 + r_2) \sqrt{h^2 + (r_1 - r_2)^2}$	$V = \frac{\pi h}{3} (r_1^2 + r_1 r_2 + \frac{2}{2})$
<p>Pyramid :</p> 	$S = a L + b L$ <p>(bottom excluded)</p>	$V = \frac{1}{3} a b h$
<p>Oblate Spheroid (rotation around minor axis) :</p> 	$S = 2 \pi a^2 + \frac{\pi b^2}{e} \ln \left(\frac{1+e}{1-e} \right)$ <p>where $e = \left(1 - \left(\frac{b}{a} \right)^2 \right)^{\frac{1}{2}}$</p>	$V = \frac{4 \pi}{3} a^2 b$

SHAPE**SURFACE AREA****VOLUME**

Prolate Spheroid
(rotation about
major axis):



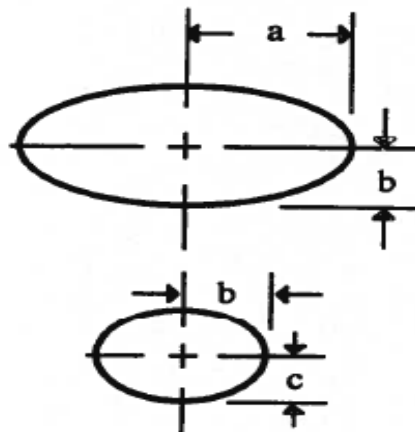
$$S = 2\pi b^2 + \frac{2\pi ab}{e} \sin^{-1}(e)$$

$$\text{where } e = \left(1 - \left(\frac{b}{a}\right)^2\right)^{\frac{1}{2}}$$

and $\sin^{-1}(e)$ is expressed in radians,
1 radian = 57.2988°

$$V = \frac{4\pi}{3} a b^2$$

Triaxial Ellipsoid
all three perpendicular
sections are ellipses):



$$V = \frac{4}{3}\pi abc$$

Measurement methods and its application

- Measurement for each physical properties
- Experimental measurement is very costly, labour intensive and require specialist knowledge.
- Computer model – there is a need for models that can predict complicated phenomena

Chemical Properties

Objective:

To understand the chemical compositions of food and agricultural materials

Chemical compositions of food and agricultural materials

- Knowledge on the approximate compositions of food and agricultural materials is useful for estimating densities and thermal properties.
- Similarity between food and agricultural materials ; Contains 5 main component ;
 Water, protein, carbohydrates, lipid and ash
- Difference in the composition of individual components
- Composition of food and agricultural materials not only influence nutritional value but also on moisture adsorption and electromagnetic properties.

Water

- Most of food and agricultural materials contain significant amounts of water.
- The amount of water is important because it can affects market value and length of time they can be successfully stored.
- Moisture content also affects mechanical properties, density, frictional properties and electromagnetic properties.

Moisture content

- Moisture content expresses the amount of water present in a moist sample.
- 2 way to express moisture content;
 - Moisture content wet basis (MC_{wb})
 - Moisture content dry basis (MC_{db})
- Moisture content wet basis is the amount of water per unit mass of moist (or wet) sample.

$MC_{wb} = \text{mass of water} / \text{mass of moist sample (mass of water + mass of dry solids)}$

- Moisture content dry basis is the amount of water per unit mass of dry solids (bone dry) present in the sample

$MC_{db} = \text{mass of water} / \text{mass of dry solids}$

Carbohydrates

- Starch, sugar and gums are the major carbohydrates in our food systems.
- Sources of carbohydrates – these include such as wheat, maize, rice, potatoes, sugar, bread etc.
- The function of carbohydrates such as starch and sugar are providing the energy to our body.

Source data for the following table is from –
Stroshine , R. (1998). Physical Properties of Agricultural
Materials and food products. Purdue University

Table 3.1. Approximate Composition of Selected Cereal grains and Oilseeds, Processed Foods, and Edible Portions of Raw Fruits and Vegetables and Raw Meats and Animal Products. (Source: Watt and Merrill, 1963).(continued on next page).

Food Product	Percentage Composition					Ash
	Water	Protein	Fat	Carbohydrate:		
				Total	Fiber ^a	
Cereal Grains and Oilseeds:						
Corn	13.8	8.9	3.9	72.2	2.0	1.2
Peanuts (raw, with skin)	5.6	26.0	47.5	18.6	2.4	2.3
Popcorn (unpopped)	9.8	11.9	4.7	72.1	2.1	1.5
Rice	12.0	7.5	1.9	77.4	0.9	1.2
Rye	11.0	12.1	1.7	73.4	2.0	1.8
Sorghum	11.0	11.0	3.3	73.0	1.7	1.7
Soybeans	10.0	34.1	17.7	33.5	4.9	4.7
Wheat (hard red spring)	13.0	14.0	2.2	69.1	2.3	1.7
Wheat (soft red winter)	12.5	12.3	1.8	71.7	2.3	1.7
Wheat (durum)	13.0	12.7	2.5	70.1	1.8	1.7
Fruits and Vegetables (Raw, Edible Portions):						
Apples	84.4	0.2	0.6	14.5	1.0	0.3
Asparagus spears	91.7	2.5	0.2	5.0	0.7	0.6
Bananas	75.7	1.1	0.2	22.2	0.5	0.8
Beans (green, snap)	90.1	1.9	0.2	7.1	1.0	0.7
Blueberries	83.2	0.7	0.5	15.3	1.5	0.3
Carrots	88.2	1.1	0.2	9.7	1.0	0.8
Cauliflower	91.0	2.7	0.2	5.2	1.0	0.9
Celery	94.1	0.9	0.1	3.9	0.6	1.0
Cherries (sour)	83.7	1.2	0.3	14.3	0.2	0.5
Cherries (sweet)	80.4	1.3	0.3	17.4	0.4	0.6
Grapes (American type- Concord, Delaware, etc.)	81.6	1.3	1.0	15.7	0.6	0.4
Lettuce (Crisphead - Iceberg, New York, etc.)	95.5	0.9	0.1	2.9	0.5	0.6
Oranges (California Valencia) ^b	85.6	1.2	0.3	12.4	—	0.5
Peaches	89.1	0.6	0.1	9.7	0.6	0.5
Pears (with skins)	83.2	0.7	0.4	15.3	1.4	0.4
Peas (green, immature)	78.0	6.3	0.4	14.4	2.0	0.9
Pineapple	85.3	0.4	0.2	13.7	0.4	0.4
Potatoes	79.8	2.1	0.1	17.1	0.5	0.9
Squash (summer, zucchini)	94.6	1.2	0.1	3.6	0.6	0.5
Squash (winter, butternut)	83.7	1.4	0.1	14.0	1.4	0.8
Strawberries	89.9	0.7	0.5	8.4	1.3	0.5
Sweet Potatoes	70.6	1.7	0.4	26.3	0.7	1.0
Tomatoes	93.5	1.1	0.2	4.7	0.5	0.5

^aPercent of total weight that is fiber.

^bValue is for a peeled orange. Valencia is a summer orange.

Table 3.1. (Cont'd) Approximate Compositions of Food Products (Edible Portion)

Food Product	Percentage Composition					Ash
	Water	Protein	Fat	Carbohydrate: Total	Fiber ^a	
Meats (Raw, Edible Portions) and Animal Products:						
Beef (choice chuck, 82% lean)	60.8	18.7	19.6	0.0	0.0	0.9
Beef (choice sirloin, 73% lean)	55.7	16.9	26.7	0.0	0.0	0.8
Butter	05.5	0.6	81.0	0.4	0.0	2.5
Cheese (American, pstrzd procs.)	43.2	19.8	24.0	7.1	0.0	5.9
Cheese (natural, cheddar)	37.0	25.0	32.2	2.1	0.0	3.7
Cheese (natural, swiss)	39.0	27.5	28.0	1.7	0.0	3.8
Chicken (light meat, w/o skin)	73.7	23.4	1.9	0.0	0.0	1.0
Chicken (dark meat, w/o skin)	73.7	20.6	4.7	0.0	0.0	1.0
Cream (light, whipping)	62.1	2.5	31.3	3.6	0.0	0.5
Eggs	73.7	12.9	11.5	0.9	0.0	1.0
Fish (cod)	81.2	17.6	0.3	0.0	0.0	1.2
Fish (white perch)	75.7	19.3	4.0	0.0	0.0	1.1
Fish (salmon, Chinook)	64.2	19.1	15.6	0.0	0.0	1.1
Fish (tuna, bluefin)	70.5	25.2	4.1	0.0	0.0	1.3
Lamb (choice loin, 72% lean)	57.7	16.3	24.8	0.0	0.0	1.3
Milk (cow's, whole - 3.5% fat)	87.4	3.5	3.5	3.9	0.0	0.7
Milk (cow's, skim)	90.5	3.6	0.1	5.1	0.0	0.7
Milk (cow's, dried skim, instant)	4.0	35.8	0.7	51.6	0.0	7.9
Pork (ham, 72% lean)	54.3	15.2	29.1	0.0	0.0	0.8
Pork (loin, 76% lean)	54.8	16.4	28.0	0.0	0.0	0.8
Turkey (light meat)	73.0	24.6	1.2	0.0	0.0	1.2
Turkey (dark meat)	73.6	20.9	4.3	0.0	0.0	1.1
Food Products:						
Bread, white ^a	35.8	8.7	3.2	50.4	0.2	1.9
Bread, whole wheat ^a	36.4	10.5	3.0	47.7	1.6	2.4
Corn Flakes	3.8	7.9	0.4	85.3	0.7	2.6
Crackers (graham, plain)	6.4	8.0	9.4	73.3	1.1	2.9
Crackers (saltines)	4.3	9.0	12.0	71.5	0.4	3.2
Ice Cream (ca. 10% fat)	63.2	4.5	10.6	20.8	0.0	0.9
Ice Milk	66.7	4.8	5.1	22.4	0.0	1.0
Oatmeal (dry)	8.3	14.2	7.4	68.2	1.2	1.9
Orange Juice ^b	87.8	1.0	0.3	10.5	0.1	0.4
Rice, white (milled and polished)	12.0	6.7	0.4	80.4	0.3	0.5
Soup, cnds'd cream mushroom	79.3	1.9	8.0	8.4	0.2	2.4
Soup, condensed tomato	81.0	1.6	2.1	12.7	0.4	2.6
Spaghetti (dry)	10.4	12.5	1.2	75.2	0.3	0.7
Wheat Flour (hard wheat)	12.0	11.8	1.2	74.5	0.4	0.46
Wheat Flour (soft wheat)	12.0	9.7	1.0	76.9	0.4	0.42
Wheat Flakes	3.5	10.2	1.6	80.5	1.6	4.2

^aMade with 1 to 2 % nonfat dry milk.^bMade from California Valencia (summer) oranges

Mechanical Properties

(Focus on deformation of solid)

Objectives:

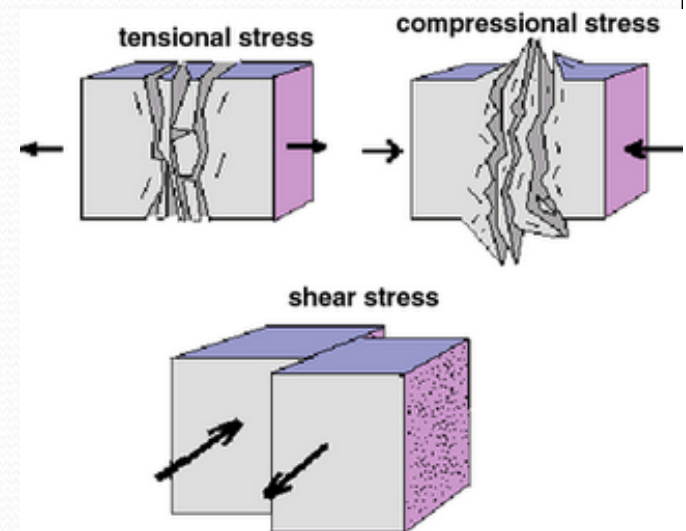
1. To explore the significance of solid foods and agricultural products properties with respect to the following
 - To improve quality control in the food industry
 - To correlate consumer acceptance with some definite property, eg. Hardness of peanut brittle – with consumer acceptance
2. To determine mechanical properties through tensile, compression, shear and bending test
 - It is useful in size reduction and conveying operation.
 - Mechanical damage to fruits, vegetables, grains and seeds: failure criteria; external forces during handling; detection and evaluation of damage

Introduction

- Mechanical properties are important to processing and consumption
- Mechanical properties are behaviour of food/ agricultural materials when subjected to external forces.
- The forces acting on the material are expressed as stress.
 - Stress is defined as force components acting on a body per unit cross-sectional area or area of the deformed specimen (N/mm^2 or Pa)



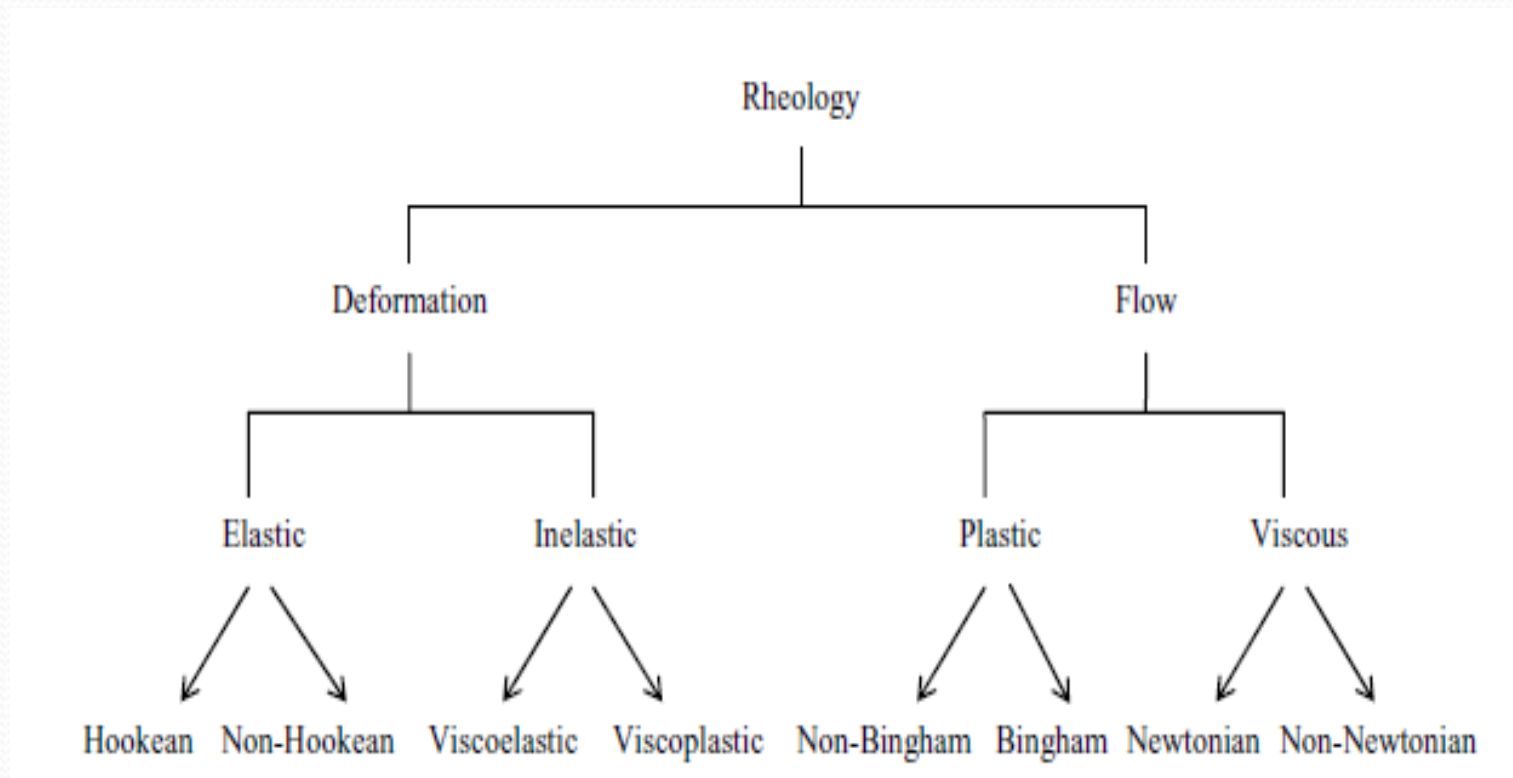
- 3 stresses that characterize foods mechanically:
 - compressive – directed toward the material
 - tensile – directed away from the material
 - shearing – directed tangentially to the material
- Shear stress is the most prevalent with fluids or viscous materials
- Stress can act on food at different mechanical situations:
 - Static – constant stress or strain
 - Dynamic – varying stress or strain
 - Impact – stress exerted and removed after a short period of time
- Solid foods are mechanically characterized by compression tests or impact tests.
 - Equipment: Universal testing machines



- The response of materials to stress is deformation, *strain*.
 - Strain is the change in size or shape of a body in response to the applied force.
 - Strain is a dimensionless ratio.
- The relationship between stress and strain is known as rheology
 - Rheology – a science devoted to the study of deformation and flow

- A material can deform in 3 ways: elastic, plastic or viscous.
 - (1) Elastic deformation
 - Young's modulus, E
 - (2) Plastic deformation: deformation does not occur as long as the stress is below a limit value of yield stress. Deformation is permanent.
 - (3) Viscous deformation: deformation (flow) occurs instantly with the application of stress and it is permanent. The rate of strain is proportional to the stress. (Details on Rheological properties)
- Deformation depends on many factors
 - Rate of applied force
 - Previous loading
 - Moisture content
 - Biomaterial composition

• Classification of rheology



Mechanical-rheological behaviour of fluid or viscous foods is the flow behaviour:

Newtonian or non Newtonian

Pseudoplastic and Bingham

Will discussed in details in Lecture 6

Knowledge on rheological and mechanical properties of food systems;

-In design of flow processes for quality control

-in predicting storage and stability measurements,

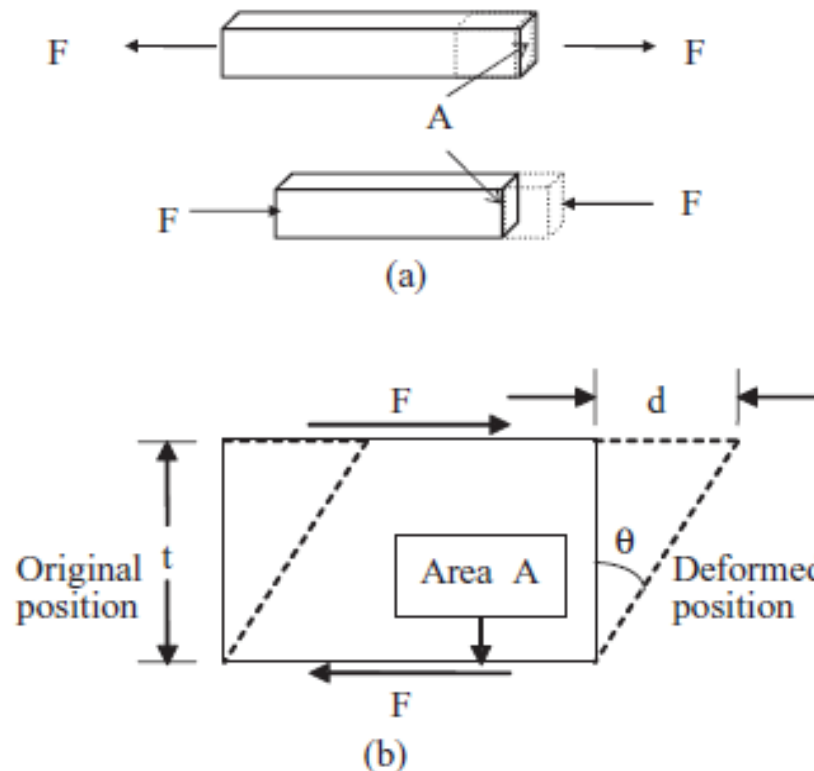
-in understanding and designing texture.

Deformation of material

Normal stress (σ) is the force applied perpendicular to the plane per unit area.

- Tensile or compressive stress

Shear stress (τ) is the force applied parallel to the plane per unit area



- a) Tensile and compressive normal stress
- b) Shear stress

- Stresses and strain can also be described as dilatational or deviatoric.
- Dilatation stress or strain causes change in volume.
- Deviatoric stress or strain causes change in shape but negligible changes in volume

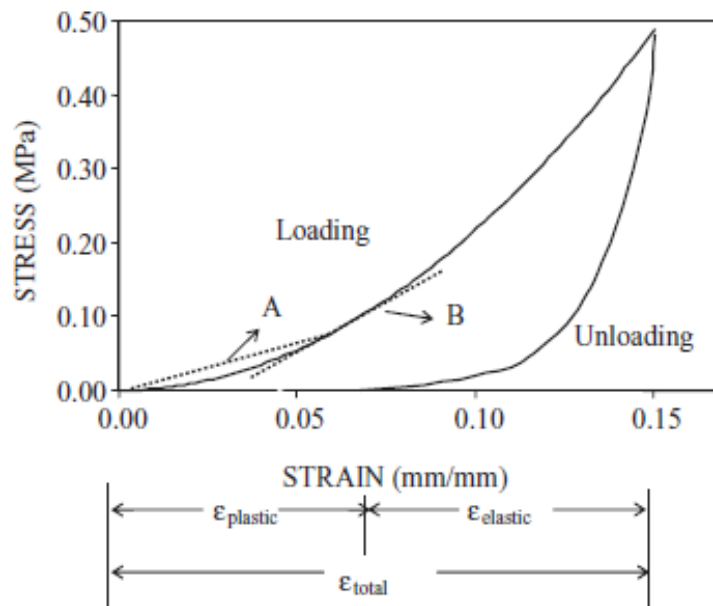
$$\text{Dilatation} = \frac{V_f - V_0}{V_0}$$

V_0 = Initial volumes; V_f = Final volumes

Strain can be categorized into 2 groups: Normal strain and Shear strain

$\epsilon = \frac{\Delta L}{L}$ » **Normal strain** is the change in length per unit length in the direction of the applied normal stress

$\gamma = \tan \theta = \frac{d}{t}$ » **Shear strain** is defined as the change in the angle formed between two planes that are orthogonal prior to deformation as a result of the application of stress



Stress-strain curve for
compression of a food
material

- **Plastic strain** – strain that is not recovered during unloading
- **Elastic strain** – strain that is recovered during unloading
- **Degree of plasticity** – the ratio of plastic strain to total strain when a material is loaded to a certain load and unloaded
- **Degree of elasticity** – the ratio of elastic strain to total strain
- Material that showing **elastic behaviour** is known as **Hookean solid**.
- Young' s Modulus or **Modulus of elasticity** (E): defined as the ratio of normal stress to strain

$$E = \frac{\sigma}{\epsilon}$$

- Shear modulus or **Modulus of rigidity** (G)- describe relationship between the shear stress and shear strain.

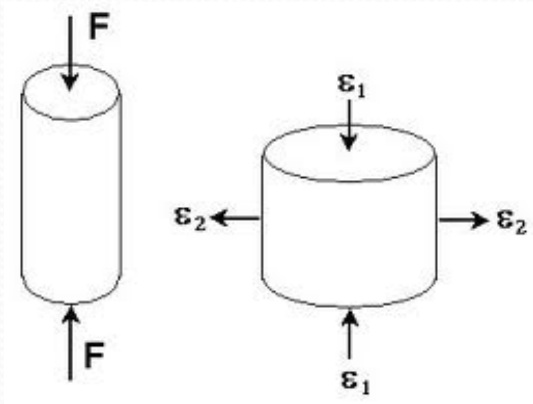
$$G = \frac{\tau}{\gamma}$$

- Force applied from all directions - results in a volume change,
 - Modulus - **bulk modulus** (K). It describes response of solid to dilatational stresses

$$K = \frac{\text{Pressure change}}{\text{Volume change / Original volume}} = \frac{\text{Average normal stress}}{\text{Dilatation}}$$

- **Poisson's ratio (μ):**

- When a material is compressed in one direction, it usually tends to expand in the other two directions perpendicular to the direction of compression
- The Poisson ratio is the ratio of the fraction (or percent) of expansion divided by the fraction (or percent) of compression, for small values of these changes.



$$\mu = \frac{\text{Change in width per unit width}}{\text{Change in length per unit length}} = \frac{\Delta D / D}{\Delta L / L}$$

- **Bioyield point** is defined as the point at which an increase in deformation is observed with a decrease or no change of force. Bioyield point is an indication of initial cell rupture.
 - Corresponds to a failure in the microstructure of the sample.
- **Rupture point** is a point on the stress- strain or force- deformation curve at which the axially loaded specimen ruptures under a load.
 - Corresponds to a failure in the macrostructure of the specimen.

Apparent modulus of elasticity

- For biological materials, the apparent modulus of elasticity is used to relate stress to strain.
- Defined using secant or tangent definition.
- Secant definition- the apparent modulus of elasticity is the ratio of the stress to the strain at a given point.
- Tangent definition – the slope of the stress-strain curve at a given point on the curve

Table 4.1. Values of apparent modulus of elasticity grains, seeds, and vegetables as determined by uniaxial compression tests.

Product ^a	Loading Rate (mm/min)	E (MPa)	Comments ^a	Reference
Corn (maize)				
13.3% m.c.	6.8	400	Measured at strains of 0.142 and 0.197 for 13.3% m.c. and 18.7% m.c., respectively	Zoerb and Hall (1960)
18.7% m.c.	6.8	219		
Melon ("Galia")				
outer flesh	50	0.644	Apparent modulus, E, calculated at the proportional limit.	Mizrach et al., (1991)
inner flesh	50	0.209		
Melon ("Superstar")				
outer flesh	25.4	0.802	Measured at a strain of 0.10	Cardenas-Weber, et al. (1991)
inner flesh	25.4	0.263		
Potato (Sweet)				
freshly dug	25.4	4.19	Measured at strains of 0.317 and 0.293 for freshly dug and stored 22 wks, respectively.	Wright and Splinter (1968)
stored 22 wks	25.4	5.20		
Rice (white)				
10% m.c.	5.0	337	Apparent modulus calculated from slope of stress versus strain curve between a strain of 0.333 times and 0.666 times the failure strain.	Wouters and de Baerdemaeker (1988)
15% m.c.	5.0	250		
Rice (parboiled)				
10% m.c.	5.0	343	See Comments for white rice. Apparent moduli of parboiled rice were distinctly different from those of parboiled rice.	Wouters and de Baerdemaeker (1988)
15% m.c.	5.0	209		
Soybean cotyledon				
9.1% m.c.	250	158	Measured at a strain of 0.10. Values taken from initial (time equal to zero) points of stress relaxation curves.	Liu et al. (1990)
13% m.c.	250	95		
20% m.c.	250	42		
Wheat				
13.6% m.c.	68	317	Measured at strains of 0.118 and 0.237 for 13.6 and 19.8% m.c., respectively	Zoerb and Hall (1960)
18.7% m.c.	68	239		
Wheat (Seneca)				
9.1% m.c.	0.51	1586	Measured a strain of approximately 0.005	Shelief and Mohsenin (1967)

^aMoisture contents are reported on a wet basis

Stress –strain curves for uniaxial compression

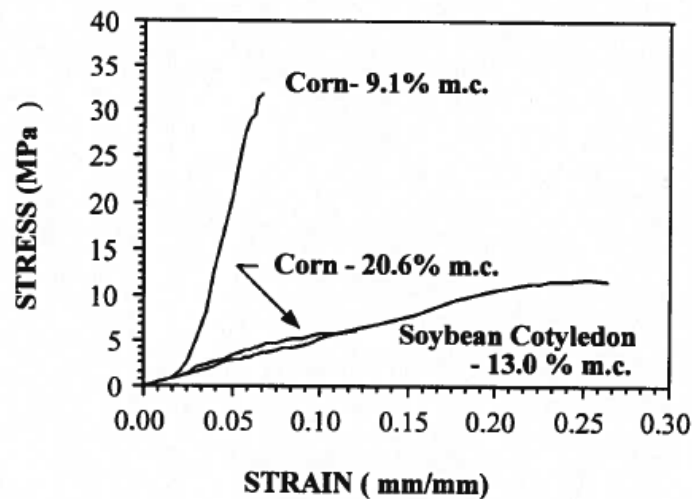
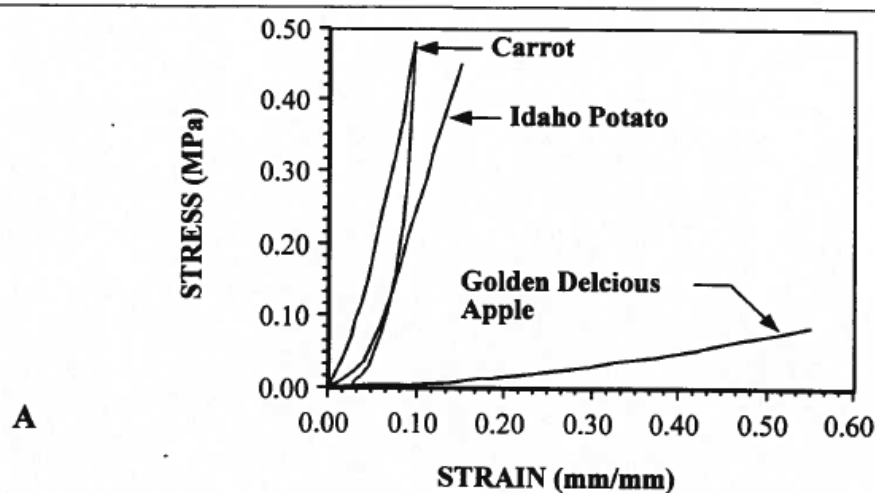


Figure 4.6. Stress versus strain curves for uniaxial compression of cylindrical or cubical samples of agricultural materials. **A.** Curves for several vegetables and fruits. **B.** Curves for a corn kernel (Waananen, 1987) and a soybean seed (Liu, 1989).

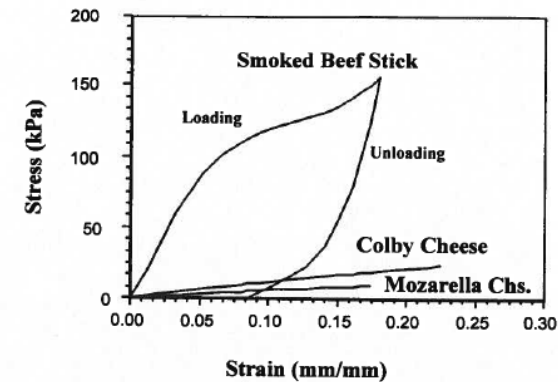


Figure 4.7. Stress versus strain curves for uniaxial compression of cylindrical samples of food materials—a smoked beef stick (ingredients: beef, spices and flavoring, dextrose, paprika, sodium erythrobate, and sodium nitrite) and two types of cheese.

Viscoelastic behavior

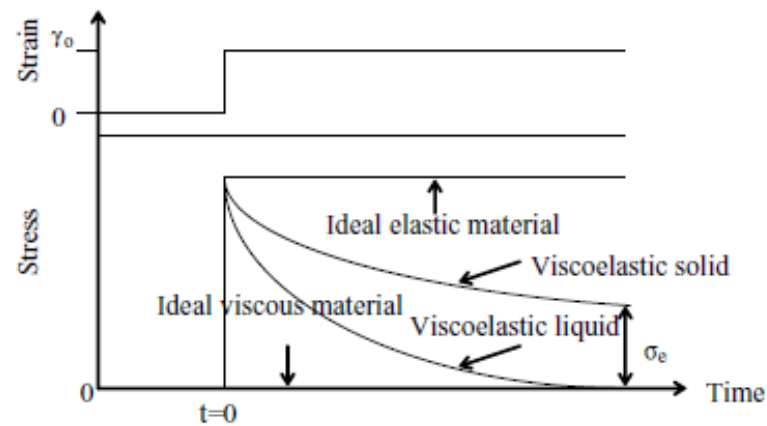
- Viscous fluid generally exhibit viscosity while solids exhibit elasticity.
- Some foods show both viscous and elastic properties which know as viscoelastic materials, when undergoing deformation.
- Examples: Viscoelastic material – wheat flour dough
Viscoelastic foods – dairy cream, ice cream mix, cheese and most gelled products
- There are different methods to study viscoelastic materials : stress relaxation test, creep test and dynamic test

Stress Relaxation Test

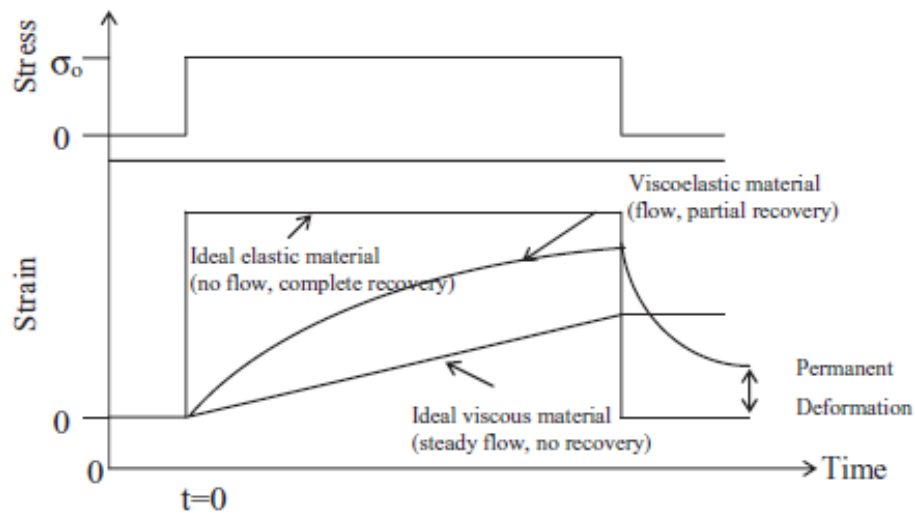
- Stress relaxation is when food materials are deformed to a fixed strain and strain is held constant, the stress required to maintain this strain decreases with time.
- In this test, stress is measured as a function of time as the material is subjected to a constant strain.
- Test can be conducted in shear, uniaxial tension or uniaxial compression.

Creep Test

- Creep is when a constant load is applied to biological materials and if stresses are relatively large, the material will continue to deform with time.
- In creep test, an instantaneous constant stress is applied to the material and strain is measured as a function of time.
- Creep test can be performed in uniaxial or compression.



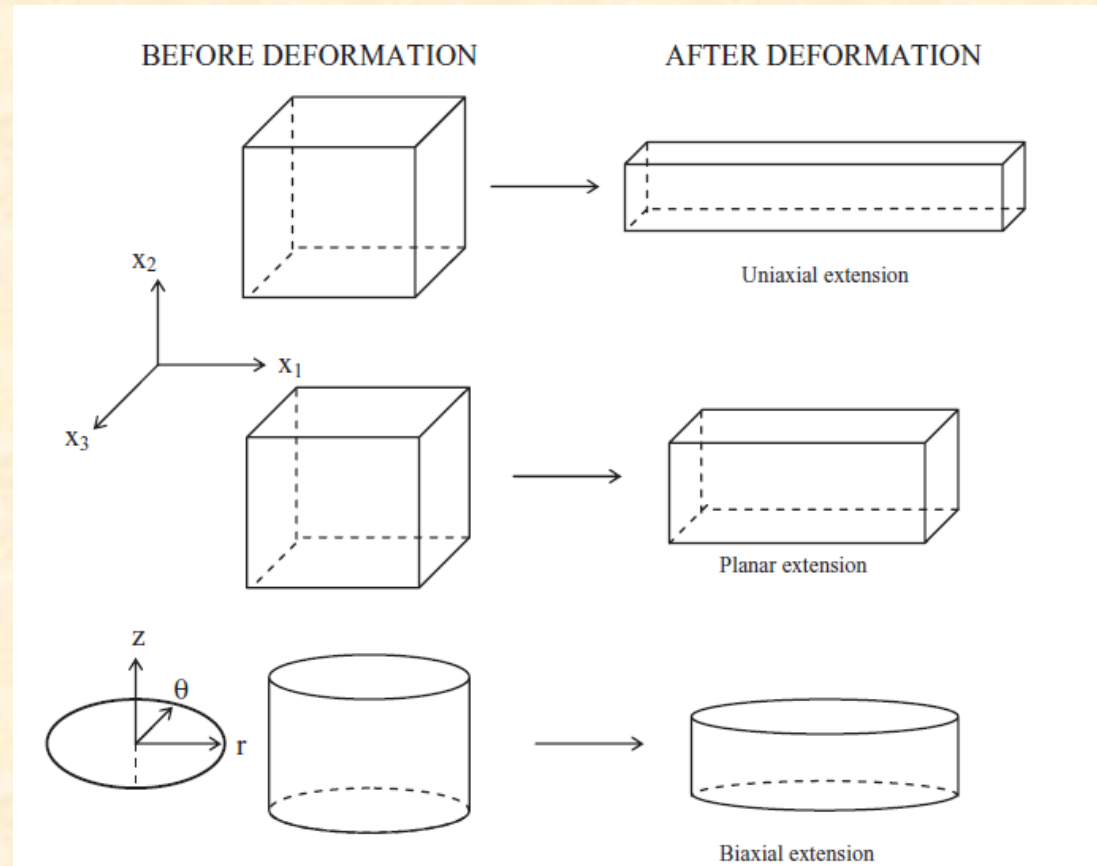
Stress relaxation curves for elastic, viscous and viscoelastic materials



Creep and recovery curve for elastic, viscous and viscoelastic materials

Extensional deformation

- 3 types of extensional deformation: uniaxial, planar and biaxial






Uniaxial extension – stretched in one direction with a size reduction in the other two direction.




Planar extension – stretched in the x_1 direction with decrease in x_2 while width in the x_3 direction remain unchanged.




Biaxial extension – flow produces a radial tensile stress

Testing Method

- Uniaxial Compression
 - A popular method of testing for agricultural product/food material
- Tensile loading
 - Less common than compression testing for agricultural product/food material
 - Suitable for testing packaging materials
- Bending tests
 - Can be used for determination of the critical tensile stresses at failure
- Torsional Loading

NAME OF EQUIPMENT	FUNCTION	LAB	PICTURE
Instron Machine (Model 5566)	For testing tensile, compression, fatigue and impact on a material	Engineering Properties of Biomaterials and Neutraceutical Laboratory	
Pharma Test Dissolution Tester	<p>-To characterize the dissolution properties of the active drug, the active drug's release and the dissolution from a dosage formulation.</p> <p>-Dissolution testing is used to formulate the drug dosage form and to develop quality control specifications for its manufacturing process.</p>	Engineering Properties of Biomaterials and Neutraceutical Laboratory	
Malvern Particle Size Analyzer	For measuring particle size and particle size distribution	Engineering Properties of Biomaterials and Neutraceutical Laboratory	

NAME OF EQUIPMENT	FUNCTION	LAB	PICTURE
Micromeritics GeoPyc 1360 envelope and T.A.P Density Analyzer	<p>-To measure the envelope density of porous objects of irregular size and shape.</p> <p>measures the packing volume.</p> <p>-Calculates the bulk density of granular and powdered samples under a wide range of compaction conditions.</p>	Engineering Properties of Biomaterials and Neutraceutical Laboratory	
Hunterlab UltraScan Pro	For color testing	Quality of Food Processing Laboratory	
Rheometer AR-G2	For rheological of food material analysis	Quality of Food Processing Laboratory	

NAME OF EQUIPMENT	FUNCTION	LAB	PICTURE
TA XT PLUS Texture Analyzer	For analysis the texture of food material	Quality of Food Processing Laboratory	 A TA XT PLUS Texture Analyzer, a white laboratory instrument with a black probe and a yellow warning label, used for measuring the texture of food materials.
Viscometer	For viscosity analysis	Quality of Food Processing Laboratory	 A Brookfield DV-II + Viscometer, a blue and white laboratory instrument with a digital display and several buttons, used for measuring the viscosity of liquids.
Moisture Analyzer	For moisture content analysis	Quality of Food Processing Laboratory	 A moisture analyzer, a white laboratory instrument with a green display screen and a circular sample pan, used for determining the moisture content of solid samples.

Rheology Properties

(Focus on Viscosity and Flow of Liquids)

Introduction

- Liquids and semisolids are usually pumped during processing
- Viscosity plays a huge part in pump and conveyance system design
- Viscosity may be dependent on moisture content, concentration, composition and prior treatments

Flow of material

Viscosity is defined as the resistance of a fluid to flow.
The unit of dynamic viscosity is Pa.s (SI system).
Viscosity varies with temperature.

$$\tau_{yz} = -\mu \frac{dv_z}{dy}; \text{ where } \tau = \text{shear stress (N/m}^2 = \text{Pa),}$$

$$\frac{dv_z}{dy} = \text{shear rate (s}^{-1}\text{),}$$

μ = proportionality constant

aka dynamic viscosity (Pa-s)

Kinematic viscosity: dynamic viscosity/density of fluid

$$\nu = \frac{\mu}{\rho}, m^2/s = \text{stokes}$$

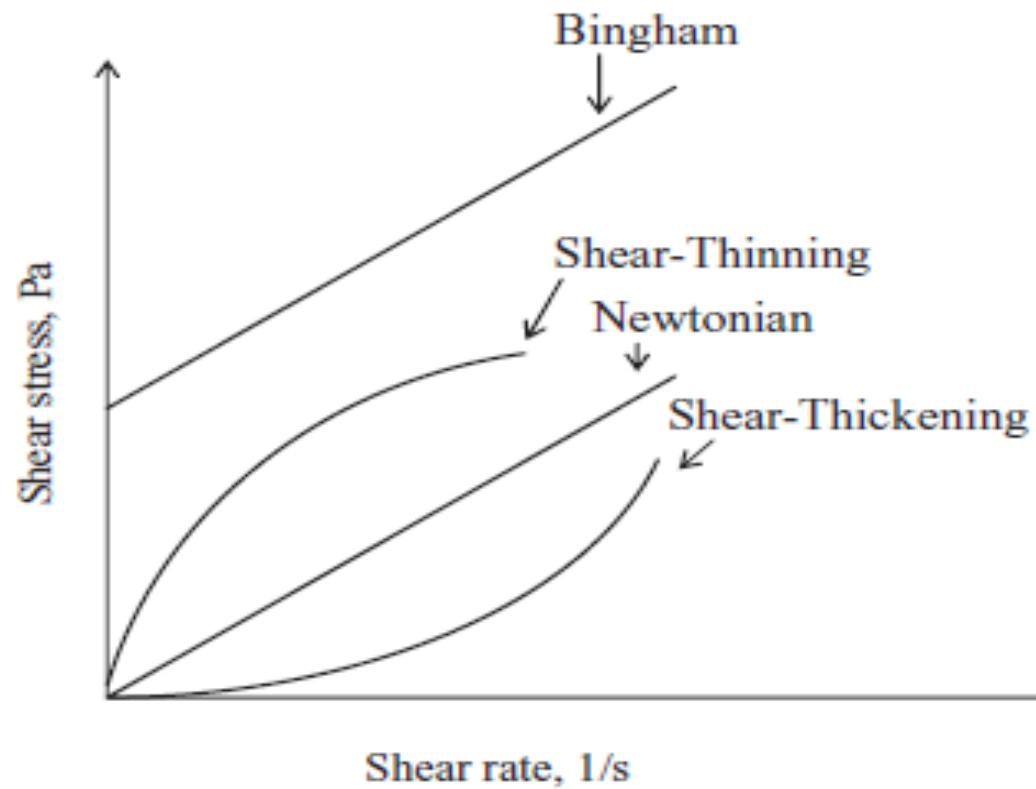
Based on relationship between shear stress and shear rate:

1. Newtonian fluids (linear relationship)
2. Non-Newtonian fluids (non-linear relationship)

- Newtonian fluids – fluids that follow Newton's law of viscosity. The slope of the shear stress vs shear rate, which is viscosity, is constant and independent of shear rate in Newtonian fluids (Figure 1 and 2)

- Examples: Gases; oils; water and most liquids that contain more than 90% water such as tea, coffee, fruit juices and milk.





The slope of shear stress versus shear rate graph is not constant for non-Newtonian fluids.

Figure 1

Table 6.1. Values of viscosity for Food Products and Agricultural Materials which are Newtonian.

Product	Temperature °C	Viscosity Pa s	Reference
Apple Juice (20° Brix)	27	0.0021	Saravacos (1968)
Apple Juice (60° Brix)	27	0.0300	Saravacos (1968)
Corn Syrup (48.4 % Total Solids)	27	0.053	Harper (1960)
Cream (10% fat)	40	0.00148	Phipps (1969)
Cream (20% fat)	40	0.00238	Phipps (1969)
Grape Juice (60° Brix)	27	0.11	Saravacos (1968)
Honey (Sweet Clover)	25	4.80	Munro (1943)
Milk (Homogenized)	40	0.00110	Caffyn (1951)
Milk (Homogenized)	20	0.0020	Caffyn (1951)
Oils: Corn	25	0.0565	Acton and Saffle (1971)
Peanut	25	0.0656	Acton and Saffle (1971)
Soybean	30	0.0406	Whorlow (1980)

Non-Newtonian fluids – Fluids that do not follow Newton's law of viscosity. The viscosity is termed as consistency or apparent viscosity.

Non-newtonian foods can be divide into two categories: time-independent and time - dependent

Time-independent flow behaviour : shear thinning (pseudoplastic) and shear thickening (dilatant)

(a) Shear Thinning (Pseudoplastic) Fluids.

- These types of fluids, the shear rate increases friction between layers decreases

- Examples; Dairy cream, fruit and vegetables purees, concentrates, salad dressing



(b) Shear thickening Fluids.

-In these types of fluids, as shear rate increases, the internal friction and apparent viscosity increase.

-If the increase in viscosity is accompanied by volume expansion shear thickening fluids are called dilatant fluids.

-Examples; Corn starch suspension, chocolate syrups, high solids



Shear thinning or shear thickening fluids obey the power law model

k = consistency coefficient (Pa.s)

n = the flow behaviour index

τ = shear stress

$$\tau = k \left[\frac{dv}{dy} \right]^n$$

For shear thinning (pseudoplastic) fluids $n < 1$

For shear thickening fluids $n > 1$.

Newtonian fluids , $n = 1$ and $k = \mu$

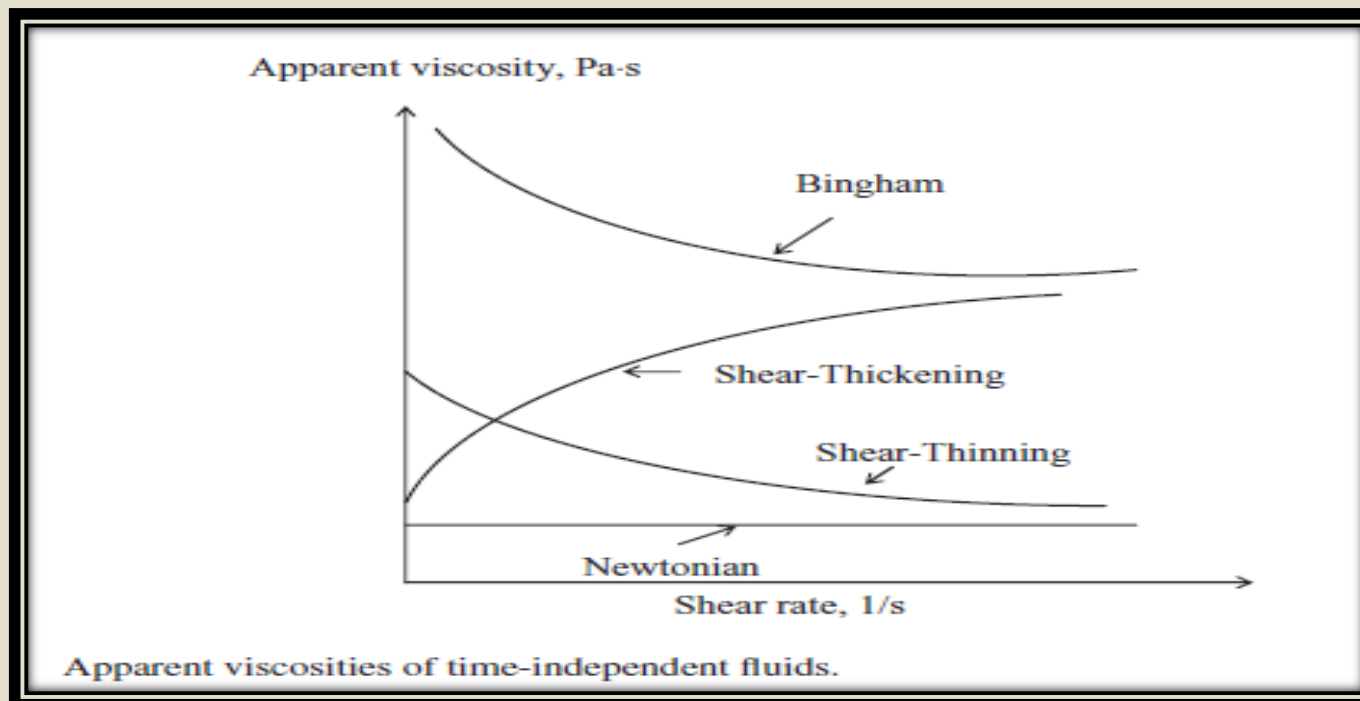


Figure 2

Table 6.2. Values of constants for Foods and other Agricultural Materials which can be described using the general form of the Herschel-Bulkley model but which have no yield stress ($\tau_y = 0$, Equation 6.2).

Product	K	n	Conditions	Reference
	Pa s ⁿ		Temp (°C), Shear Rate, etc.	
Apple Sauce	16.7	0.302	20°C, 3.3 - 530 s ⁻¹	Haugen and Tung (1976)
	2.4	0.438	25°C, 0.1 - 1.1 s ⁻¹	
Blueberry Pie Filling	6.1	0.426	20°C, 3.3 - 530 s ⁻¹	Haugen and Tung (1976)
Feed Slurries: Ground Corn	0.003	1.56	Room temp., Extrusion rheometer, Feed:water= 1: 1.10	Herum et al (1966)
Ground Corn (63.6% m.c.)	0.31	0.62	Room temp., pipe 25.4 mm (1 in.) diam. Extrusion rheometer	Mitchel and Peart (1968)
Ground Corn (69.3% m.c.)	0.0044	1.4	Room temp., pipe 25.4 mm (1 in.) diam. Extrusion rheometer	Mitchel and Peart (1968)
Ground Corn	0.0035	1.3	Room temp., pipe 12.7 mm (.5 in.) diam. Extrusion rheometer	Mitchell and Peart (1968)
Feed Slurry (Mixed Swine Ration)	15.7	0.279	Room temp., Extrusion rheometer, Feed:Water = 1:1.50	Herum et al (1966)
Mayonnaise	6.4	0.55	25°C, 30 - 1300 s ⁻¹	Saravocos and Moyer (1967)
Mustard	19.1	0.39	25°C, 30 - 1300 s ⁻¹	Saravocos and Moyer (1967)

Bingham Plastic Fluids

In these types of fluids, fluid remains rigid when the magnitude of shear rate is smaller than the yield stress (τ_0) but flows like a Newtonian fluid when the shear stress exceeds τ_0 .

Examples: Toothpaste, mayonnaise, tomato paste, ketchup.

Eq. for behavior of Bingham plastic fluids:

$$\tau_{yz} = \tau_0 + k \left(\frac{dv_z}{dy} \right)$$



Herschel-Buckley Fluid

This type of fluids - the shear stress rate curve is non-linear with a positive yield stress.

- A minimum shear stress or yield stress must be exceeded before flow begins.

Fluids that obey the Herschel-Buckley model are characterized by the presence of a yield stress term (τ_0) in the power law equation:

$$\tau = k \left[\frac{dv}{dy} \right]^n + \tau_0$$

Examples: minced fish paste and raisin paste

Notes: The power law, Newtonian and Bingham plastics model are all special cases of the Herschel –Buckley model.

The Herschel –Buckley model is the one most commonly used.

For a Newtonian fluid, $\tau_0 = 0$, $n = 1$

For a Bingham fluid, $\tau_0 > 0$, $n = 1$

For a shear thinning fluid, $\tau_0 = 0$, $0 < n < 1$

For a shear thickening fluid, $\tau_0 = 0$, $\infty > n > 1$

For a Herschel-Buckley fluid, $\tau_0 > 0$, $\infty > n > 0$

** $k > 0$

- Another expression, known as the Casson equation:

$$\tau = k \left[\frac{dv}{dy} \right]^{\frac{1}{2}} + \tau_0^{\frac{1}{2}}$$

- This equation is used to interpreting the flow data of chocolate.
- The square root of shear stress is plotted against the square root of shear rate to obtain a straight line.
- Line slope gives the consistency coefficient and the square of the intercept gives the yield stress

Time dependent viscosity

Non-Newtonian foods with time dependent flow properties: thixotropic and rheopectic fluids.

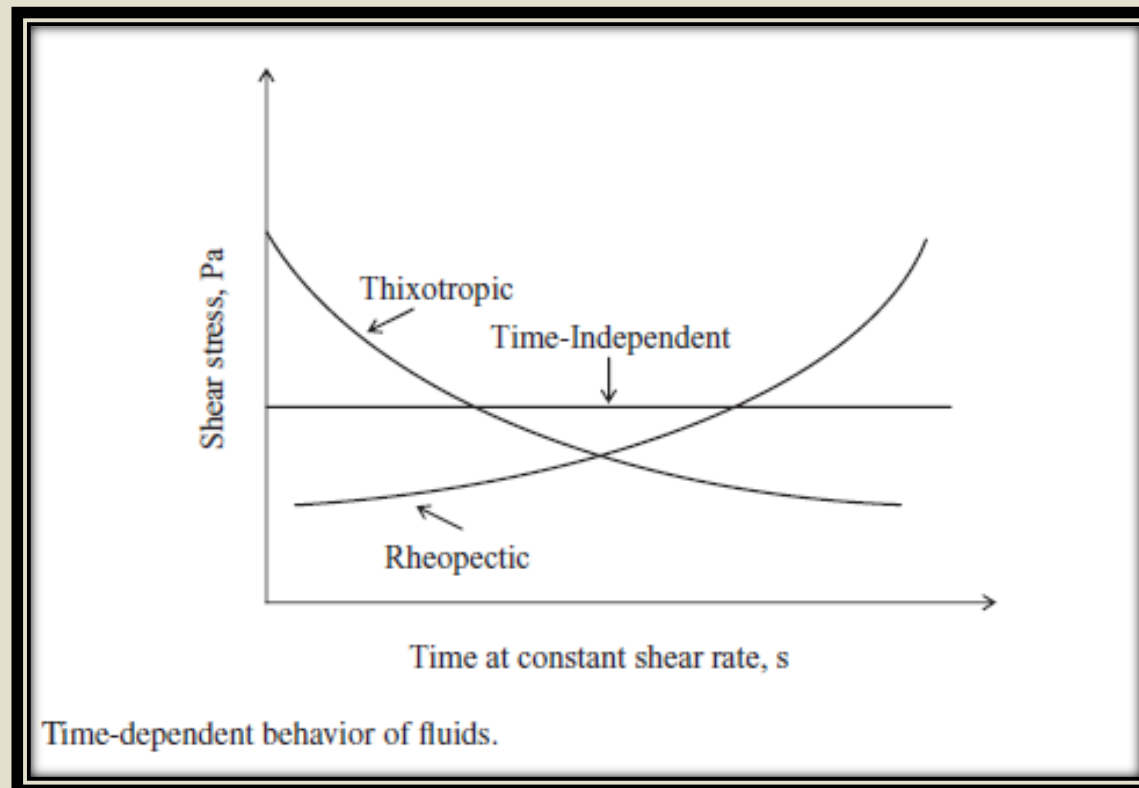
(a) Thixotropic fluids are fluids that exhibit decreasing shear stress and apparent viscosity with respect to time at fixed shear rate.

- Examples: condensed milk, gelatin and egg white.

(a) In Rheopectic fluids, at fixed shear rate, the viscosity increases with time.

Rarely observed in food systems.

- Example: Highly concentrated starch solutions- gravy



Viscometers



Example

- Rheological data for commercial milk chocolate at 40C is shown in the following. Using Casson model, determine the consistency coefficient and the yield stress.

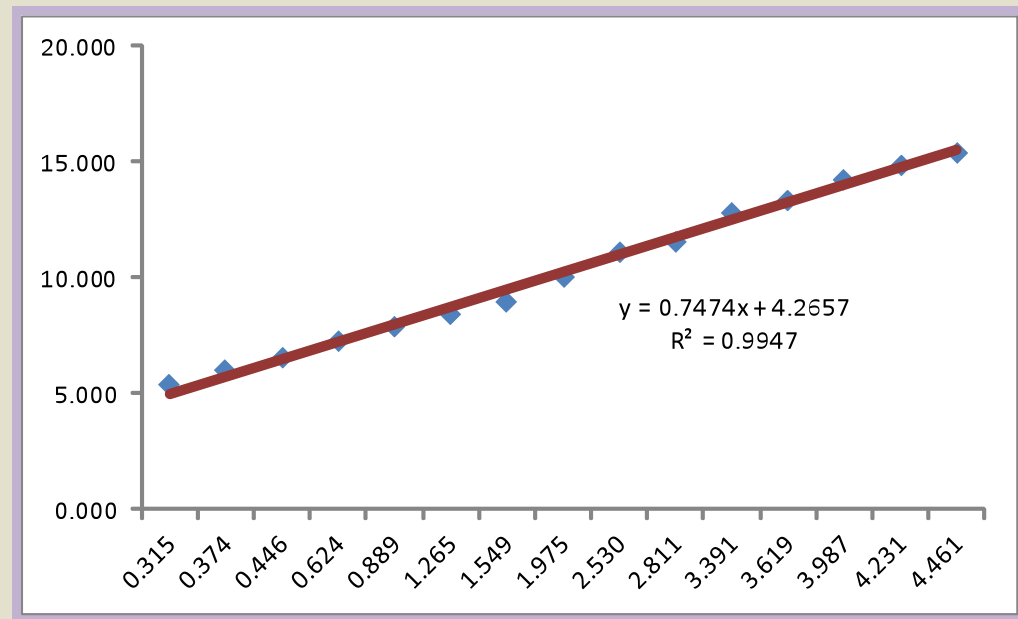
Shear rate	Shear stress
0.099	28.6
0.14	35.7
0.199	42.8
0.39	52.4
0.79	61.9
1.6	71.4
2.4	80.9
3.9	100
6.4	123.8
7.9	133.3
11.5	164.2
13.1	178.5
15.9	201.1
17.9	221.3
19.9	235.6

Solution

- Use the equation :

$$\tau = k \left[\frac{dv}{dy} \right]^{\frac{1}{2}} + \tau_0^{\frac{1}{2}}$$

Shear rate	Shear stress	Shear rate ^0.5	Shear stress^0.5
0.099	28.6	0.315	5.348
0.14	35.7	0.374	5.975
0.199	42.8	0.446	6.542
0.39	52.4	0.624	7.239
0.79	61.9	0.889	7.868
1.6	71.4	1.265	8.450
2.4	80.9	1.549	8.994
3.9	100	1.975	10.000
6.4	123.8	2.530	11.127
7.9	133.3	2.811	11.546
11.5	164.2	3.391	12.814
13.1	178.5	3.619	13.360
15.9	201.1	3.987	14.181
17.9	221.3	4.231	14.876
19.9	235.6	4.461	15.349



The slope is 0.7474 and intercept is 4.2657

The consistency coefficient is $K = 0.7474 \text{ Pa}^{0.5} \text{s}^{0.5}$

And yield stress $\sigma_0 = (4.2657)^2 = 18.20 \text{ Pa}$

Texture of foods

Introduction

Texture refers to those qualities of a food that can be felt with the fingers, tongue, palate, or teeth.

Texture is one of the most important quality characteristics of foods.

Foods have different textural properties.

Food texture assessed by consumers visually (appearance) and also during eating eg. during biting, mouthfeel

- Food texture can be evaluated by sensory or instrumental methods.
- Sensory methods used a taste panel containing trained panelist and a lot of samples.
- Instrumental methods are less expensive and less time consuming.



- Texture is affected by several factors :
 - Mechanics or rheology
 - Geometry
 - Chemistry
 - Thermal
 - Psychology

Thus instrumental methods, only measures the mechanical and physical aspects only

Evaluation of texture involves measuring the response of a food when it is subjected to forces such as cutting, shearing, chewing, compressing or stretching.

Weakness for instrumental methods;

eg. not comprehensive – limited to certain aspects; the eating process may be different

Texture test

(1) Compression (deformation) test measures the distance that a food is compressed under a standard force.



(2) Snapping-Bending – This test measures the force required to bend or snap brittle food such as biscuits or crackers.

- The 3 point bending test is the most commonly used snapping bending test (Figure 1).

- 3 point bending has loading at a single central point for a beam supported at either end. The deflection at the centre of the beam produced by a given force expressed as:

$$\rho = \frac{FL^3}{48EI} \quad \text{-----(1)}$$

where ρ = deflection at the center of the beam, F = force, L = length between supports, E = Young's modulus and I = second moment of area.

For a rectangular section beam having length of w and thickness of t :

$$I = wt^3/12$$

For a solid square beam; $I = t^4/12$

For a solid cylindrical beam having a radius of r , $I = \pi r^4/4$

Substituting I for a rectangular section beam into Eq. (1) :

$$\rho = \frac{FL^3}{4Ewt^3}$$

The snapping force can be expressed as : $F = \frac{2}{3}\sigma_{\max}\frac{wt^2}{L}$

Where σ_{\max} is the maximum stress.

For bars with cylindrical cross sections such bread sticks, the eq. becomes:

$$F = \sigma_{\max}\frac{\pi r^3}{L}$$

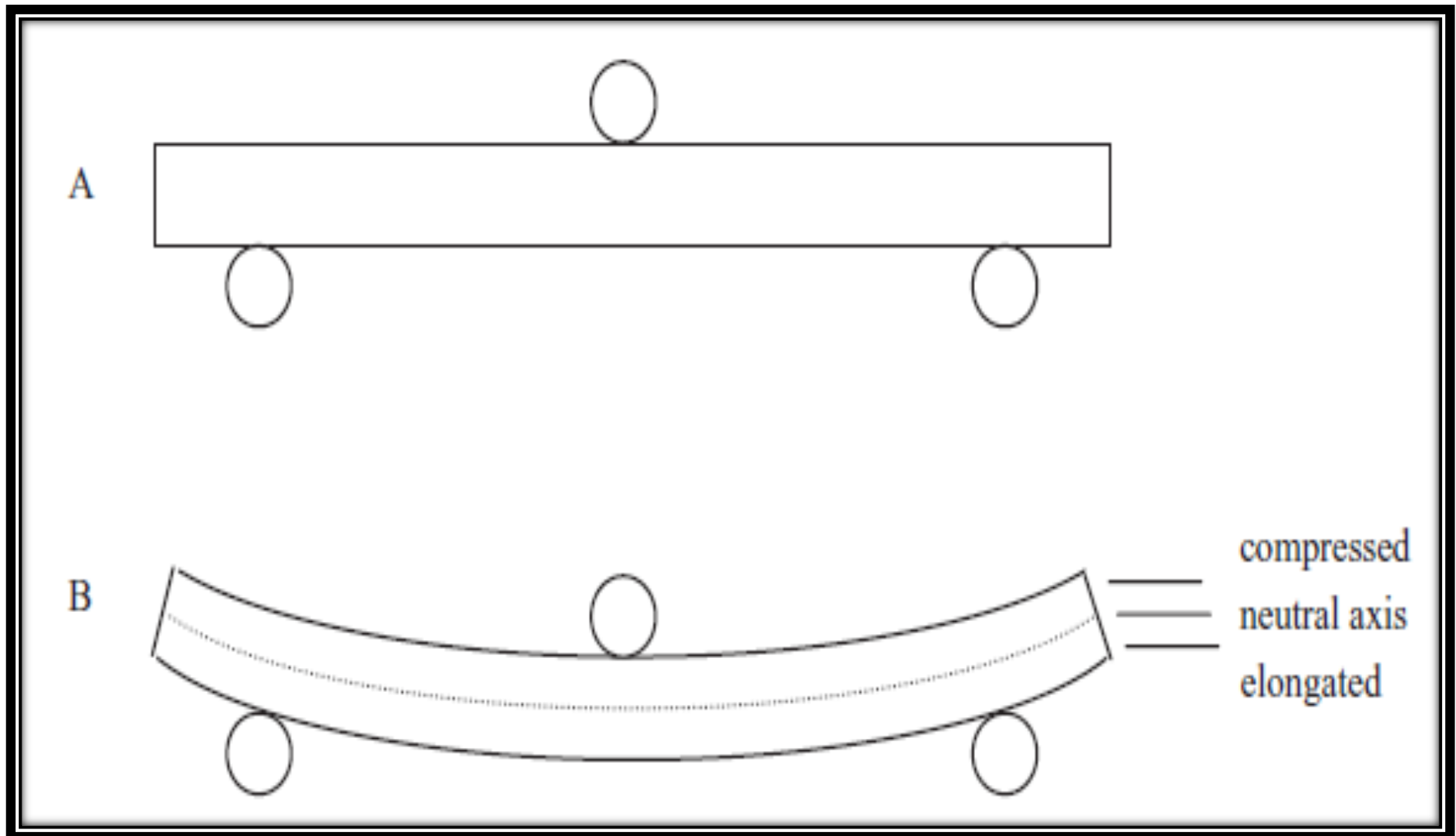


Figure 1: 3 point bending test

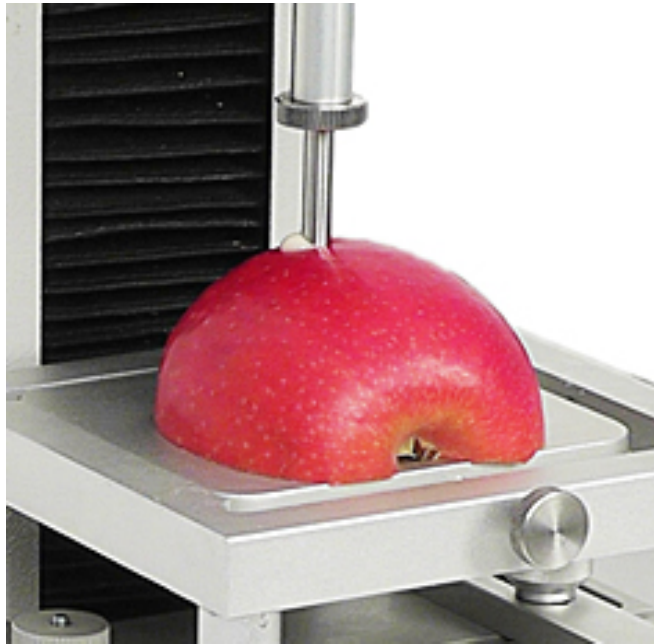


(3) Cutting Shear

- Pea Tenderometer measures the quality and maturity of fresh peas, and works via the principle of cutting shear. It consists of a grid of blades rotated at constant speed through a second grid of blades. As the peas are cut by the blades, the maximum force is measured.
- The Kramer Shear press was also developed to determine the texture of peas. It is widely used to determine the texture of fruits and vegetables.

(4) Puncture test measures product's firmness or hardness.

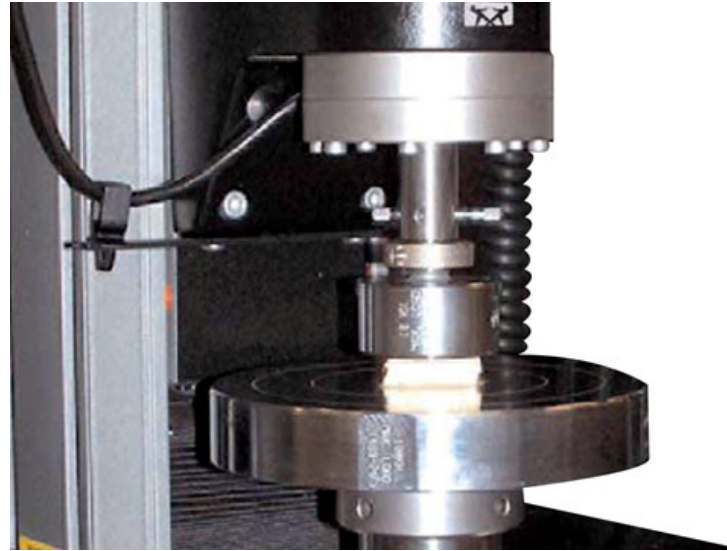
- Use a probe that pierce into the food which includes a spring to measure force
- The probe is pressed onto the sample's surface
- Force is applied until the probe punctures the surface and pierce into the sample
- Maximum force is measured when the probe pierced the surface
- Due to the force has reached a point where the surface yields to the force, hence, termed yield point
- It is mostly used for fruits, gels, vegetables and some dairy or meat products.



Puncture test



Pea tenderometer



Instron machine



Texture analyzer



(5) Penetration

- The penetrometer was developed for measuring the firmness or yield point of semisolid foods such as thick puddings, gels and spreadability of butter.
- Penetrometers were originally designed to measure the distance that a cone or a needle sinks into a food such as margarine or mayonnaise under the force of gravity for a standard time.
- This is a simple and relatively inexpensive apparatus .

(6) Texture Analyzer

- Probes and fixtures to meet the test requirements.



Penetrometer



Texture
Analyzer

Texture Profile Analysis (TPA)

- TPA compresses a bite sized piece of food twice to simulate the chewing action of the teeth.
- Compression is usually 80% of the original length of the sample.
- As a results of TPA, sensory properties such as gumminess, cohesiveness etc can be determined.
- Texture analyzers are used to obtain texture profile analysis.
- The force curve generated as a function of time is known as a texture profile.
- The instrument compress sample twice, 2 positive and 2 negative curve are obtained. (Figure 2)
- Peak forces and areas under the curves are used to determine various properties of foods.

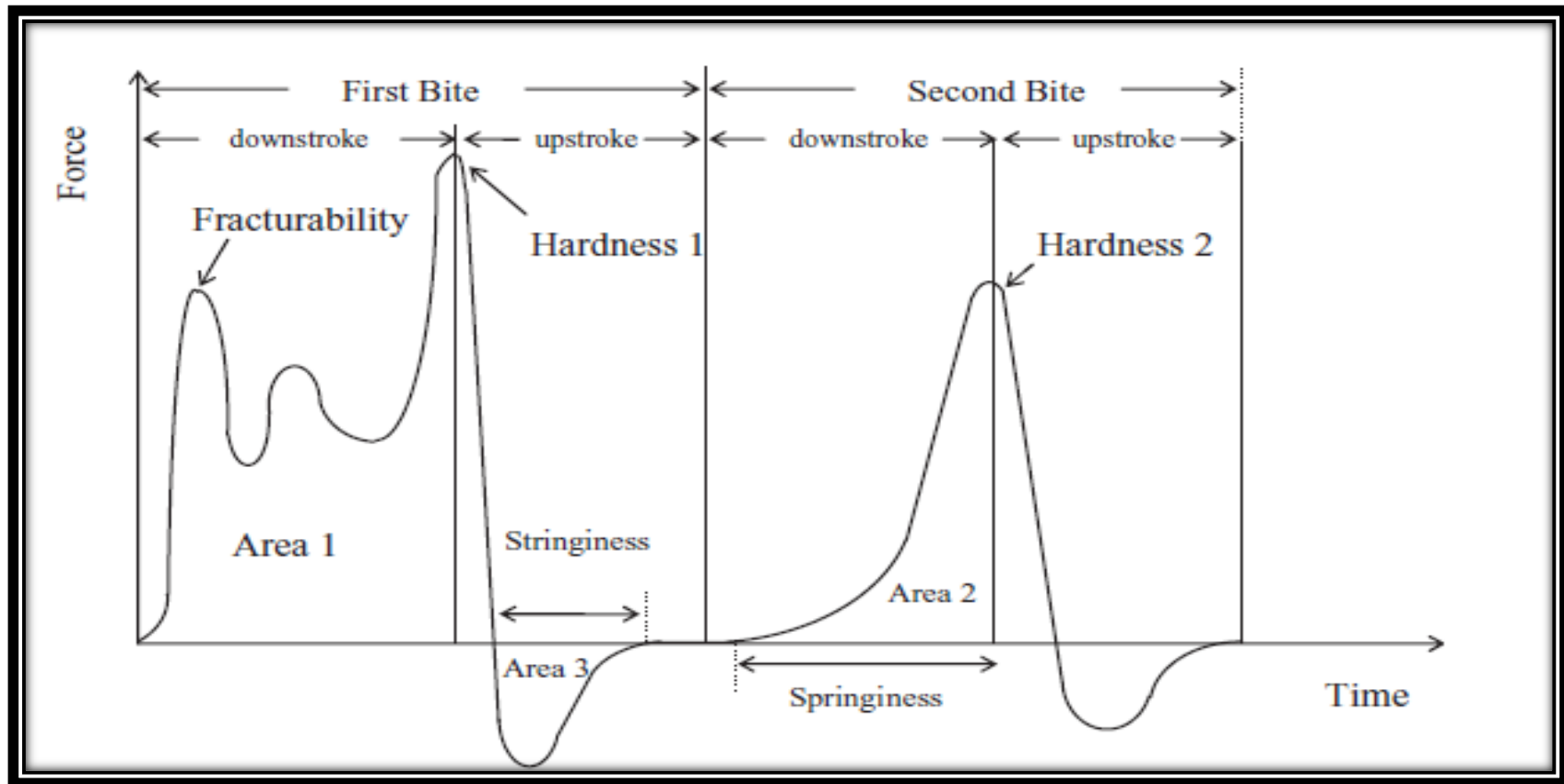


Figure 2: Generalized texture profile

Parameters***Sensory definition*****Hardness**

The hardness value is the peak force of the first compression of the product.

**Fracturability
(Britleness)**

Not all products fracture; but when they do fracture the Fracturability point occurs where the plot has its first significant peak during the probe's first compression of the product.

Cohesiveness

Cohesiveness is how well the product withstands a second deformation relative to how it behaved under the first deformation. It is measured as the area of work during the second compression divided by the area of work during the first compression.

Adhesiveness

Is the negative force area for the first bite representing the work required to pull the plunger away from the food.

Sometimes referred to as stickiness, this is related to how a food adheres to the inside of the mouth surfaces during chewing

**Springiness
(Elasticity)**

Springiness is how well a product physically springs back after it has been deformed during the first compression. The spring back is measured at the downstroke of the second compression, so the wait time between two strokes can be relatively important.

Gumminess

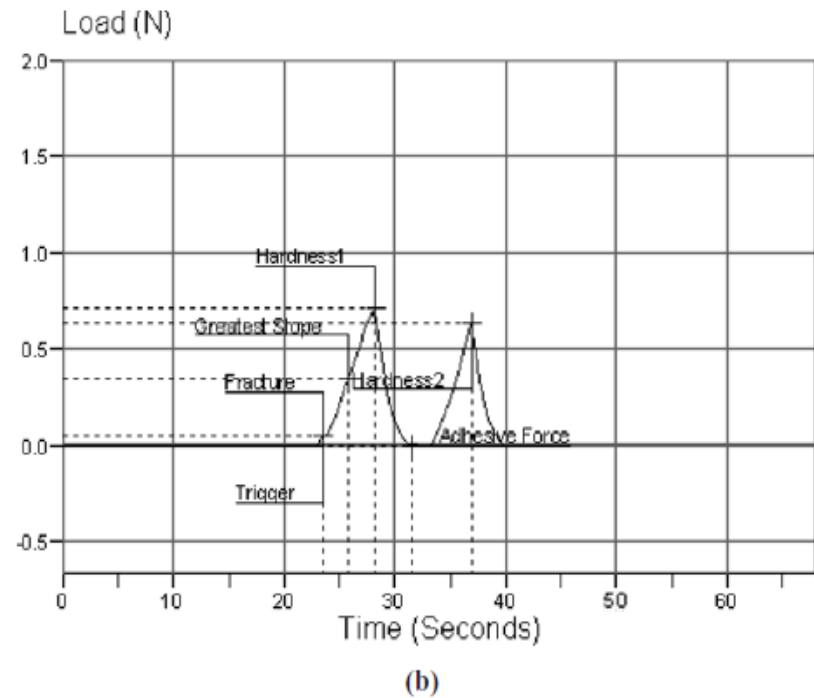
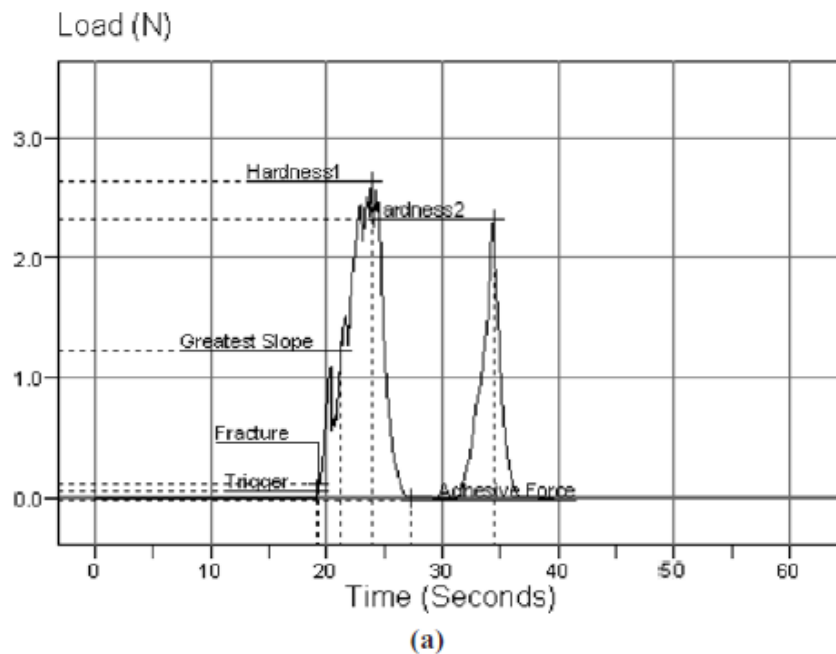
A combination of hardness and cohesiveness, this is the amount of effort that goes into preparing a semi-solid food for swallowing.

Applies to semi-solid products only if they have no springiness and undergo permanent deformation.

Chewiness

A combination of gumminess and springiness, this is the amount of effort that goes into preparing a solid product for swallowing

Applies for solid products.

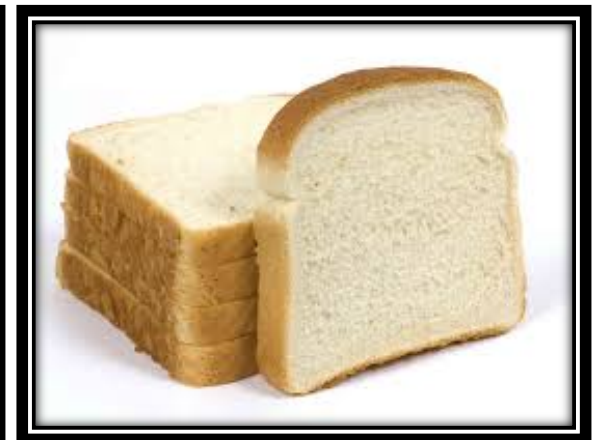


Texture profiles for different food examples: (a) chicken nugget; (b) bread.

Chicken nuggets: very high fracturability and hardness values

-Indicating the crispness of the product

Bread crumb: softer texture



Empirical measurement methods for foods

Table 1: Typical Empirical Testing Instruments and Applications for Food Products

Device	Common Application
Adams Consistometer	consistency of semi fluid food purees
Armour Tenderometer	beef tenderness
Baker Compressimeter	staleness of bread
Ballauf Pressure Tester	puncture testing of fruit and vegetables
BBIRA Biscuit Texture Meter	hardness of cookies and crackers
Bloom Gelometer	puncture test of gelatins and gelatin jellies
Bostwick Consistometer	flow of baby foods and similar purees
Chatillon Pressure Tester	puncture testing of fruit and vegetables
Effi-Gi Pressure Tester	puncture testing of fruit and vegetables
Extensigraph	behaviour of wheat dough
Farinograph	baking quality of wheat flour
FMC Pea Tenderometer	quality and maturity of fresh green peas
FTC Texture Test System	attachments for many foods
GF Texturometer	attachments for many foods
Haugh Meter	egg quality
Hilker-Guthrie Plummet	firmness of cultured cream
Instron Universal Testing Machine	attachments for many foods
Kramer Shear Press	tenderness of peas and other particulate foods
Magness-Taylor Pressure Tester	puncture testing of fruit and vegetables
Marine Colloids Gel Tester	puncture test marine extract gels
Mixograph	baking quality of wheat flour
Ottawa Pea Tenderometer	quality and maturity of fresh green peas
Ottawa Texture Measuring System	attachments for many foods
Pabst Texture Tester	firmness of particulate foods
Penetrometer	firmness of butter and margarine
Plint Cheese Curd Torsiometer	setting of cheese curd
Resistograph	baking quality of wheat flour
Ridgeline	stiffness of pectin and fruit jellies
Stevens Compression Response Analyzer	attachments for many foods
Succulometer	maturity and quality of fresh sweet corn
SURDD Hardness Tester	hardness of fats and waxes
Torry Brown Homogenizer	toughness of fish
USDA Consistometer	consistency of semifluid food purees
Van Dorr Pressure Tester	puncture testing of butter
Warner-Bratzler Shear	toughness of meat

<http://www.campdenbri.co.uk/videos/bread-quality-testing-video.php>