FDE449
Physical Properties of Foods

Content

1) Solid rheology
2) Texture
3) Rheological methods

Solid Rheology

Foods are subjected to forces during processing, particularly during:

- size reduction operations
- expression (pressing) processes
- in addition, packaging material such as cans and flexible pouches will undergo stress, particularly during heating, as the contents expand.

- From the mechanical point of view, equipment should be designed to withstand high pressures.

- Also of extreme importance is the mechanical properties of food and their relationship to texture.

Solid rheology and texture

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

- Foods have different textural properties.

- These differences lead to changes in the natural structure of the food.

Reasons;

- variety,
- maturity (for harvested food),
- processing methods

Perception of texture

- Chewing breaks the food down and makes it more digestible. During this process, information is transmitted from various sensory receptors in the mouth to specific parts of the brain, where it is integrated with other incoming information as well as information stored.
- in the memory to give an overall impression of texture. If this does not conform to what we would expect from that particular food, we may well be disappointed with its quality. For example,
- we expect our steak to be tender and juicy, and not chewy or tough; liver should be smooth, and not hard or fibrous;
- apples should be crisp, firm and juicy, and not starchy, soft or dry;
- an ice-cream should be smooth and creamy, and not icy or gritty.
- biscuits to be crispy or crunchy rather than soft, and bread to be soft or doughy or perhaps hard and crusty.
- Margarine to spread easily.

Deformation

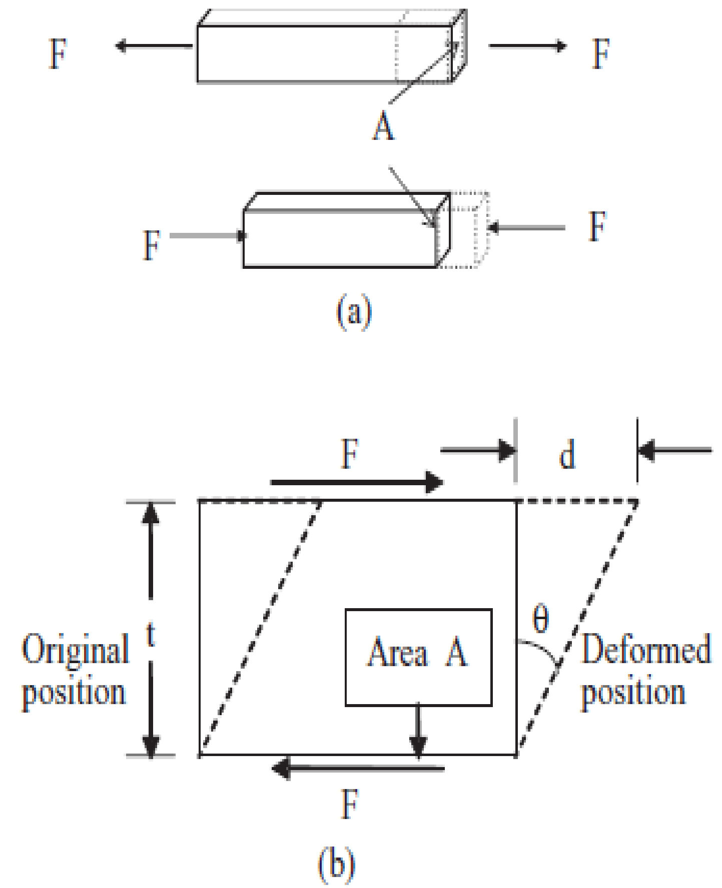
- Solid foods are subject to deformation with the effect of applied force.
- Solids can be subjected to many different forces.
- Any material can deform under tension.
- Materials can also change shape with their own weight.
- Stress and strain are two important factors in the deformation of the material.

Stress

- Stress is defined as force per unit area.
- expressed in Pa (N/m^2).

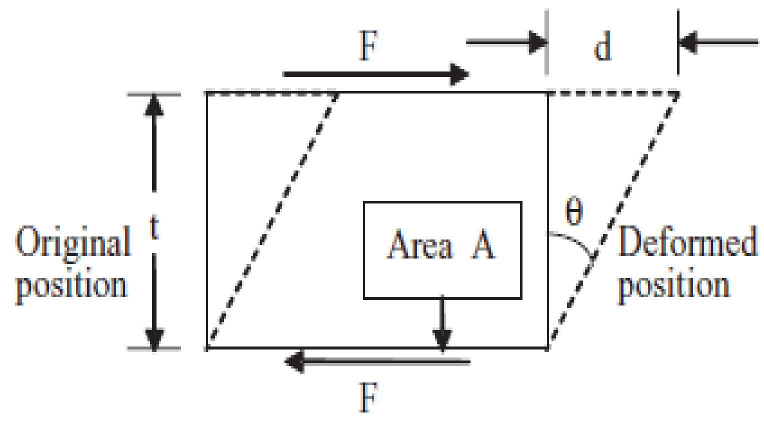
Stress can be categorized into two groups:

- normal stress and
- shear stress.
- The difference between these two stresses depends on the area that the force acts.
- Normal stress (σ) is defined as the force applied perpendicular to the plane per unit area.
- Pressure is an example of normal stress. Normal stress can be tensile or compressive depending on whether it tends to stretch or to compress the material on which it acts.



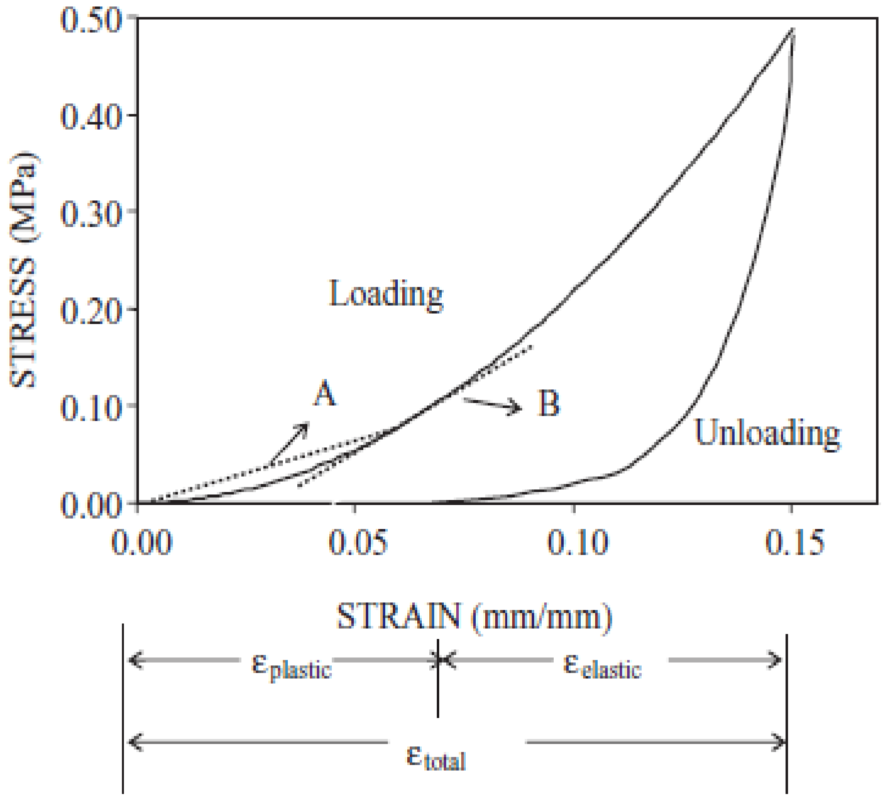
(a) Tensile and compressive normal stress and
(b) shear stress

- In shear stress, the stress acts tangential to the surface.
- Shear stress (τ) is defined as the force applied parallel to the plane per unit area.
- Strain is the unit change in size or shape of a material referred to its original size or shape when a force is applied.



(b)

$$\text{Strain} = \frac{\text{Extension}}{\text{Original lenght}}$$



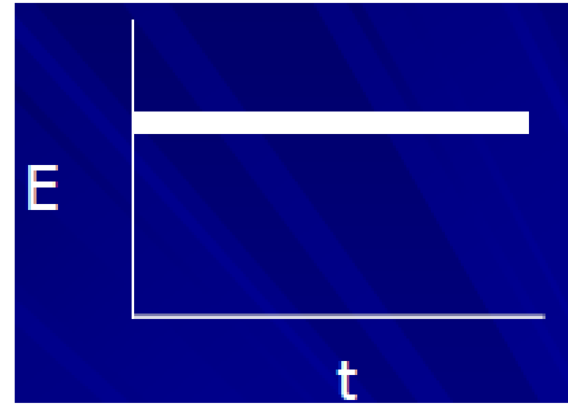
Stress-strain curve for compression of a food material

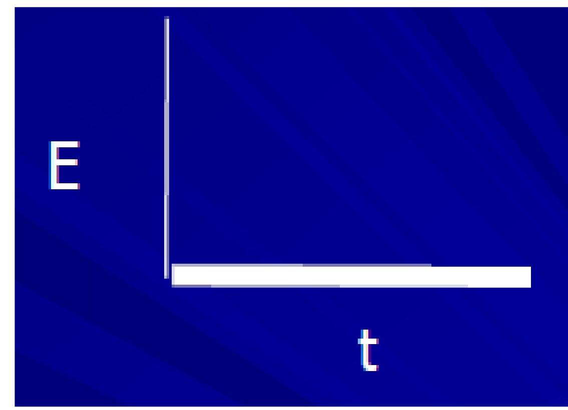
Viscoelastic behaviour

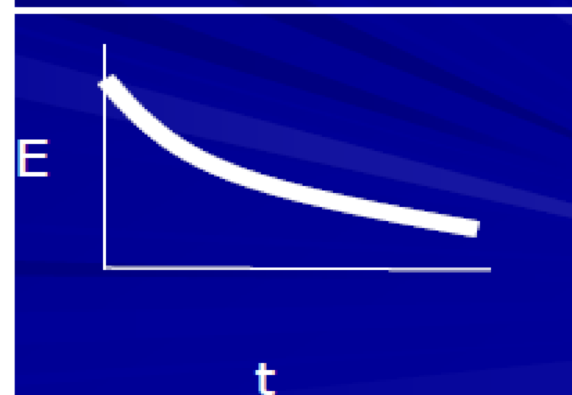
- When a force is applied to a viscous fluid, it will start to deform and this deformation is proportional with the magnitude of force applied.
- It deforms continuously until the force is removed so that it cannot return to its original position.
- Viscous fluids generally exhibit viscosity while solids exhibit elasticity.
- Some foods show both viscous and elastic properties which are known as viscoelastic materials.
- example for viscoelastic fluids:

  wheat flour dough.

- Dairy cream, ice cream mix, marshmallow cream, cheese, and most gelled products are also viscoelastic foods.





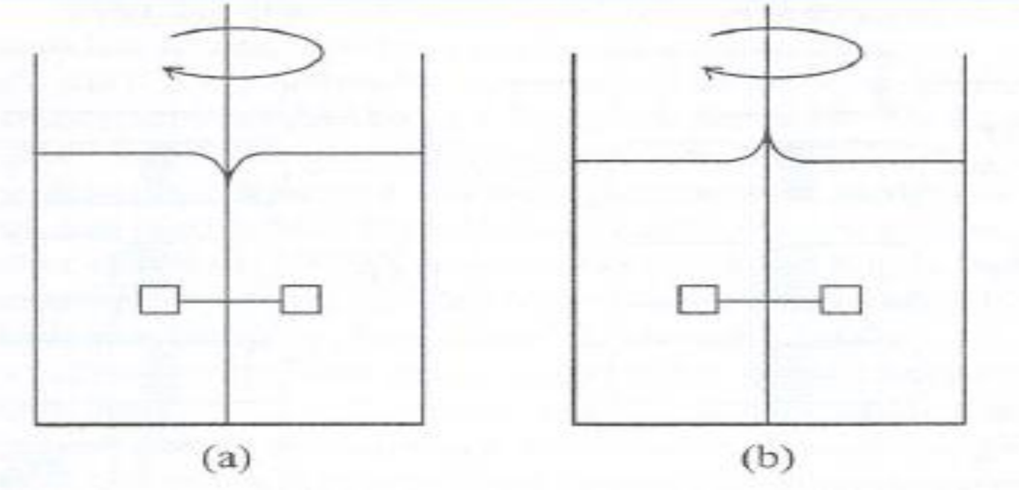


Reason for viscoelasticity

- Long polymer chains in molecular structure make the polymeric matrix viscoelastic at the micro level.
- Most of the solid and liquid foods containing long chain biopolymer chains show viscoelastic properties.
- Starch, gum substances, gels
- The most typical viscoelastic food example is dough made from wheat flour.
- Gel foods containing milk cream, cheese and starch show viscoelastic properties.

Weissenberg effect

- When a viscous liquid is agitated, it creates a circular motion (vortex).
- If a viscoelastic fluid is mixed with a rotating arm, it tends to climb into the arm.
- This effect is known as the "Weissenberg effect".
- The effect observed when making cake or bread dough.

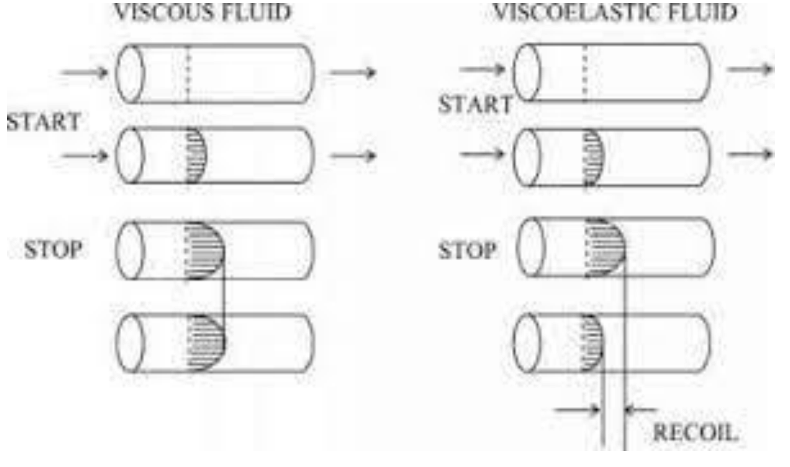


(a) Vortex formation (b) Weissenberg effect

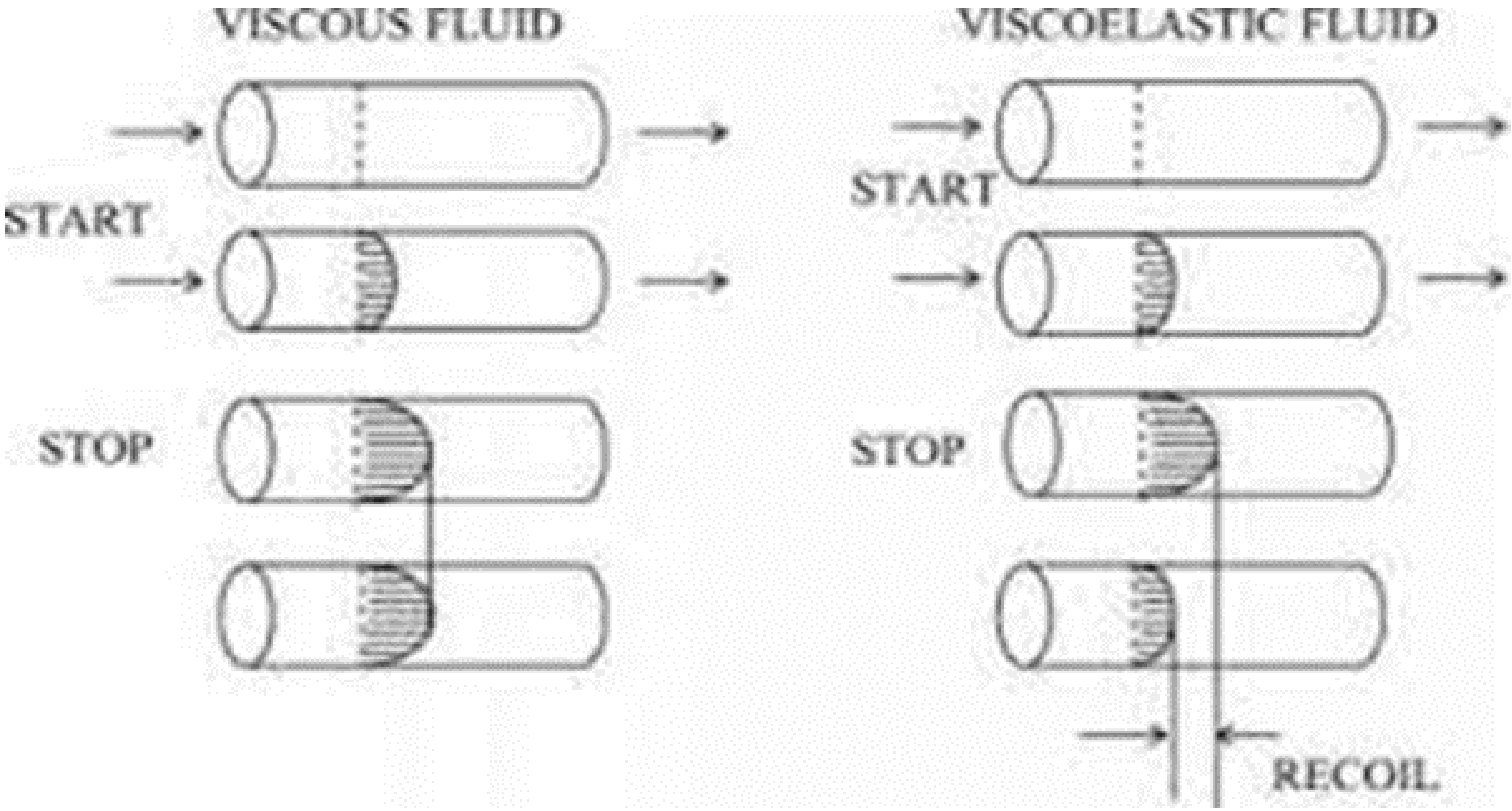
Recoil effect

- When the flow of a viscoelastic material is stopped, tensile forces in the fluid cause the particles to move back.

- In viscous fluids, on the other hand, the particles stay where they are when their motion is stopped, they do not move.



Recoil effect



Elastic behaviour of solid foods

Hookean Solids:

- Pure elastic behavior of solid is defined as when a force is applied to a material, it will instantaneously and finitely deform and when the force is released the material will instantaneously returns to its original form. Such solid materials are called Hookean solids.
- The amount of deformation is proportional to the magnitude of the force. The rheological representation of this type of solid is a spring.
- There are three types of moduli may be calculated for a Hookean solids depending upon the method of applying the force:

  1. Modulus of elasticity (E)

  2. Modulus of rigidity (G)

  3. Modulus of bulkiness (K)

Rheological methods

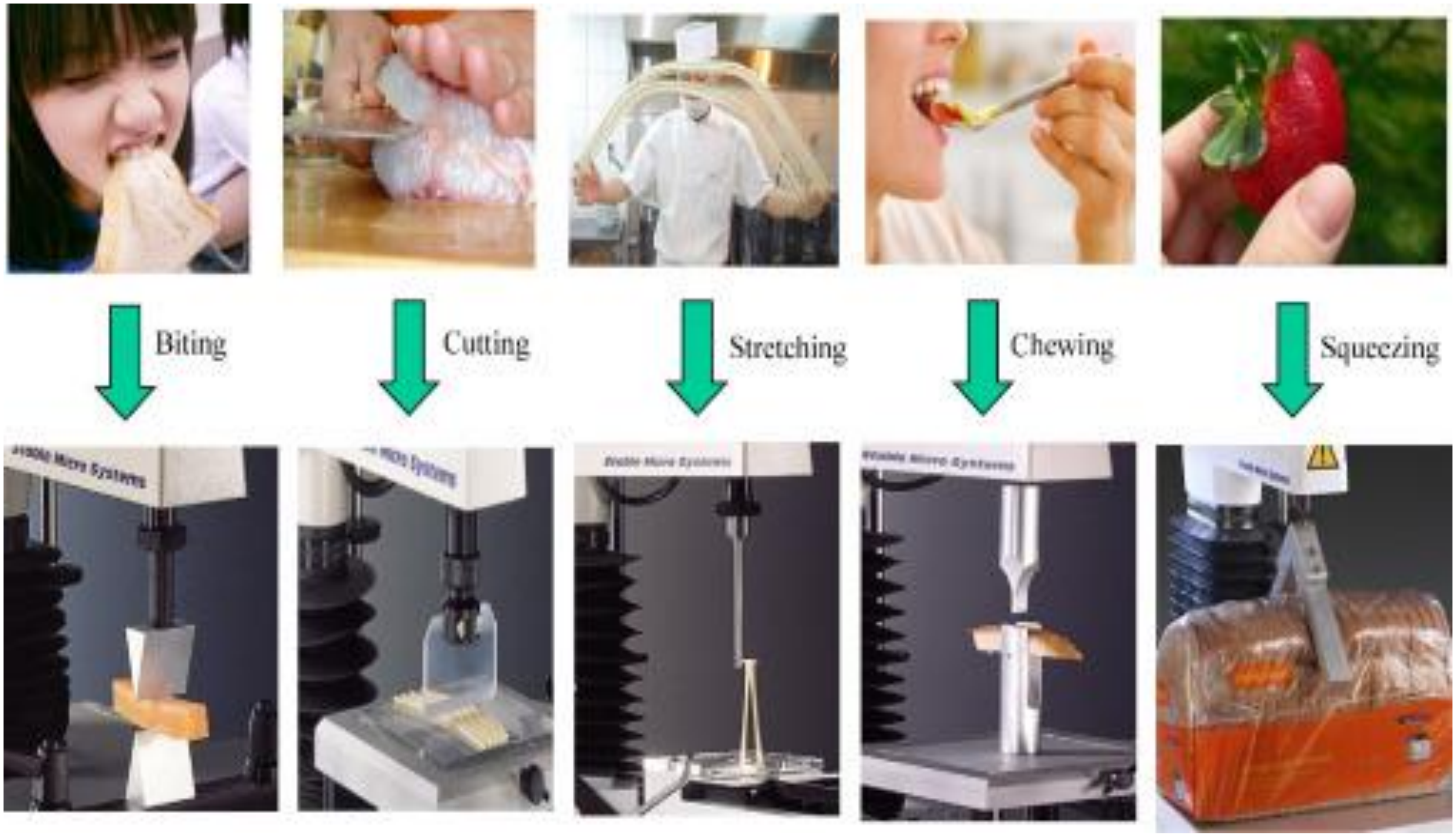
- 1. Imitative methods
- 2. Empirical methods
- 3.Chemical and microscopic methods
- The food industry uses many empirical instruments to measure the flow behaviour of food products.
- It is applied in quality control, correlation to sensory data, or ever serve as official standards of identity.
- Many empirical instruments have been developed to evaluate the flow behaviour of dough.
- Instrumental methods require less intensity and result in less time.

Application of food rheology

- Cereals
- Dairy products
- Meat
- Fruits
- Vegetables

Texture

- Texture is derived from the Latin word «textura».
- primarily the response of the tactile senses to physical stimuli that result from contact between some part of the body and the food.
- The International Organization for Standardization (ISO) defines texture as “all the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile, and where appropriate, visual and auditory receptors.”
- It is also believed that texture should be connected to the sensations experienced while food is transformed in the oral cavity.
- By simulating human behaviors, such as biting, cutting, stretching, chewing, squeezing, etc., modern food texture analyzers can accurately assess the degree to which people are satisfied by or are fond of foods



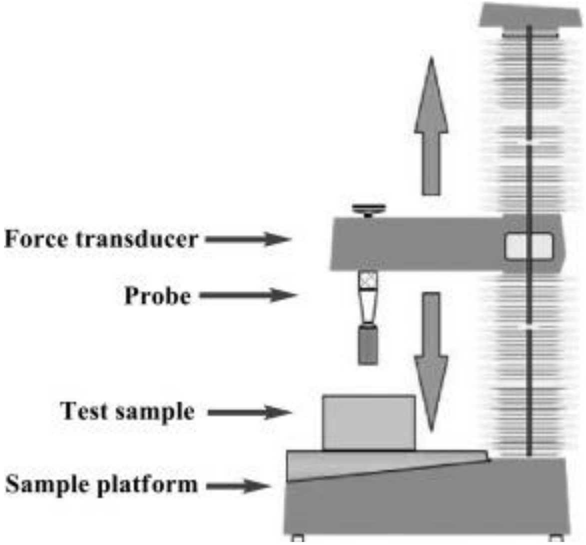
The relationships between food texture evaluation and human behaviors.

Textural methods

- Compression (deformation) test (bread)
- Crushing, bending (biscuits, crackers)
- cutting power
- Punching (fruits, gels, vegetables, some dairy and meat products)
- Penetration (penetrometer)
- Texture profile analysis

Texture analyzer

- The basic working principle of the texture analyzer is that the arm of force first provides stable strength to the test sample by moving up and down, then the sample changes due to the produced pressure or deformation force.
- Subsequently, the probe transmits the changes of stress or deformation to the force transducer and as a result, the different parameters of food texture are obtained.
- These parameters are hardness, fractures, springiness, chewiness, firmness, toughness, fibrousness, gumminess, stickiness/tackiness, cohesiveness, yield, extension, resilience, and gel strength.



The basic structure of a texture analyzer.

Compression test

In the compression deformation test;

-The compression distance is determined under a standard compression force. Or;

- The force required to compress a food at a standard distance is determined.

- It is a test used to measure the firmness or durability of foods such as bread and cake.

Penetrometers

- The distance that a conical head or needle penetrates into the sample for a certain period of time is measured.
- It is used in margarine, butter, fruit, vegetable and meat and meat products.

Shear test

- The maximum force required to cut the food is determined.
- Warner-Bratzler Shear, Allo-Kramer Shear.
- Used for meat and meat products
- Tenderometer- used to determine the ripeness and crispness of fruits and vegetables.

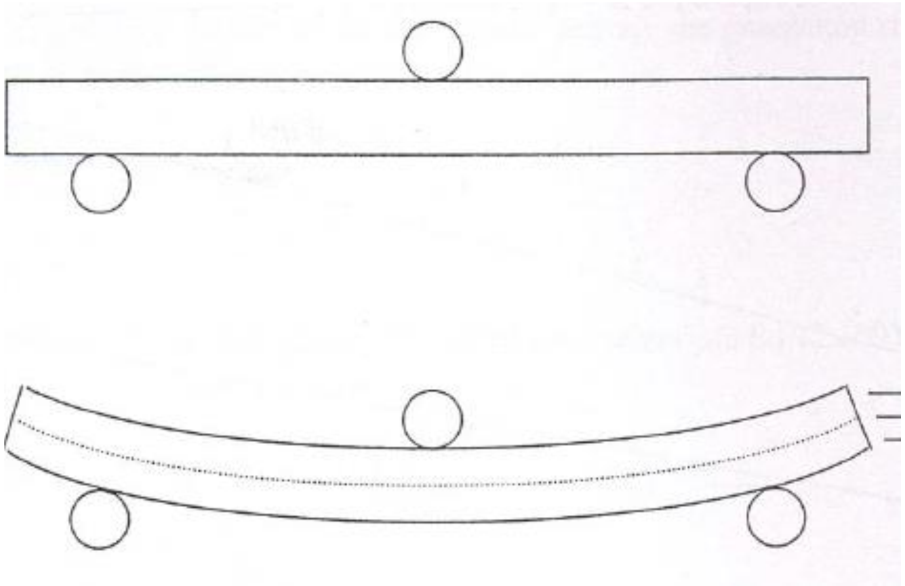
Warner-Bratzler Shear

Allo-Kramer shear

Tenderometer

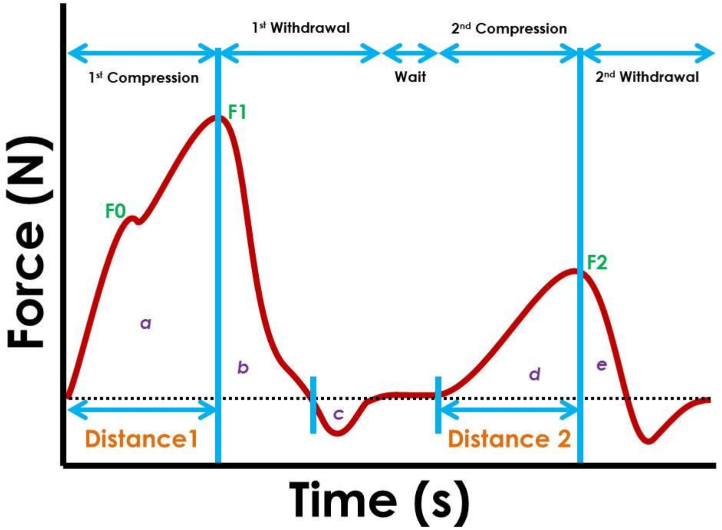
Snapping and bending test

- In the snapping-bending test, the force required for snapping or bending is measured in foods that are easy to break, such as biscuits and crackers.



Texture profile analysis

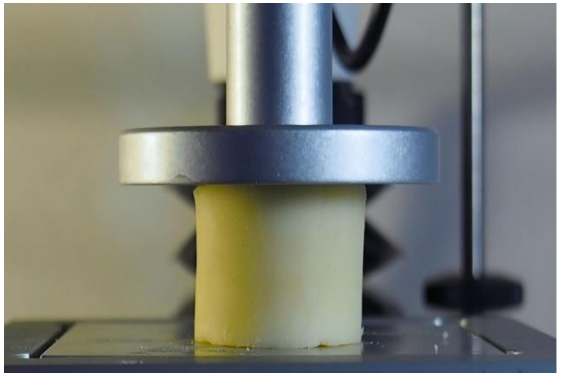
Within multiple industries, texture profile analysis seeks to quantify various physical properties such as:



- hardness,
- adhesiveness,
- fracturability,
- cohesiveness,
- springiness,
- gumminess,
- Chewiness,
- resilience by driving a probe into a sample at a specific rate,
- repeating the compression.

Texture Profil Analysis (TPA)

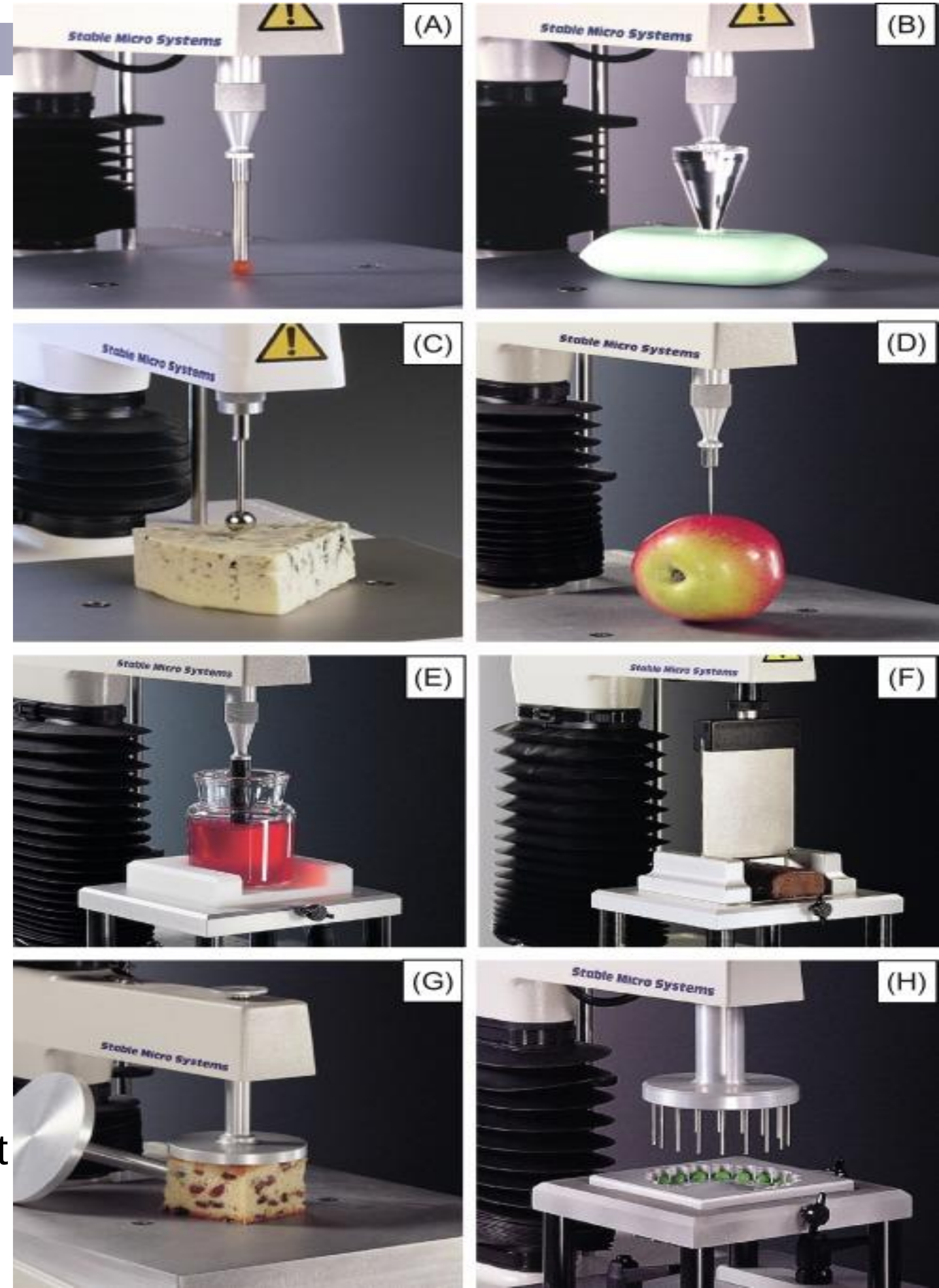
- Texture Profile Analysis is a popular double compression test for determining the textural properties of foods.
- During a TPA test samples are compressed twice using a texture analyzer to provide insight into how samples behave when chewed.
- The TPA test was often called the "two bite test" because the texture analyzer mimics the mouth's biting action.
- The textural identity of any food is rarely a simple matter of understanding a singular attribute such as hardness or cohesiveness. The texture of any food is multi-faceted and tied to consumers' sensory expectations.
- The beauty of TPA as an analytical method is that it can quantify multiple textural parameters in just one experiment.



Probe selection and application

- At present, commercial texture analyzers can be used to measure all the common texture parameters in food.
- Different samples need to select different suitable test probes.

Fig. The different types of probes. (A) cylinder probe; (B) conical probe; (C) spherical probe; (D) needle probe; (E) gel probe; (F) shear probe; (G) compression plate; (H) multiple pea test rig.



Probe selection and application

- ***Cylinder probes***
- ***Conical probes***
- ***Spherical probes***
- ***Needle probes***
- ***Shear probes***
- ***Compression plates***

Tools used to determine the rheological properties of dough

1. Farinograph

- In baking, a farinograph measures specific properties of flour.
- The farinograph is a tool used for measuring the shear and viscosity of a mixture of flour and water.
- The primary units of the farinograph are Brabender Units, an arbitrary unit of measuring the viscosity of a fluid.

By using the farinograph's results, the followings are determined:

- Water absorption
- Dough viscosity, including peak water to gluten ratio prior to gluten breakdown
- Peak mixing time to arrive at desired water/gluten ratio
- The stability of flour under mixing
- The tolerance of a flour's gluten

The output from this device is called a farinogram.

Farinograph

- The farinograph is a tool to assess baking qualities and performance of wheat flour doughs.
- It records the resistance to deformation, or the consistency of dough mixed from flour and water.

To millers and bakers, farinographs are essential for:

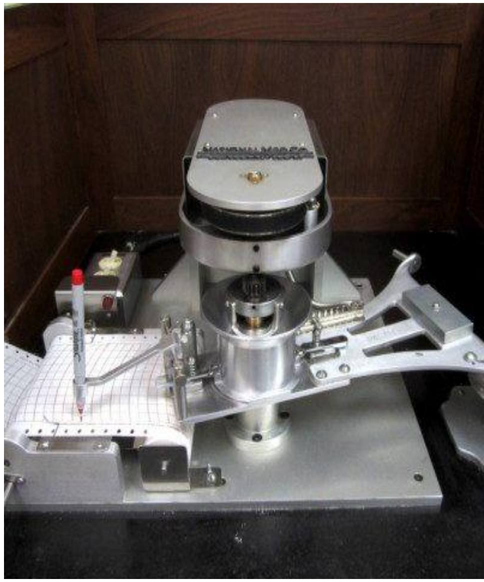
- Adjusting dough mixing parameters: absorption, time, pre-hydration ratio
- Studying the effect of flour improvers dough handling properties
- Establishing quality control measures to properly handle wheat crop changeovers.
- Preparing wheat and flour blends to comply with flour specifications

How does the farinograph work?

- Farinographs measure and record the resistance to deformation of a flour/water dough against the mixing action of blades over time and at a specific speed (rpm) and temperature.
- Dough resistance is expressed as motor torque, in dimensionless units known as Farinograph or Brabender Units (FU or BU).
- During the test, the dough is developed and further broken down.
- Resistance has traditionally been known as “consistency.” The maximum consistency of the dough is adjusted to a fixed value (500 FU) by altering the quantity of water added (i.e. % absorption).

2. Mixograph

- The mixograph is a dough testing equipment used to assess the baking quality of flours from soft, hard and durum wheat. It provides information on the mixing and absorption characteristics of flour.
- The mixograph helps millers, bakers and plant breeders to:
- Classify wheats according to baking strength and define their end use or application
- Optimize flour blends and streams at the mill
- Detect proteolytic activity (sprout damage) in wheat
- Evaluate the conformity of incoming flour at the bakery
- Adjust mixing time and water absorption
- Perform genetic improvement of wheat cultivars
- Study the effect of ingredients and dough conditioners on dough mixing properties
- Match quality of flour with type of bakery product



How does the mixograph work?

- The mixograph is a recording dough pin mixer that rapidly develops a dough sample.
- It measures and records resistance of a dough to mixing.
- It consists of small dough mixer constructed in such a manner that the force required (torque) to turn a head over a static bowl containing dough is measured and recorded as a graphical curve called mixogram.
- As the gluten-forming proteins hydrate and coalesce, they form gluten strands which bind together to form an elastic matrix.
- During measurement, the force increases to a maximum and then decreases as the dough is overmixed.

3. Extensograph

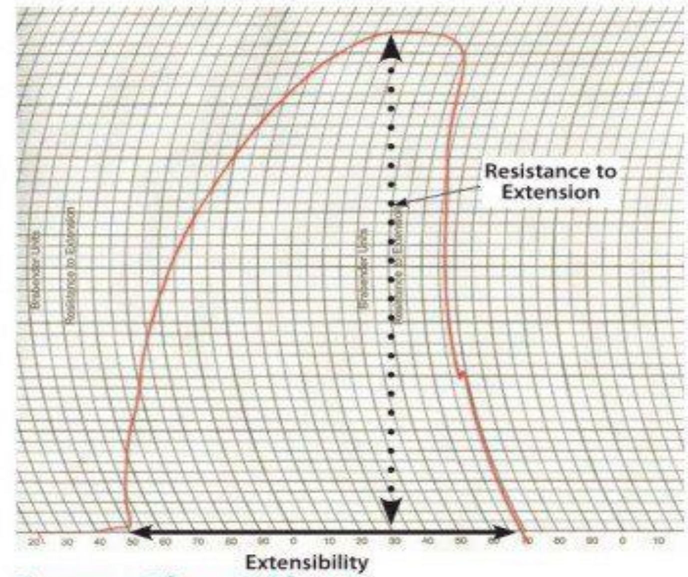
- An extensograph is a tool used for measuring the flour quality and stretching behavior of dough.
- Extensional properties, which determine the course of dough expansion during proofing and baking, have a direct effect on:

*Loaf volume

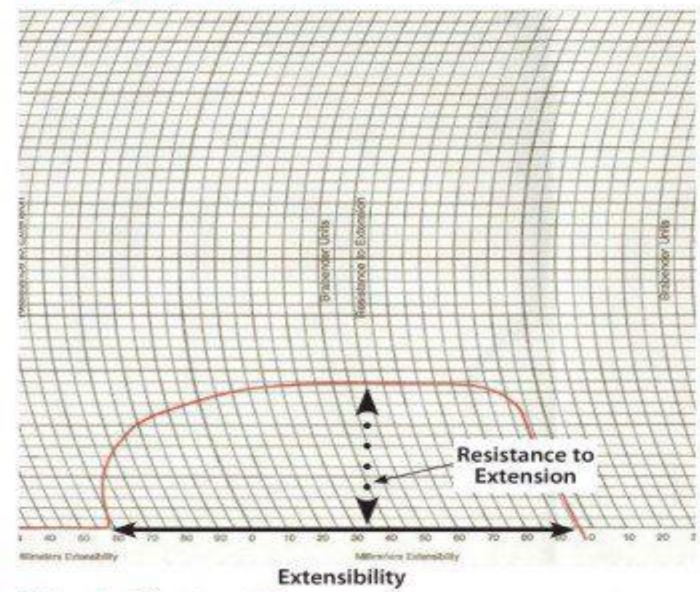
*Quality of texture of bread crumb

How does the extensograph work?

- Information on the extensional properties of bread dough is read directly from the diagram of the extensograph curve, also referred to as the extensogram. The extensogram represents changes in resistance, also called the strength, of the dough to extension (R) as a function of the extension distance (E).
- See figure comparing a strong gluten dough to a weak gluten dough.
- Results from an extensograph are useful in determining the gluten strength and bread-making characteristics of flour.
- Changes to formulas such as fermentation time, type of flour or new supplier, dough additives can all be evaluated by an extensograph.



Strong Gluten Flour



Weak Gluten Flour

4. Alveograph

- An alveograph is a rheological tool used to assess the baking performance of flours used in baked products (bread, noodles, tortillas, biscuits, etc.).
- It is based on injecting air into a thinly stretched sheet of dough to form a bubble, simulating gas/carbon dioxide release and retention during dough fermentation and oven spring during baking.

Bakers use alveograph data to gain understanding of fluctuations in dough rheological changes by assessing:

- Tenacity
- Elasticity
- Baking strength
- Resistance of dough to deformation
- Extensibility

Alveograph

The alveograph helps millers and bakers to:

- Classify wheats or flours according to baking strength
- Optimize the flour blends and streams at the mill
- Detect proteolytic activity (sprout damage) in wheat
- Evaluate the conformity of incoming flour at the bakery
- Adjusting mixing, water absorption, proofing conditions for given doughs (time, relative humidity, temperature)
- Assess the need for dough conditioners (redox agents, emulsifiers, enzymes for strengthening or weakening of dough)
- Unlike the extensograph, which uses tensile strength by stretching the sample dough piece in only one direction, the alveograph subjects the dough to extension in two dimensions.