

FOOD SCIENCE AND TECHNOLOGY

Lecture07

Lecture 07: Physical Properties of Foods

Hello everybody. Namaste.



Now in the seventh lecture of this course, today we will talk about the physical properties of foods. Here in the next half an hour or so, we will discuss the importance of the physical



Now in the seventh lecture of this course, today we will talk about the physical properties of foods. Here in the next half an hour or so, we will discuss the importance of the physical properties of food, the application of physical properties, size and shape, particle characterization, volume, density, and porosity. Finally, we will talk about the surface

properties of food. So, how these physical properties are important in the food processing industry or the food system, let us talk about you know many of the characteristics that define the quality. For example, texture, structure, appearance, or even stability such as the water activity of the food, are linked to its physical properties. Several cutting-edge research studies have been undertaken to develop foods with novel physical structures. Food physics has become a very important area of food science and engineering. These researches allow us to observe the changes in food characteristics during processing operations and thus help to predict and prevent potential processing failures.

Physical properties are an important aspect of food quality, and they also relate to food safety. A simple example you can see here that has been illustrated in the form of these two figures like you see that savory or extrudates, both are prepared by using the extrusion technology already cold or hot extrusion or then frying is done.

Importance of physical properties

- Many of the **characteristics** that **define** the **quality** (e.g., texture, structure, and appearance) and **stability** (e.g., water activity) of a food product are **linked** to its **physical properties**.
- Several "cutting edge" research undertaken to develop foods with novel physical structures.
- These researches allows to **observe** the change in **food characteristics** during processing operations, thus help to **predict** and **prevent** potential processing failures.
- Physical properties are an important aspect of food quality and relate to food safety.

Extrudate
Savory
✓ Low density
✓ Better digestibility

Chocolate
Solid foam
✓ High thermal stability

https://foodnova.com
https://www.anscof.com
Sources: https://food.edu.com
https://www.n

Then savory it has a little hard density or more density, a hard texture, etc. Whereas, extrudates have low density and because of their low density, they sometimes have better digestibility. So, similarly, the chocolate if you can see the chocolate. It is a solid form of chocolate, a more dried form of chocolate, which has high thermal stability. So, it is the physical characteristics, and physical properties of foods that influence their quality, safety, and all.

Application of physical properties of food

- Physical properties describe the unique way a food material responds to process conditions involving mechanical, thermal, electrical, & electromagnetic processes, that allows for optimum design of food equipment and processes.
- Knowledge of a food's physical properties is necessary for
 - Defining and quantifying a description of the food material,
 - Providing basic data for food engineering and unit operations, and
 - Predicting behavior of new food materials.

<https://www.amazon.in>
 source: <https://www.stproteins.com>
 Niharani N. B. et al., (2017)

So, the application of physical properties in food processing or the food processing industry, let us talk about. Physical properties, as I told you earlier, describe the unique way a food material responds to process conditions, whether it is a mechanical process, thermal process, electrical, electromagnetic process, all that, and that allows for optimum design. Even the physical properties of the food are used for designing handling equipment, even optimization of process parameters, etc. To get desirable quality characteristics, shape, and size of the food. Knowledge of food's physical properties is necessary for defining and quantifying a description of the food material. Providing basic data for food engineering and unit operations and predicting the behavior of new food materials. The physical properties are very important in this. You can see here again, I have just tried to illustrate to you that is the soybean. So, the whole soybean seed, when we want to characterize this, basically we go for measuring its hardness, etcetera. Whereas the same soybean, when it is used for protein extraction, then the solubility of the protein and the physical properties become of major importance. Then again, during the extrusion process, when these proteins or soya flour, etcetera, are extruded in the preparation of soya chunks, etc. Then during the extrusion, the major important characteristics become thermal stability whereas the soya chunks, when it is made, its volume, and how much volume it has got, become important. So, these are whether, in the extrusion or protein extraction or soya chunks final preparations in all the similar processes or any other food process operations, physical properties become very important.

Then, thermal properties. These are the characteristics of the food material that define its response toward temperature and its transfer or retention when the food comes in contact with heat. These are the thermal properties: how they respond to the thermal temperature and other conditions. Thermal properties play an important role in determining the rate of heat transfer. And you know that from your earlier classes also, in the school classes, these

are now taught, that is, what are the different modes of heat transfer, like conduction, convection, and radiation?

Thermal properties

- Characteristics of the material that define its response towards temperature, and its transfer or retention.
- Thermal properties play an important role in determining the rate of heat transfer.
- Calculations for mode (conduction, convection & radiation) and state (steady and unsteady) of heat transfer plays a crucial role in understanding the thermal properties and their application in several systems.

Mode of heat transfer: Conduction, Convection, Radiation

Steady state: $Q=10W/m^2$ at 0 min, $Q=10W/m^2$ at 10 min

Unsteady state: $Q=10W/m^2$ at 0 min, $Q=8W/m^2$ at 10 min

Source: <https://homeworkstudy.com>, <https://thermefast.com>

These are the modes of heat transfer that have been shown here in this diagram picture. Similarly, there are states of heat transfer, whether it is steady-state heat transfer or unsteady-state heat transfer. So, all these play a crucial role in understanding the thermal properties and their application in several food systems.

The various thermal properties include specific heat, thermal conductivity, thermal diffusivity, and other properties.

Thermal properties (Contd...)

- Specific heat** (kJ/kg°C): Quantity of heat that is gained or lost by a unit mass of product to achieve a unit change in temperature, without a change in state. $c_p = \frac{Q}{m(\Delta T)}$
- Thermal conductivity** (W/m°C): The amount of heat that will be conducted per unit time through a unit thickness of material. $k = \frac{Q \Delta x}{A \Delta T}$
- Thermal diffusivity** (m²/s): The amount of heat that will be conducted per unit time through a unit thickness. $\alpha = \frac{k}{\rho c_p}$
- Thermal expansion** (1/°C): The change in volume of a material as a function of change in temperature. $\beta = \frac{\Delta V}{V \Delta T}$

Source: <https://www.actionfacts.net>, <https://bio.com>, <https://www.azom.com>, <https://www.phenixgroup.com>

So, specific heat is the quantity of heat that is gained or lost by a unit mass of a product to achieve a unit change in temperature without a change in its state. This is mathematically represented by C_p , where 'Cp' is the specific heat, and its unit is KJ/ Kg°

$$C_p = \frac{Q}{m \Delta T}$$

The other important thermal property is thermal conductivity, that is, watt per meter degree centigrade. It is the amount of heat that will be conducted per unit of time through a unit thickness of material.

$$k = \frac{Q\Delta x}{A\Delta T}$$

where ΔT is the temperature difference, Q is the amount of heat transferred, k is the thermal conductivity, Δx is the thickness of the material and A is the surface area that is all shown here in this figure.

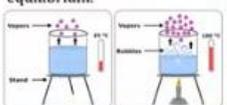
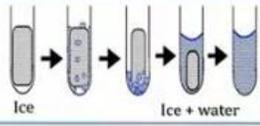
Thermal diffusivity (m^2/s) is another important property. That is, the amount of heat that will be conducted per unit time through a unit thickness, which gives the thermal diffusivity.

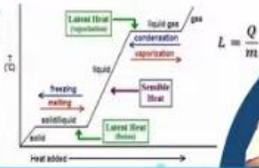
$$\alpha = \frac{k}{\rho C_p}$$

Another important property is thermal expansion ($/^\circ C$). The change in volume of a material as a function of temperature change.

$$\beta = \frac{\Delta V}{V\Delta T}$$

Thermal properties (Contd..)

- Melting/freezing point ($^\circ C$):** The temperature at which the solid and liquid phases of a substance are in equilibrium.
 
- Boiling point ($^\circ C$):** The temperature at which the vapor pressure of liquid equals the external atmospheric pressure.
 
- Latent heat (J/kg):** The amount of heat absorbed or released to change the state of a substance without changing its temperature.
 - Heat absorbed by system - Latent heat of vaporization
 - Heat released by system - Latent heat of fusion



<https://medium.com>
 Source: <https://sl.pinterest.com>
<https://dribbble.com>

Then, other thermal properties include melting point, boiling point, latent heat, and so on. The melting point or freezing point in $^\circ C$, they are represented. The temperature at which the solid and liquid phases of a substance are in equilibrium; that may be the melting point or freezing point, as the case may be. The melting point is when solids melt to liquid; the freezing point is when liquids are solidified, they go into the solid phase. So, here you can see how ice and then ice plus water are in equilibrium when they are in solid phases as well as liquid phases. Then, the boiling point is the temperature at which the vapor pressure of a liquid equals the external atmospheric pressure. When the liquid temperature rises; that

is, water boils at 100°C. 100°C is the boiling point of water; it evaporates, and the temperature remains the same.

Similarly, latent heat is measured in joules per kilogram; it is the amount of heat absorbed or released to change the state of a substance without changing its temperature. It may be latent heat of vaporization, where heat is absorbed by the system, or Latent heat of fusion, where heat is released by the system. You can see here in this figure that the solid is converting into liquid, and then, as I told you earlier, it may be freezing or melting. So, here in this case, it is the latent heat of fusion. Then, the liquid's temperature rises; that is the sensible heat, and finally, it may go to the gaseous state, and then from the gaseous state, it might return to the liquid state. This could be condensation or evaporation, as the case may be, and for both of these, the heat required for the condensation or evaporation process is called the latent heat of evaporation.

$$L = \frac{Q}{m}$$

where 'L' is the latent heat of vaporization or fusion, 'Q' is heat added (for vaporization) or removed (for fusion), and 'm' is mass.

Thermal properties are highly important in different unit operations. For example, as shown here, dough is put into a baking oven, and it is converted into bread, cake, pancake, or whatever the case may be.

❖ Importance of thermal properties

Analysis of thermal properties
Equipment designing
Optimum process designing

- Careful analysis and control of thermal properties is important for
 - ✓ Optimum process & equipment designing
 - ✓ Food safety, nutrients and structure retention
 - ✓ Energy efficiency and sustainability
 - ✓ Design storage & handling systems
 - ✓ Support innovations

Source: www.abrcqin.com

Through the baking oven, heat is applied and transferred into the dough. Then, if there is expansion, carbon dioxide is released, and other processes take place. So, it is very important to regulate this thermal process, including thermal conductivity and heat transfer. Even other factors like mass transfer and related processes are important. Therefore, we need to analyze the thermal properties for proper process conditioning, proper process

optimization, optimum process design, equipment design, and other considerations. So, food safety, nutrient structure retention, energy efficiency, and sustainability, design of storage and handling systems, support for innovations, optimum processes, and equipment design. All these things are achieved through careful analysis and control of thermal properties in food.

Now, let us discuss mechanical properties.

Mechanical properties

- Mechanical properties refer to the **characteristics** of the material that deals with its **response** towards **application of force**.

Strength-related properties ◆ Describe a material's ability to withstand forces without breaking or deforming permanently <ul style="list-style-type: none">✓ Tensile & compressive strength✓ Shear & yield strength	Deformation-related properties ◆ Material responds when subjected to forces, including how it bends, stretches <ul style="list-style-type: none">✓ Elasticity✓ Plasticity
Fracture-related properties ◆ Material behaves when subjected to forces that may cause it to crack or break <ul style="list-style-type: none">✓ Brittleness✓ Toughness✓ Fracturability	Time-dependent mechanical properties ◆ Material behaves when subjected to forces over an extended period or under cyclic loading <ul style="list-style-type: none">✓ Creep✓ Fatigue✓ Viscoelasticity

NPTEL

Mechanical properties refer to the characteristics of a material that determine its response to the application of force. When a force is applied to any material, how the material behaves is its mechanical property. For example, strength-related properties describe a material's ability to withstand force without breaking or deforming permanently. These include tensile and compressive strength, shear, and yield strength. Then, deformation-related properties include elasticity and plasticity. They describe how materials respond when subjected to forces, including how they bend and how they stretch. So, these are elasticity and plasticity. Fracture-related mechanical properties describe how materials behave when subjected to forces that may cause them to crack or break. The various properties included in this category are brittleness, toughness, fracturability, and so on. Then, time-dependent mechanical properties include creep, fatigue, viscoelasticity, etc. These describe how materials behave when subjected to forces over an extended period or under cyclic loading.

Similarly, there are other mechanical properties like hardness and wear-related mechanical properties. These describe a material's resistance to deformation. Indentation or surface wear includes hardness and resistance. Then, flexibility and rigidity describe a material's ability to bend or flex and its resistance to bending or deformation. These include flexibility, stiffness, rigidity, and so on.

Mechanical properties (Contd..)

Hardness and wear-related properties ❖ <i>Material's resistance to deformation, indentation, or surface wear</i> ✓ Hardness ✓ Wear resistance	Flexibility and rigidity ❖ <i>Material's ability to bend or flex and its resistance to bending or deformation</i> ✓ Flexibility ✓ Stiffness/Rigidity
Impact-related properties ❖ <i>Material responds to sudden, forceful impacts</i> ✓ Impact strength ✓ Resilience	Poisson's ratio ❖ <i>Materials behave when subjected to stretching or compressive forces, in terms of lateral contraction or expansion</i> ✓ Poisson's ratio




 Source: <https://www.indianart.com>
<https://www.aapt.org>

Impact-related mechanical properties include impact strength and resilience, describing how materials respond to sudden forceful impacts. And finally, Poisson's ratio. This describes how materials behave when subjected to stretching or compressive forces in terms of lateral contraction or expansion, and it is expressed as Poisson's ratio.

Then, optical properties. The optical properties of food can be described as the interaction of light with food materials.

Optical properties

- **Optical properties** of food can be described as **interaction of light with food material**

- 1 **Color**
• Most important property • Measures absorbance and reflectance
- 2 **Transparency and opacity**
• Transparency: Ability to pass the light • Opacity: Ability to obstruct the light
- 3 **Gloss and shine**
• Reflective property of the food surface • Relate with freshness of food
- 4 **Light scattering**
• Observed in heterogenous foods • Particles in system scatter light
- 5 **Refractive index**
• Light bends when passed through food
- 6 **Surface reflection**
• Amount of light that bounces off the surface of food





 Source: <https://www.indianart.com>
<https://www.aapt.org>

For example, color is the most important optical property. It measures absorbance and reflectance. Then transparency and opacity. Transparency means the ability to pass light. Opacity is the ability to obstruct light. Then gloss and shine mean the reflective properties of the food surface. They relate to the freshness of the food. Light scattering, is observed in heterogeneous foods. Particles in the system scatter light. Then refractive index. Light bends when passing through food. Surface reflection is the amount of light that bounces off the surface of the food.

So, these are the various optical properties, as you see, you know, the visible light spectrum, etc., which is wavelength and frequency, are shown here in this table. This is very common in physics classes; you might have studied it.

Optical properties (Contd...)

- Visible light is part of electromagnetic wavelength between 380 and 770 nm.
- Light when interact with food, follow phenomenon such as reflection, diffraction and refraction.
- These phenomenon are tend to change when optical wavelengths and frequencies changes.
- Different optical properties are dependent on each phenomenon.
- Other physical and chemical properties can also be related with the optical properties and measured on respective relations.
e.g. Sugar concentration, presence of coloring pigment, morphological structure, chemical composition, etc.

The slide includes a diagram of the electromagnetic spectrum with wavelength (nm) and frequency (Hz) scales. The visible spectrum is highlighted with a rainbow. Below the spectrum are diagrams illustrating reflection, refraction, diffraction, and scattering.

Source: <https://colicci.com.org>
Winkler, J. N. (2022)

Visible light is part of the electromagnetic wavelength between 380 to 770 nanometers. When light interacts with food, it follows phenomena such as reflection, diffraction, or refraction which is shown here, that is, there may be complete transmission of light, or it may be reflected or it may be refracted, that is, the light passes through, but not directly transmitted there is some bending of the light; this is diffraction. There is also absorption or scattering. So, these are the various phenomena that take different optical properties and are dependent on each phenomenon. Other physical and chemical properties can also be related to the optical properties, and they can be measured based on respective relations. For example, sugar concentration, presence of coloring pigment, morphological structure, chemical composition of the food materials, etc. They may influence light reflection, scattering, and all those things, and accordingly, the optical properties will be different.

So, one very important optical property is the refractive index, which is the ratio of the speed of light in a vacuum to the speed of light in the material.

Refractive index

- Refractive index is the ratio of speed of light in vacuum to the speed of light in the material.
- As a beam of light crosses the interface between two media of different physical properties, causes light wave to travel at different propagation velocities causing refraction.
- According to Snell's law, increase in angle of incidence increases angle of refraction.
- RI is dependent on purity of the material, temperature and wavelength.
- Assumption in TSS measurement - sugar present in juice is sucrose.

Snell's law $\frac{v_a}{v_j} = \frac{n_a}{n_j} = \frac{\sin \theta_a}{\sin \theta_j}$ v: Velocity of light, n: Refractive index

Drude's equation $\epsilon^* = \epsilon_0 + Na^*$

Maxwell's relation $n^* = \sqrt{\epsilon^*}$

ϵ^* : Complex relative permittivity, N : Number of resonators, a^* : Complex polarization potential, n^* : Complex RI.

Source: <https://phofactor.com>

As the beam of light crosses the interface between the two media, you can see here that it is coming in air, light, and then there is a let us say, one medium is air, the other medium is a juice, maybe fruit juice or sugar juice, etc. Then, when the light comes, it crosses two media, then different physical properties cause that, depending upon the concentration of juice, what are the various solids, and all those things. It causes the wave to travel at different propagation velocities and causes refraction. So, you can see here that the light, it was coming, has refracted, and this is the angle of refraction, that is, theta j and this deviates; otherwise, normally it should come here if this glancing angle. It should be the angle of deviation, and then this is the angle of incidence, that is, at what angle this is falling on the surface of the other material. So, according to Snell's law, an increase in the angle of incidence increases the angle of refraction. So, the refractive index is dependent on the purity of the material, temperature, wavelength, and also the various constituents of its composition. Here, it is assumed that in TSS measurement, the sugar present in the juice is sucrose, and accordingly, you can find that out. So, there are different laws like Snell's law, Drude's equations, Maxwell's equations, etc.

Snell's law states that

$$\frac{V_a}{V_j} = \frac{N_a}{N_j} = \frac{\sin \theta_a}{\sin \theta_j}$$

where 'V' is the velocity, and 'N' is the refractive index.

In Drude's equation, $\epsilon^* = \epsilon_0 + Na^*$

In Maxwell's relation, $n^* = \sqrt{\epsilon^*}$

So, the ' ϵ^* ' is the complex relative permittivity. ' a^* ' is the complex polarization potential, ' N ' is the number of resonators, and ' n^* ' is the complex refractive index.

Then, color measurement. This again, you know that different materials; we see some materials, some food like tomato, it may be yellow; tomato is now red in color, mango may be yellow in color, green other foods may be green; different food materials are different in color.

Color measurement

- Food-light interaction:** Different pigments in food absorb and reflect certain wavelengths, which incident in our eyes.
- Role of human vision:** Photoreceptor cells (cones) are sensitive to specific wavelength of light signals. The brain combines signals from cones to interpret a wide range of colors in food.
- Color measurement devices utilize similar mechanism based on Lambert-Beer law & CIE Lab**
 $E = k(\lambda) c d$ E: Extinction, k: Extinction coefficient, c: concentration, d: sample thickness
- Concentration of color absorbing pigment plays important role in color measurement.**

L* (0 to 100) - Dark to light
a* (-100 to 100) - Green to red
b* (-100 to 100) - Blue to yellow
 ✓ Most shades of a* and b* fall within -50 to 50

The diagram shows a light source (light bulb) emitting light through a diffraction grating. The light is dispersed into a spectrum. A diode array captures the light, and the data is sent to a data processor. The processor outputs three values: $R = 41.8$, $G = 87.3$, and $B = 8.8$.

Source: <https://support.hunterlab.com>
www.datascoder.com

So, what is the food-light interaction? That is, the different pigments in food absorb and reflect certain wavelengths which are incident in our eyes. And what happens with the role of human vision? How do we see that differently? How do we observe these lights? That is, photoreceptor cells which are cones in our system are sensitive to specific wavelengths of light signals. And when any material comes, then these photoreceptor cells. They take the signal light and it is sent to the brain. And then the brain, our human brain, combines these signals from cones. To interpret a wide range of colors in the food, and it immediately gives that. Yes, this is red; this is yellow; this is black, and so on. So, the color measurement devices also utilize a similar mechanism. It is based on either Lambert-Beer law, CIE Lab Hunter Lab colorimeter (LAB index), and so on. So, here,

$$E = k\lambda cd$$

Where 'E' is the extinction, 'k' is the extinction coefficient, 'c' is the concentration and 'd' is the sample thickness. So, the concentration of color-absorbing pigment plays an important role in color measurement. As you can see here, the light source interacts with the sample, and the resulting light is dispersed by the diffraction grating. The diode array captures the data, which is then sent to the analyzer for processing, generating various outputs. Similarly, L a b value. L* is 0 to 100; it may be dark to light; a* is from -100 to 100; it may be green to red; and b* is -100 to 100; it may be blue to yellow. So, most shades of a* and b* fall within that -50 to 50.

Then, volumetric properties, like physical properties, that describe volumetric changes in food.

Volumetric properties

- Physical properties that describe volumetric changes in food.

Volume

- Volume is defined as the amount of 3-dimensional space occupied by an object. In the SI system, the unit of volume is m^3 .

Volume measurement of solids

- Volume can be calculated from the characteristic dimensions in the case of objects with regular shape.
- Volumes of solids can be determined experimentally by liquid, gas, or solid displacement or even by image processing method.



$$V_s = \frac{\text{Weight of the liquid displaced by solid}}{\text{Density of liquid}} = \frac{(W_{p2} - W_{p1}) - (W_{s2} - W_{s1})}{\rho_l}$$

V_s = Volume of the solid (m^3),
 W_{p2} = Weight of the pycnometer filled with liquid (kg),
 W_{p1} = Weight of the empty pycnometer (kg),
 W_{s2} = Weight of the pycnometer containing the solid sample (kg),
 W_{s1} = Weight of pycnometer containing solid sample with no liquid (kg),
 ρ_l = Density of the liquid (kg/ m^3).

Kim et al., 2021
 Source: en.wikipedia.org
 sciencemotes.org

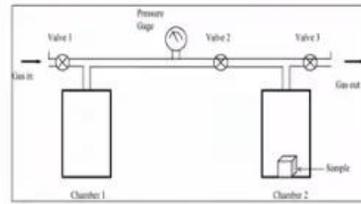
Volume is defined as the amount of three-dimensional space occupied by an object. In the SI system, the unit of volume is a m^3 . There may be different shapes and volumes, etc. You can see here, that is, it may be rectangular; it may be circular; it may be triangular. It may be square; it may be a rod; it may be a cylindrical shape, etc. And there are all these different-shaped objects. There is a way that one can calculate this volume, whatever this is, for example, for a cylindrical-shaped material, $\pi r^2 h$, a circular-shaped material (sphere) it is $\frac{4}{3}\pi r^3$. All these things can help you measure the volume. The volume can be calculated from the characteristic dimensions in the case of objects with regular shapes. Volumes of solids can be determined experimentally by liquid, gas, or solid displacement, by image processing methods, or by using a pycnometer, etcetera. That is the 'Vs' in the pycnometer, like here you can see, or you have a measuring cylinder, you put the liquid in, and then you put the solid in and see how much volume displacement occurs here. ΔV . So, this is how you can measure the volume of the liquid displaced by the solid and the density of the liquid, by which you can determine what the irregular material is and what its volume is. The equation is given here.

Similarly, another method, like the gas displacement method, is also used for volume measurement. Here, volumes of particle solids and materials with irregular shapes can be determined by the displacement of gas or air in a pycnometer, where

$$V_s = V_2 - V_1 \left(\frac{P_1 - P_2}{P_2} \right)$$

o **Gas displacement method for volume measurement**

- Volumes of particulate solids and materials with irregular shape can be determined by displacement of gas or air in pycnometer.



$$V_s = V_2 - V_1 \left(\frac{P_1 - P_2}{P_2} \right)$$

- V_s = Volume of the solid (m³)
- P_1 = Equilibrium pressure when valve 2 is closed (Pa).
- P_2 = New pressure (Pa).
- V_1 = Volume of the first chamber (m³)
- V_2 = Volume of sample chamber (m³)



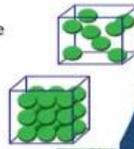
Source: Sahin & Sumnu, 2006

Here is the setup: there is a chamber 1, and there is a chamber 2. There is a gas, and then a sample is a solid sample. How much gas is it displaced? That is V_s is the volume of the solid you are measuring. P_1 is the equilibrium pressure when valve 2 is closed, and P_2 is the new pressure. V_1 is the volume of the first chamber, and V_2 is the volume of the sample chamber. So, with this, you can calculate the volume of irregular material by the gas displacement method.

Then, another very important property is density. The density of a material is the amount of material occupying a certain space, and it is expressed in mass per unit volume.

Density

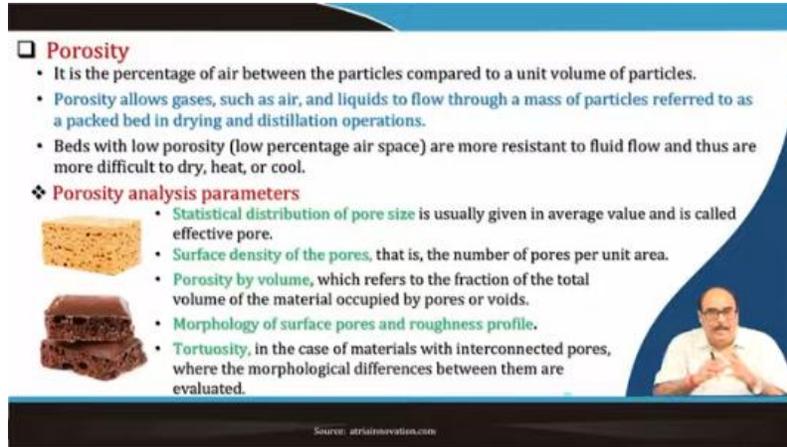
- Density (ρ) of a material is the amount of that material occupying a certain space and is expressed in mass per unit volume.
- Materials consisting of particles or grains with interstitial air spaces.
- **Particle density** is the mass divided by the volume of the particle alone.
- **Bulk density** is the mass of a group of individual particles divided by the space occupied by the entire mass, including the air space.
- Materials without internal air spaces, such as fluids and solids, have equal particle and bulk density.
- The ratio of the absolute density of a material to the density of a reference material is called relative density or **specific gravity**.
- The density of processed products dictate the characteristics of its container or package.
- **Product density influences the amount and strength of packaging material.**



Material consisting of particles or grains with interstitial spaces. And you can see here that it is more dense, here it is less dense, as particles that air might be there. So, particle density is the mass divided by the volume of the particle alone. Bulk density is the mass of a group of individual particles divided by the space occupied by the entire mass, including the air space. Materials without internal air spaces, such as fluids and solids, have equal particle and bulk density. The ratio of the absolute density of a material to the density of a reference material is called relative density or specific gravity. The density of processed products dictates the characteristics of their container or the package that is. What is the strength of the packaging material required? How should the type of packaging, volume of the

packaging, etcetera be determined? Here, the density, whether true density or specific density, all of these play a major role.

Then another property is porosity.



Porosity

- It is the percentage of air between the particles compared to a unit volume of particles.
- Porosity allows gases, such as air, and liquids to flow through a mass of particles referred to as a packed bed in drying and distillation operations.
- Beds with low porosity (low percentage air space) are more resistant to fluid flow and thus are more difficult to dry, heat, or cool.

Porosity analysis parameters

- **Statistical distribution of pore size** is usually given in average value and is called effective pore.
- **Surface density of the pores**, that is, the number of pores per unit area.
- **Porosity by volume**, which refers to the fraction of the total volume of the material occupied by pores or voids.
- **Morphology of surface pores and roughness profile.**
- **Tortuosity**, in the case of materials with interconnected pores, where the morphological differences between them are evaluated.

Source: atsumivation.com

It is the percentage of air between the particles compared to a unit volume of particles. Okay, porosity allows gases such as air and liquids to flow through a mass of particles, referred to as a packed bed, in drying and distillation operations. You can see here these two pictures, one has more porosity, the other has less porosity, more pore size, more pores, bigger pore size, etc., Beds with low porosity, that is, the low percentage of air space, are more resistant to fluid flow and thus are more difficult to dry, heat, or cool down. Porosity analysis parameters are the statistical distribution of pore size and it is usually given in the average value and is called the effective pore. Surface density of the pores, that is, the number of pores per unit area. Porosity by volume refers to the fraction of the total volume of the material occupied by pores or voids. Morphology of surface pores and roughness profile is another characteristic. Then, tortuosity in the case of materials with interconnected pores where the morphological differences between them are evaluated, is measured by tortuosity.

Porosity is an important parameter in predicting diffusional properties in cellular foods. Porosity is defined as the volume fraction of air or the void fraction in the sample and is expressed by void volume divided by total volume.

Porosity (Contd...)

- Porosity is an important parameter in predicting diffusional properties of cellular foods.
- Porosity (ϵ) is defined as the volume fraction of the air or the void fraction in the sample and expressed as

$$\text{Porosity} = \frac{\text{Void volume}}{\text{Total volume}}$$

❖ **Methods of determining 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 by means of compression.
- **Optical method:** It is determined from the microscopic view of a section of the porous medium.
- **Density method:** In this the porosity is calculated from the measured densities.

$$\epsilon_{app} = 1 - \frac{\rho_{app}}{\rho_s}$$
- **Gas pycnometer method:** Porosity can be measured directly by measuring the volume fraction of air using the air comparison pycnometer.



There are various ways by which porosity can be determined either by direct method, indirect method, optical methods, density methods, or gas pycnometer methods. In the direct method, porosity is determined from the difference in bulk volume of a piece of porous material and its volume after the destruction of all voids using compression. In the optical methods, porosity is determined from the microscopic view of a section of the porous medium. In the density method, the porosity is calculated from the major densities like E_{app} is equal to $1 - \frac{\rho_{app}}{\rho_s}$. In the gas pycnometer method, porosity can be measured directly by measuring the volume fraction of air using the air compression pycnometer.

Then, surface properties, another important property that many foods are a mixture of multiphase material that is a mix of solids, liquids, and gas.

Surface properties

- Many foods are a mixture of multi-phase materials (i.e., a mix of solid, liquid, and gas).
- The boundary between these phases, the interface, plays a significant role in the properties of the food.

			
Foam	Emulsion	Semi-solid foam	Solid foam
A foam, a gas in a liquid, are whipped creams and toppings	A liquid in a liquid, example is mayonnaise	A solid foam example is the meringue on pies	

- Uniform distribution of oil and water throughout a food material incorporates the use of surface properties.
- Surface properties are important in unit operations such as spray drying, aeration, hydrogenation, and fermentation and is also important in cleaning operations.



The boundary between these phases, the interphase phase, plays an important, significant role in the properties of the food. You can say that the surface property foam, emulsion or semi-solid foam, or solid foam that is a foam is when there is a gas in a liquid, they are

whipped cream-like or toppings, etcetera. Emulsion is when two immiscible liquids, there is a liquid in a liquid, an example is mayonnaise and Semi-solid or solid foam, it is an example of the meringue in pies, etc. So, there is a uniform distribution of oil and water throughout a food material and it incorporates the use of surface property. Surface properties are important in unit operations such as spray drying, aeration, hydrogenation, and fermentation, and are also important in cleaning operations, etc.

Many on the surface of the material, that is what is the how it is sticking and all those things, what forces etcetera are there. So, detergent how it will act, all those things are then there is a surface tension like very important characteristics of materials. Molecules at the surface of the liquid are attracted inward due to the van der Waals attractions or van der Waals forces and this creates a force on the surface that minimizes the surface area and is known as surface tension.

Surface tension

- Molecules at the surface of the liquid are attracted inward due to van der Waals attractions.
- This creates a force on surface that minimize the surface area and is known as surface tension.
- Surface tension can be defined as the tendency of a surface of a liquid to behave like a stretched elastic membrane.
- The surface tension (σ) is expressed as free energy per unit surface area (N/m).
- It is also defined as the force per unit length on the surface that opposes the expansion of the surface.
- This definition can be seen in the figure, in which a bar is pulled with force F to expand a liquid film that is stretched like a bubble film on a wire frame.

$$\sigma = \frac{\text{Work done}}{\text{Increase in area}} = \frac{FL}{2Ld} = \frac{F}{2d}$$

d: Distance between wires A and B,
L: Distance that the bar is advanced to the left, the factor 2 is introduced since there are two liquid surfaces (each at front and back)

Source: www.alfa-processi.com
Sahin & Sumnu, (2006)

Surface tension can be defined as the tendency of a substance of a tendency of the surface of a liquid to behave like a stretched elastic membrane. The surface tension is expressed as free energy per unit surface area (N/m). It is also defined as the force per unit length on the surface that opposes the expansion of the surface. This definition can be seen in the figure here. That is in which a bar is pulled with a force ‘F’. This bar is pulled with a force F to expand this liquid and the liquid film is stretched like a bubble film on the wireframe. So, here your surface tension is the work done divided by the increase in area.

$$\sigma = \frac{FL}{2Ld} = \frac{F}{2d}$$

where ‘d’ is the distance between A and B, and ‘L’ is the distance that the bar is advanced to the left. The factor 2 is introduced since there are two liquid surfaces, each at the front and the back.

Then, equations governing the surface tensions.

Equations governing surface tension

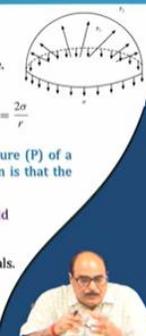
- ❖ **Laplace equation**
 - Internal pressure (P_1) tend to explode the bubble and external pressure (P_2) tend to implode.
 - This equation gives pressure difference inside and outside the spherical bubble.

Force due to surface tension $F = (P_1 - P_2)\pi r^2$ $F = 2\pi r\sigma$ At $(P_1 - P_2) = 0$, $\Delta P = P_1 - P_2 = \frac{2\sigma}{r}$

- ❖ **Kelvin equation**
 - Curvature of a surface affects the vapor pressure. Kelvin equation gives the vapor pressure (P) of a droplet having a radius r at temperature T . The assumption to obtain the Kelvin equation is that the surface tension is independent of the curvature of the surface.

$\ln\left(\frac{P}{P^0}\right) = \frac{2\bar{V}\sigma}{rRT}$ P^0 : Vapor pressure of the planar surface; \bar{V} : Molar volume of the liquid

- ❖ **Surface activity**
 - Substances that reduce surface tension at very low concentrations are surface-active materials.
 - These materials have both hydrophilic and lipophilic groups, allowing them to position themselves at the boundary between two different phases.
 - By concentrating at the surface, these substances significantly lower the surface tension, which can be measured using the **Gibbs adsorption isotherm**.



Source: Sahil & Sumita, (2006)

There are various equations like the Laplace equation, Kelvin equation, and surface activity, all these things are used to govern the surface tension. Like in the Laplace equation, internal pressure P_1 tends to explode the bubble, and external pressure P_2 tends to implode. This equation gives the pressure difference inside and outside a spherical bubble. Force due to surface tension

$$F = (P_1 - P_2)\pi r^2$$

$$F = 2\pi r\sigma$$

Surface tension, and that you can find out.

Then, the Kelvin equation is $\ln\left(\frac{P}{P^0}\right) = \frac{2\bar{V}\sigma}{rRT}$

So, P^0 is the vapor pressure at the planar surface, and ' \bar{V} ' is the molar volume of the liquid. That is the curvature of a surface affects the vapor pressure. The Kelvin equation gives the vapor pressure ' P ' of a droplet having a radius ' r ' at temperature ' T '. The assumption to obtain the Kelvin equation is that the surface tension is dependent on the curvature of the surface, then surface activity. Substances that reduce surface tension at very low concentrations are surface-active materials and these materials have both hydrophilic and lipophilic groups allowing them to position themselves at the boundary between the two different phases. By concentrating at the surface, these substances significantly lower the surface tension which can be measured using Gibbs adsorption isotherm.

Surface activity, such as various emulsifiers and hydrocolloids, are good examples of surface-active materials as you can see here, that are in the oil phase and there is a liquid

❖ **Surface activity**

- Emulsifiers and hydrocolloids are good examples for surface-active materials.
- These materials have both polar or hydrophilic and nonpolar or lipophilic groups

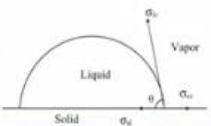
Where, Γ is adsorption of solute at the surface (kg-mole/m²),
 σ is surface tension (N/m),
 R is the gas constant (8314.34 J/kg-mole · K),
 a is activity of solute in the bulk solution,
 c is concentration of solute in the bulk solution (kg-mole/m³)
 m is a constant with a value of 1 for dissociating substances

$$\Gamma = -\frac{1}{mRT} \frac{d\sigma}{d \ln a} \cong -\frac{1}{RT} \frac{d\sigma}{d \ln c}$$

❖ **Interfacial tension**

- Surface tension appears in interfaces (liquid-liquid boundaries) is called interfacial tension.
- Interfacial tension arises at the boundary of two immiscible liquid due to the imbalance of intermolecular forces and the energy balance known as the Dupre' equation.
- Generally, the higher the interfacial tension, the lower is the miscibility.
- Emulsifiers and detergents function by lowering the interfacial tension.

Dupre' equation $W_a = \sigma_{sv} + \sigma_{lv} - \sigma_{sl}$


Chaudhri, (2020)
 Source: Sahis & Sumita, (2006)

phase, the aqueous phase, and these hydrocolloids have a hydrophilic head as well as a hydrophobic tail this keeps the material that is in both the oil phase and aqueous phase together that is, these materials can have both polar or hydrophilic and non-polar or hydrophobic groups and this can be calculated using this given equation.

$$\Gamma = -\frac{1}{mRT} \frac{d\sigma}{d \ln a} \cong -\frac{1}{RT} \frac{d\sigma}{d \ln c}$$

That is, 'Γ' is the adsorption of the solute at the surface, 'σ' is the surface tension, 'R' is the gas constant, 'c' is the concentration of solute, and 'm' is a constant.

Then another is the interfacial tension, Interfacial tension is the surface tension that appears at interfaces. The liquid-liquid boundary is called interfacial tension. Interfacial tension arises at the boundary of two immiscible liquids due to the imbalance of intermolecular forces and the energy balance known as Dupre's equation. Generally, the higher the interfacial tension, the lower the miscibility. You can see here that the liquid solids Emulsifiers and detergents function by lowering the interfacial tension in Dupre's equation:

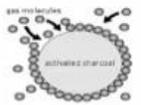
$$W = \sigma_{sv} + \sigma_{lv} - \sigma_{sl}$$

W is the work of adhesion, σ_{sv} , σ_{lv} , and σ_{sl} represent the surface tensions at solid-vapor, liquid-vapor, and solid-liquid interfaces, respectively. So, you can determine whether it will be immiscible or how these emulsifiers lower the surface tension.

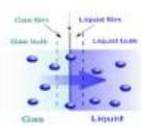
The surface phenomena, another important property are the physical and chemical processes that occur at the interface between two phases such as solid and liquid or liquid and gas, and absorption and adsorption, these are the two important surface phenomena that are also shown here in the figure.

❖ Surface phenomena

- Surface phenomena are the physical and chemical processes that occur at the interface between two phases, such as a solid and a liquid or a liquid and a gas.



gas molecules
activated charcoal



Gas film
Liquid film
Solid matrix
Liquid phase
Glass
Liquid

- **Adsorption** is the surface phenomenon, in which accumulation of the substance (adsorbate) like solid, liquid or gas on the surface of another substance (adsorbent) occurs.
Adsorption is mainly a consequence of surface energy. The surface particles which can be exposed partially tend to attract other particles to their site.
- **Absorption** is the bulk process in which the absorbate diffuse completely into another medium which can be solid, liquid or gas.
Absorbing material remain intact in absorbent due to the presence of space within the substance but do not have any chemical relation with each other.

Source: www.ias.ac.in

Adsorption is the surface phenomenon in which the accumulation of the substance, known as the adsorbate, like solid, liquid, or gas, occurs on the surface of another substance, called the adsorbent. It occurs and adsorption is mainly a consequence of surface energy. The surface particles, which cannot be fully exposed, tend to attract other particles to their site. Absorption, as you can see here, is a total, bulk process in which the absorbate diffuses completely into another medium, which can be solid, liquid, or gas. Absorbing materials remain intact in the absorbent due to the presence of space within the substance, but they do not have any chemical relation with each other. So, this is the difference between adsorption and absorption.

Then, structural properties are the characteristics of a material that describe its molecular organization and arrangement at microscopic to macroscopic levels.

Structural properties

- Structural properties are the characteristics of a material that describe its molecular organization and arrangement at microscopic (molecular) to macroscopic (visible) levels.
- These properties influence how a material behaves under mechanical, thermal, or environmental stress and determine its physical integrity, texture, and functionality.

❑ Macroscopic properties

- ❖ **Particle characteristics**
 - Particle characteristics of raw, unprocessed, as well as processed food materials include particle size and shape, particle and bulk density, porosity, and surface area.



Longest diameter (major) and shortest diameter (minor) in grains

- The size of non-spherical objects like wheat kernels, bananas, pears, or potatoes may be described by multiple length measurements. The longest diameter (major) and shortest diameter (minor) will adequately describe the size of an ellipsoidal object such as grain kernel or potato.

These properties influence how a material behaves under mechanical, thermal, or environmental stress and determine its physical integrity, texture, and functionality, microscopic properties, such as particle characteristics of raw, unprocessed as well as processed food materials, include particle shape and size, particle and bulk density,

porosity, surface area, and so on. You can see here that the size of spherical particles, like peas or cantaloupes, is easily defined by a single characteristic, such as its diameter. or the size of non-spherical objects, like wheat kernels, bananas, peas, and potatoes, all such materials may be described by multiple length measurements. The longest diameter is the major, and the shortest diameter is the minor. These describe the size of an elliptical object, such as a grain kernel, potato, etc.

Then, particle shape and roundness. Particle shape affects the internal structure of the material and, in turn, its acceptance.

❖ **Particle shape & roundness**

- Particle shape affects the internal structure of the material and in turn its acceptance.
- Roundness is a measure of the sharpness of the corners of the solid.

$Roundness = \frac{A_p}{A_c}$ A_p = Largest projected area of object $Roundness = \frac{\sum r}{NR}$ r = Radius of curvature as defined
 A_c = Area of smallest circumscribing circle R = Radius of maximum inscribed circle
 N = Total number of corners summed

$Roundness\ ratio = \frac{r}{R}$ R : Mean radius of the object $Sphericity = \frac{D_i}{D_c}$
 r : Radius of sharpest corner D_i = Diameter of largest inscribed circle
 D_c = Diameter of smallest circumscribed circle

o The shape of an irregular object can be described as follows.

Shape	Description	Shape	Description
Round	Approaching spheroid	Truncate	Having both ends squared or flattened
Oblate	Flattened at the stem end and apex	Ribbed	In cross section, sides are more or less angular
Elliptical	Approaching ellipsoid	Lopsided	Horizontal cross section departs materially from a circle
Conic	Tapered toward the apex	Oblong	Vertical diameter greater than the horizontal diameter
Ovate	Egg-shaped and broad at the stem end		



Roundness is a measure of the sharpness of the corners of the material.

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

where A_p is the largest projected area of the object, and A_c is the area of the smallest circumscribing circle.

Roundness can also be measured in terms of

$$Roundness = \frac{\sum r}{NR}$$

where 'r' is the radius of curvature, as defined, 'R' is the radius of the maximum inscribed circle, and 'n' is the total number of corners.

The roundness ratio may also be calculated

$$Roundness\ ratio = \frac{r}{R}$$

where 'R' is the mean radius of the object, and 'r' is the radius of the sharpest corner. Similarly, another property related to particle shape and roundness is sphericity,

$$Sphericity = \frac{D_i}{D_c}$$

where D_i is the diameter of the largest inscribed circle, and D_c is the diameter of the smallest circumscribed circle. Here are various shapes and descriptions, like elliptical shapes, which approach ellipsoid or ovate, egg-shaped at the broad and the stem, etc. There are ribbed shapes in cross-section, sides are more or less angular, oblong shapes have a vertical diameter greater than the horizontal diameter, etc. So, there are different shapes, and their descriptions of all these shapes are given in this table.

Then, microscopic properties, that is, you know that food is made up of the arrangement of macromolecules such as carbohydrates, proteins, lipids, etcetera, and the molecules' cross-linking. Fiber structures, particle arrangement, and foam structures

Microscopic properties

- Food is made up of the arrangement of macromolecules such as carbohydrates, proteins and lipids.
- Molecular crosslinking, fiber structure, particle arrangement, and foam structure are some of the parameters that are considered for structural analysis.
- Surface morphology analyzed by microscopic properties are also considered as microscopic structure.

Property	Method of analysis
• Crystallinity	✓ X-ray diffraction (XRD)
• Amorphous structure	✓ Differential scanning calorimeter (DSC)
• Morphology	✓ Scanning electron microscopy (SEM)
• Network structure	✓ Atomic force microscopy (AFM)
• Cross-linking	✓ Fourier-transform infrared spectroscopy (FTIR)
• Foam structure	✓ Confocal laser scanning microscopy (CLSM)
• Particle size distribution	✓ Sieve analysis, particle size analyser



are some of the parameters that are considered for structural analysis. Surface morphology is analyzed by microscopic properties and they are also considered as microscopic structures. And, their different microscopic properties are used by different methods analyzed by different methods like here in this table. I have given major microscopic properties and methods of their analysis like crystallinity can be measured by X-ray diffraction, popularly known as XRD. Amorphous structure by differential scanning calorimeter. scanning electron microscopy can be used to analyze morphology atomic force microscopy can be used to find out network structures. Fourier transform infrared spectroscopy can be used to find out the cross-linking even the foam structure can be measured using confocal laser scanning microscopy sieve analysis particle size analyzer can be used to find out the particle size distribution.so, finally, I would say that yes, physical properties are very, very important in the food processing operations,

Summary

- Physical properties of foods are those properties that lend themselves to description and quantification by physical rather than chemical means.
- Physical properties are an important aspect of food processing, quality and relate to food safety. They are the basis for instruments and sensors.
- Major food products designing is done based on physical properties mainly thermal, mechanical and volumetric properties.
- Other properties like optical, surface and structural greatly affect due to processing.
- Many foods are a mixture of multi-phase materials, and monitoring their physical properties become of prime importance.



So, finally, I would say that yes, physical properties are very, very important in food processing operations. In the designing of the equipment, optimizing the process parameters, et cetera, one should understand very clearly how these characteristics are, that is, the behavior how the food material is behaving and there are various methods of measuring physical properties. So, in the research, whether you are in the research or you are in the food industry doing the processing of the food, one must give a good shape and good material. Nowadays, foods come in different forms, different shapes, and different characteristics, and here they are made by taking into account, of course, chemical properties and other properties also become important, but the physical properties of the foods. Many foods are a mixture of multiphase materials and monitoring their physical properties becomes of prime importance. Their optical properties, thermal properties, thermal properties, mechanical properties, all these must be considered to get good food and they are with good composition, good quality, good structure, and so on.

So, these are the references used in this lecture.

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With that, thank you very much.



THANK YOU !