
WELCOME

Engineering Properties of Biological Materials

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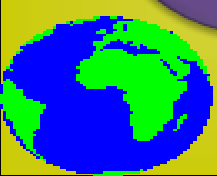
INTRODUCTION

- Engineering properties are the properties which are useful and necessary in the design and operation of various equipment employed in the field of food processing. and also for design and development of other equipment.
- The engineering properties of foods are important, if not essential, in the process design and manufacture of food products.



Classification

1. ***Thermal properties*** such as specific heat, conductivity, diffusivity, and boiling point rise, freezing point depression.
2. ***Electrical properties***, primarily conductivity and permittivity.
3. ***Structural and geometrical properties*** such as density, particle size, shape, porosity.
4. ***Mechanical properties*** such as textural (including strength, compressibility, and deformability) and rheological properties (such as viscosity).
5. ***Aerodynamic Properties*** *such as terminal velocity.*
6. ***Frictional properties*** *such as coefficient of friction and angle of repose*

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Thermal Properties

- Thermal properties of foods are related to heat transfer control in specified foods and can be classified as *thermodynamic properties* (enthalpy and entropy) and *heat transport properties* (thermal conductivity and thermal diffusivity).
- *Thermo physical properties* not only include thermodynamic and heat transport properties, but also other physical properties involved in the transfer of heat, such as freeze and boiling point, mass, density, porosity, and viscosity.

✸ ***2.1.Specific heat***, *Cp*, is the amount of heat needed to raise the temperature of unit mass by unit degree at a given temperature. The SI units for *Cp* are (kJ kg–1 K–1). Specific heat of solids and liquids depends upon temperature but is generally not sensitive to pressure.

✸ ***2.2.Thermal conductivity*** represents the quantity of heat *Q* that flows per unit time through a food of unit thickness and unit area having unit temperature difference between faces; SI units are [W m–1 K–1]. The rate of heat flow through a material by conduction can be predicted by Fourier's law of heat conduction. $\boldsymbol{Q = -\kappa A(T_1 - T_2)/x}$

2.3. Thermal diffusivity, SI units [m2/s], defines the rate at which heat diffuses by conduction through a food composite, and is related to κ and *Cp* through density ρ [kg/ m3] as follows: $\alpha=\kappa/\rho Cp$

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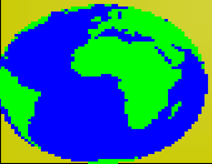


Electrical Properties

- There are two main electrical properties in food engineering:
  - Electrical conductivity and
  - Electrical permittivity
- Electrical properties are important when processing foods involving electric fields, electric current conduction, or heating through electromagnetic waves.
- These properties are also useful in the detection of processing conditions or the quality of foods.

3.1.Electrical Conductivity is a measure of how well electric current flows through a food of unit cross-sectional area A, unit length L, and resistance R. It is the inverse value of electrical resistivity (measure of resistance to electric flow) and is expressed in SI units s/m in the following relation: $\sigma = L / (AR)$

- ***3.2.Electrical permittivity*** is a dielectric property used to explain interactions of foods with electric fields. It determines the interaction of electromagnetic waves with matter and defines the charge density under an electric field.

In solids, liquid, and gases the permittivity depends on two values:

- ❖The dielectric constant ε', related to the capacitance of a substance and its ability to store electrical energy; and
- ❖The dielectric loss factor ε'', related to energy losses when the food is subjected to an alternating electrical field (i.e., dielectric relaxation and ionic conduction).

- The conductivity of a material is generally measured by passing a known current at constant voltage through a known volume of the material and by determining resistance.
- The electrical conductivity of foods has been found to increase with temperature (linearly), and with water and ionic content.

Dielectric properties are also important in the selection of proper packaging materials and cooking utensils, and in the design of microwave and radio frequency heating equipment, because they describe how the material interacts with electromagnetic radiation.

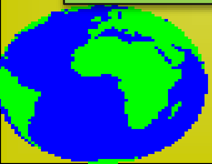
- Electrical properties are important in processing foods with pulsed electric fields, ohmic heating, induction heating, radio frequency, and microwave heating.
- Conductivity plays a fundamental role in ohmic heating, in which electricity is transformed to thermal energy when an alternating current (a.c.) flows through food.

Mechanical Properties

- The mechanical properties mainly result from the structure, physical state, and rheology.
- They can be subdivided into two groups: structural and geometrical properties, and strength properties.
- Structural and geometrical properties include mass–volume–area-related properties (density, shrinkage, and porosity), and morphological properties (surface area, roundness, and sphericity).
- Strength properties are related to solid and semi-solid stress and deformation, and intervene in food texture and rheological characterization.
- These properties are needed for process design, estimating other properties, characterizing foods, and quality determination.

4.1.Density is defined as mass per unit volume (the SI unit of density is kg/m3). Indeed, there are different forms of density such as true, material, particle, apparent, and bulk that can be used, depending on its application in process calculations or product characterization

- True and material densities are calculated by excluding volumes occupied by internal and external pores within the food, while particle, apparent, and bulk densities are determined from less accurate measurement methods that include pore volume.



4.2. Porosity indicates the volume fraction of void space or air space inside a material. Volume determination is relative to the amount of internal (or closed) or external (or open) pores present in the food structure.

Therefore, like density, different forms of porosity are also used in food processing studies, namely open pore, closed pore, apparent, bulk, and total porosities.

4.3. Shrinkage is the reduction in volume or geometric dimensions during processing.Two types of shrinkage—isotropic and anisotropic—are usually observed in the case of food materials.

✸Isotropic shrinkage is described as the uniform shrinkage of the materials under all geometric dimensions, whereas anisotropic (or non-uniform) shrinkage develops in different geometric dimensions.

✸The former is common in fruits and vegetables while the latter is known in animal tissue, such as in fish. Shrinkage occurs as a result of moisture loss (during drying), ice formation (during freezing), and formation of pores (by drying, puffing, extrusion, and frying).

4.4.Roundness is a measure of the sharpness of the corners of a solid.

4.5.Sphericity indicates how the shape of an object deviates from a sphere. Sphericity is defined from the volume, surface area, or geometric dimensions of an object.

- Sphericity and shape factors are also needed in heat and mass transfer calculations.
- Size, shape, sphericity, volume, surface area, density, and porosity are important physical characteristics of many food materials in handling and processing operations.

- Fruits and vegetables are usually graded according to size, shape, and density.
- Density and the shape factor of food materials are also necessary for predicting the freezing and thawing rate. .

4.7.Rheology and Texture

- Rheology has been defined as "a science devoted to the study of deformation and flow," or as "the study of those materials that govern the relationship between stress and strain."
- "Stress" is defined as force components acting on a body per unit cross-sectional area or area of the deformed specimen (SI units in Pa).
- "Strain" is the change in size or shape (SI units in mm or percentage) of a body in response to the applied force.
- Rheologically, the behavior of a material is expressed in terms of stress, strain, and time effects.
- There are three stresses that are commonly applied to characterize foods mechanically: *compressive* (directed toward the material), *tensile* (directed away from the material), and *shearing* (directed tangentially to the material).

Texture can be defined as those physical characteristics arising from the structural elements of the food that are sensed primarily by the feeling of touch, related to deformation, disintegration, and flow of the food under a force, and measured objectively by functions of mass, time, and length.

This indicates that texture studies include structure (molecular, microscopic, and macroscopic) and the manner in which structure reacts to applied forces.

- For instance, the Texture Profile Analysis widely used in industry defines mechanical parameters such as hardness, fracturability, cohesiveness, springiness, chewiness, gumminess, and resilience.

Aero and Hydrodynamic properties

- Aero and hydrodynamic properties such as terminal velocity of food products are important and required for designing of air and water conveying systems and separation equipment.
- The physical properties such as density, shape and size, drag coefficient etc are required for calculating the terminal velocity of the material.
- For example, in pneumatic conveying and separation process the material is lifted only when the air velocity is greater than its terminal velocity.

5.1.Terminal velocity may be defined as equal to the air velocity at which a particle remains in suspended state in vertical pipe in the condition of free fall.

The particle attains a constant terminal velocity(Vv) the net gravitational accelerating force(Fg) equals the resulting upward drag force(Fr). If V=Vv , Fg=Fr

By substituting the values of Fg and Fr, the terminal velocity can be expressed as;

$$m_p g\left[\frac{\rho_p-\rho_f}{\rho_p}\right]=1/2CA_p\rho_f V^2{}_t$$

$$\therefore\ V_t=\left[\frac{2W(\rho_p-\rho_f)}{\rho_p\rho_f A_p C}\right]^{-1/2}$$

$$C=\frac{2W\left(\rho_p-\rho_f\right)}{\rho_p\rho_f A_p V_t}$$

If density of the particle is greater than the density of the fluid, the particles move downward. If the density of the particle is lesser than the density of the fluid, the particle will rise upward.

If the separation of the mixture of wheat and foregain matters is to be achieved by air stream, the terminal velocities of each components of the mixture decide the range of the air velocity to be used for definite extent of separation.

Table.3. Air velocity requirement for air borne of some of the agricultural materials.

Grain	Unit Density, Kg/m^3	Terminal Velocity, m/s
Wheat	998-1238	9-11.5
Rye	1158-1218	8.5-10
Oats	738-968	8-9
Corn	1138-1198	34.9
Soybean	1029-1152	44.3

Frictional Properties

- The frictional properties such as coefficient of friction and angle of repose are important in designing of storage bins, hoppers, chutes, pneumatic conveying system, screw conveyors, forage harvesters, threshers etc.
- The rolling resistance or maximum angle of stability in rolling of round shape agricultural materials is useful in designing handling equipment e.g. conveying of fruits and vegetable by gravity flow

The knowledge of the frictional properties of the agricultural material is necessary; therefore, some of the important frictional properties of the agricultural products have been described here.

6.1. Static friction: The friction may be defined as the frictional forces acting between surfaces of contact at rest with respect to each other.

6.2. Kinetic friction: It may be defined as the friction forces existing between the surface in relative motion.

6.3. Coefficient of friction: The coefficient of friction may be defined as the tangent of the angle of the inclined surface upon which the friction force tangential to the surface and the component of the weight normal to the surfaces are acting.

If F is the force of friction, and W is the force normal to the surface of contact, then the coefficient of friction '*f*' is given by the relationship $f = F/W$

6.4. Rolling resistance: if a round or cylindrical shaped object rolls over a horizontal surface with force, F, and the deformation in surface occurs, there will be a resultant force,R,exerted by the surface on the body. If the moment of forces is taken about point of application of R and accelerating force is neglected, then

$$\sum M_b = F.\ a - W.\ c = 0$$

Assuming the deformation of surface as very small, a is approximately equal to r,then

$$c = \frac{F\ .\ r}{W} \quad or\ F = \frac{cW}{r}$$

The terms c and F may be defined as the coefficient of rolling resistance and rolling resistance respectively.

The rolling resistance is directly proportional to the weight of the rolling object and to the coefficient of rolling resistance which is dependent on the rigidity of the supporting surface and indirectly proportional to the effective radius of the rolling object.

6.5. Angle of repose: The angle of repose is the angle between the base and the slop of the cone formed on the free vertical fall of the granular material to the horizontal plane. The size, shape, moisture content and orientation of the grains affect the angle of repose.

There are two angles of repose,(1) static angle of repose, and (2) dynamic angle of repose.

6.5.1. Static angle of repose: It is the angle of friction taken up by granular material to just slide upon itself.

6.5.2. Dynamic angle of repose: It comes in picture when bulk of the grain is in motion like discharge of grain from bins and hoppers. The dynamic angle of repose is more important than the static.

The angle of repose , **ϕ**, is obtained from the geometry of the cone as given below.

$$\phi = \tan^{-1}\frac{2(H_a - H_b)}{D_b}$$

Where,, are the height of the cone, height of the platform and diameter of the platform respectively.

6.6. The angle of internal friction: The value of angle of internal friction is equal to the tangent of the coefficient of friction for the material.

The angle of internal friction is an important property which helps to estimate the lateral pressure in storage silos. Angle of internal friction values are also used in designing of storage bins and hoppers for gravity discharge. The coefficients of friction between grains are required as a design parameter for design of shallow and deep bins.

The angle of repose for some of the grains is given in **Table .5.**

Grain	Angle of repose
Wheat	23-28
Paddy	30-45
Maize	30-40
Barley	28-40
Millets	20-25
Rye	23-28

Conclusion

- Enthalpy and specific heat are required to calculate the heat load in food processing operations.

- Electrical properties are important in processing foods with pulsed electric fields, ohmic heating, induction heating, radio frequency, and microwave heating.

- Aero and hydrodynamic properties are important and required for designing of air and water conveying systems and separation equipment.

- The frictional properties are important in designing of storage bins,hoppers,chutes,pneumatic conveying system, screw conveyors, forage harvesters, threshers etc