PROCESSING TECHNOLOGY OF CEREALS ASFE 2201

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Physico - chemical properties of cereals, major and minor millets

FRICTIONAL PROPERTIES

Friction is a force that resists motion between two objects that are in contact with each other. Smoother surfaces exhibit less friction, while rougher surfaces exhibit more friction

Static friction arises between two objects that are not in motion with respect to each other, as for example between a cement block and a wooden floor. It increases to counterbalance forces that would move the objects, up to a certain maximum level of force, at which point the objects will begin moving. It is measured as the maximum force the bodies will sustain before motion occurs. **Kinetic friction** arises between bodies that are in motion with respect to each other, as for example the force that works against sliding a cement block along a wooden floor. Between two hard surfaces, the kinetic friction is usually somewhat lower than the static friction, meaning that more force is required to set the objects in motion than to keep them in motion

IMPORTANCE

The frictional properties of granular materials are important
In designing

- Storage bins, hoppers, chutes,
- Pneumatic conveying system, screw threshers and conveyors,
- Forage harvesters,
- Fruits and Vegetables grader

Frictional force can be expressed as

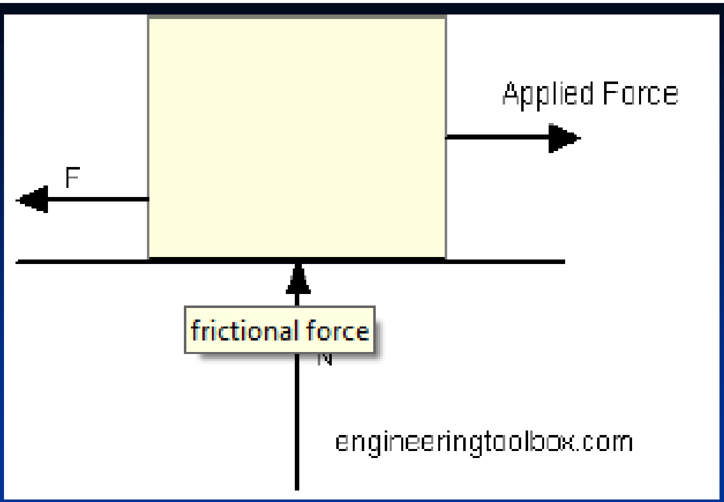
$F_f = \mu N$ (1)

where

F_f = frictional force (N)

μ = static (μ_s) or kinetic (μ_k) frictional coefficient

N = normal force (N)



For an object pulled or pushed **horizontally**, the normal force - N - is simply the weight:

$N = m g$ (2)

where

m = mass of the object (kg)

g = acceleration of gravity (9.81 m/s^2)

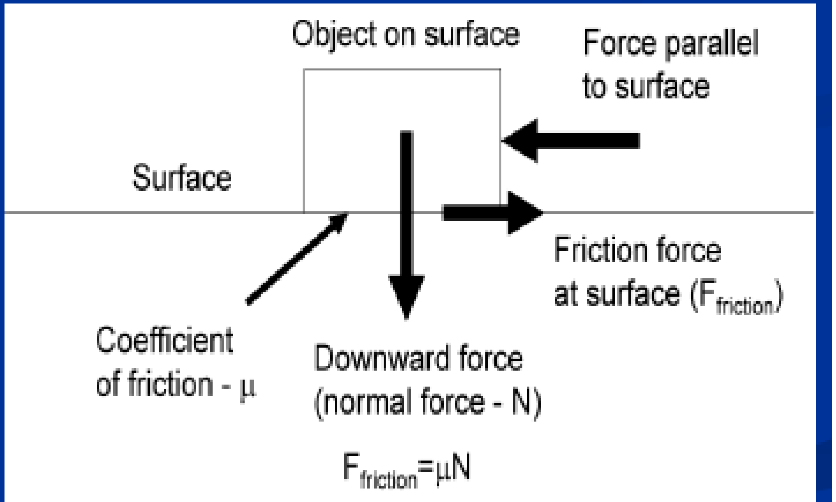


Figure 1 – Basic Definitions of the Coefficient of Friction

COEFFICIENT OF INTERNAL FRICTION

The friction of the **kernels or grains against each other** is known as internal friction where as the friction between the grain mass and the contact surface is known as static friction. The coefficient of the internal friction of the grains is required in predicting the lateral pressure on a retaining wall in silos or design of silos and hoppers for gravity flow. The method employed for the determination of the coefficient internal friction is by tri-axial compression test apparatus or Shear test apparatus.

Factors affecting frictional force

1. Load
2. Actual contact area
3. Sliding velocity
4. Nature of material in contact
5. Moisture content

ANGLE OF REPOSE

Angle of repose is important in designing a structure for storage of food grains in bulk. When a granular material is allowed to flow freely from a point into a pile, the angle which the side of the pile makes with horizontal plane is called the angle of repose (IS: 6663-1972).

The angle of repose is influenced by **size, shape, moisture content and orientation of the particles**. It has been found that the angle of repose increases with the increase in moisture content. The cohesive materials have larger angle of repose. Lower angle of repose represents easier flowability.

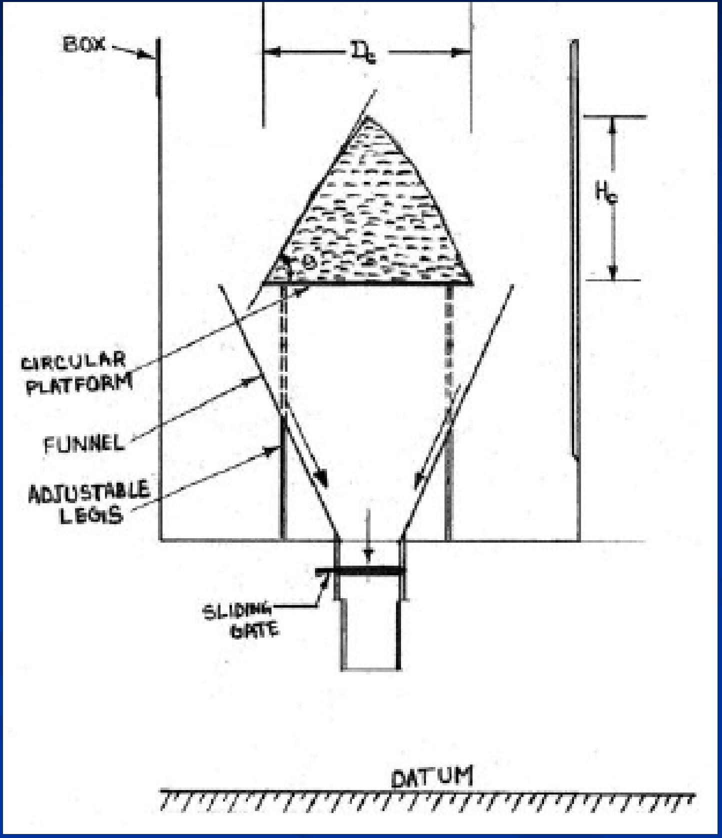
Angle of repose of the grain can be calculated experimentally using the following formulae:

$$\theta = \tan^{-1}\left(\frac{2H_c}{D_c}\right)$$

where,

H_c = height of cone formed measured with depth gauge

D_c = diameter of the platform on which the cone formed



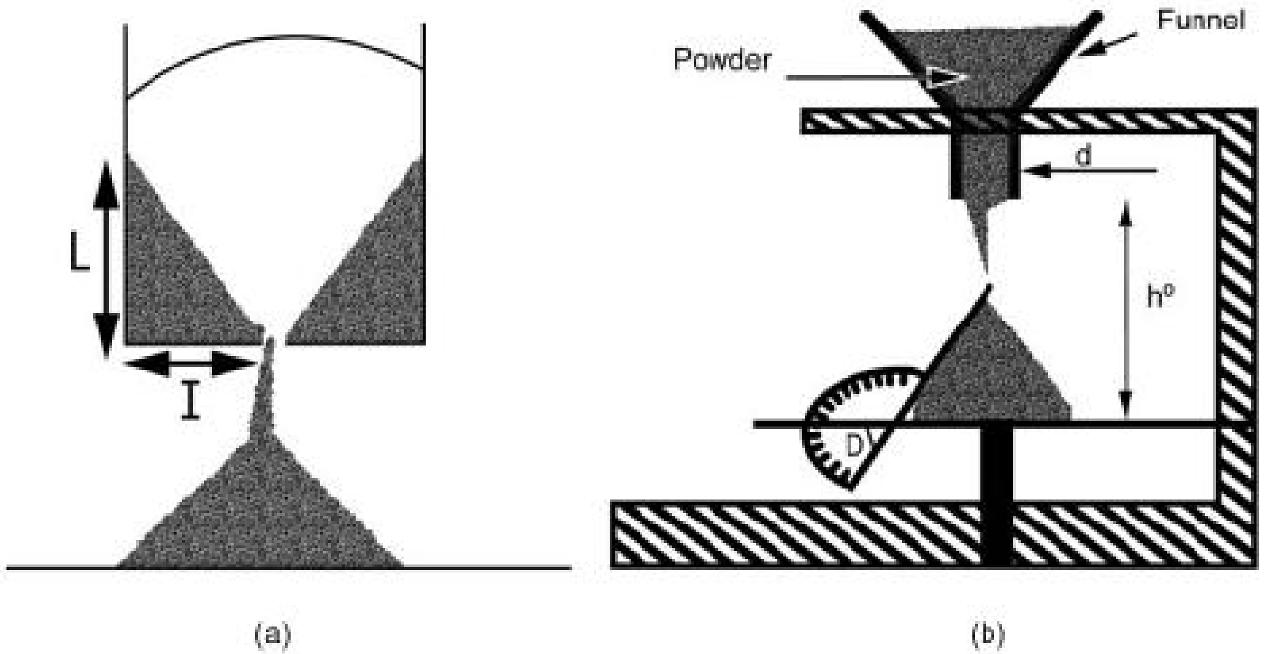
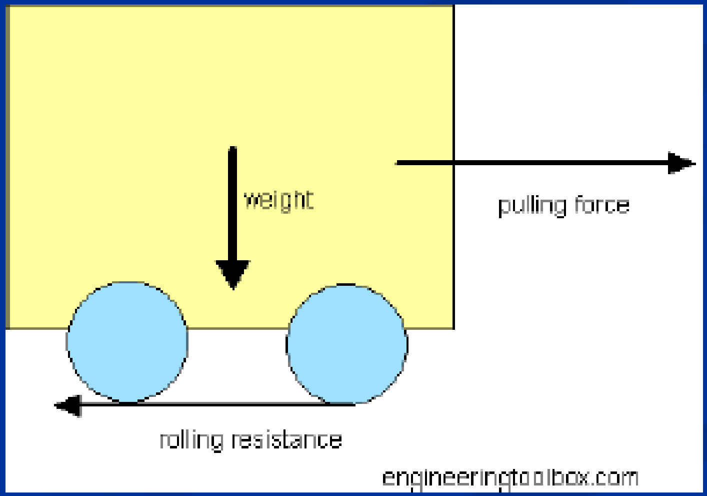
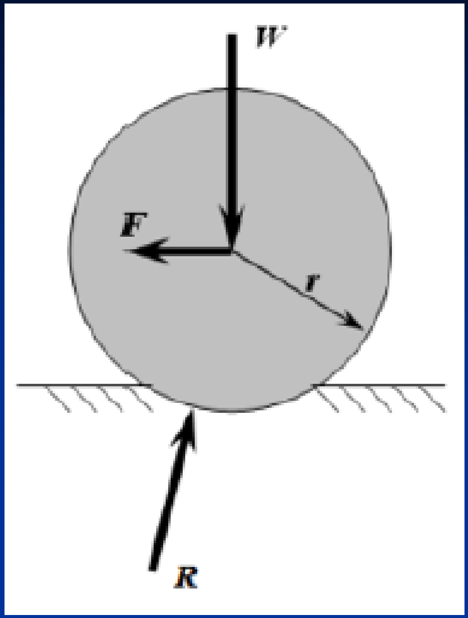


Figure 3.8. Methods to measure angle of repose (adapted from Teunou et al., 1995).

Emptying (a) and filling (b) Angle of repose

Rolling resistance is the force that resists the rolling of a wheel or other circular object along a surface caused by deformations in the object and/or surface. Generally the force of rolling resistance is less than that associated with kinetic friction. One of the most common examples of rolling resistance is the movement of motor vehicle tires on a road, a process which generates heat and sound as by-products.





The rolling resistance can be expressed as

$F_r = c\,W$ (1)

where

F_r = rolling friction (N,)

c = rolling resistance coefficient - dimensionless (coefficient of rolling friction - CRF)

W = m g = normal force or weight of body (N,)

m = mass of body (kg,)

g = accelaration of gravity (9.81 m/s^2,)

The rolling resistance can **alternatively** be expressed as

$F_r = c_l\,W / r$ (2)

where

c_l = rolling resistance coefficient with dimension length (coefficient of rolling friction) (mm,)

r = radius of wheel (mm,)

Table A.1. Common SI basic and derived units.

Quantity	SI Unit	SI Symbol	Formula
length	meter	m	
mass	kilogram	kg	
time	second	s	
electric current	ampere	A	
thermodynamic temp.	kelvin	K	
amount of matter	mole	mol	
luminous intensity	candela	cd	
plane angle	radian	rad	
acceleration, angular	radian per second squared		rad/s^2
acceleration, linear	meter per second squared		m/s^2
area	square meter	m^2	
density	kilogram per cubic meter		kg/m^3
energy	joule	J	N m
force	newton	N	$kg\ m/s^2$
frequency	hertz	Hz	s^{-1}
illumination	lux	lx	lm/m^2
inductance	henry	H	V s/A
kinematic viscosity	square meter per second		m^2/s
luminance	candela per square meter		cd/m^2
luminous flux	lumen	lm	cd sr
power	watt	W	J/s
pressure	kilopascal	kPa	kN/m^2
quantity of heat	joule	J	N m
stress	pascal	Pa	N/m^2
surface tension	newtons per meter		N/m
torque	newton meter		N m
velocity, angular	radian per second		rad/s
velocity, linear	meter per second		m/s
viscosity	newton-second per square meter		$N\ s/m^2$
voltage	volt	V	W/A
volume	cubic meter	m^3	
work	joule	J	N m

THERMAL PROPERTIES

- The raw foods are subjected to various types of thermal treatment namely heating, cooling, drying, freezing etc., for processing. The change of temperature depends on the thermal properties of the product.
- Therefore knowledge of thermal properties namely,
  - specific heat,
  - thermal conductivity,
  - thermal diffusivity

is essential for the design of different thermal equipments and for solving various problems on heat transfer operation.

Heat transfer occurs by

- ✓**Conduction,**
- ✓**Convection,**
- ✓**Radiation.**

➢These mechanisms can occur individually or simultaneously.

➢In food processing, heat transfer is usually a combination of conduction and convection.

Heat capacity

Heat capacity may be defined as the **thermal capacity**, is the measurable physical quantity that characterizes the amount of heat required to change a substance's temperature by a given amount. In the International System of Units (SI), heat capacity is expressed in units of joule(s) (J) per kelvin (K).

It is the Ratio of heat supplied to the corresponding temp rise

$$C = Q / \Delta t$$

Specific heat

Specific heat (*cp*) or mass heat capacity is the heat required to increase the temperature of one unit of mass by one degree. The subscript (*p*) is included because specific heat of solids and liquids is determined at constant pressure.

$$Q = Mc_p(T_2 - T_1)$$

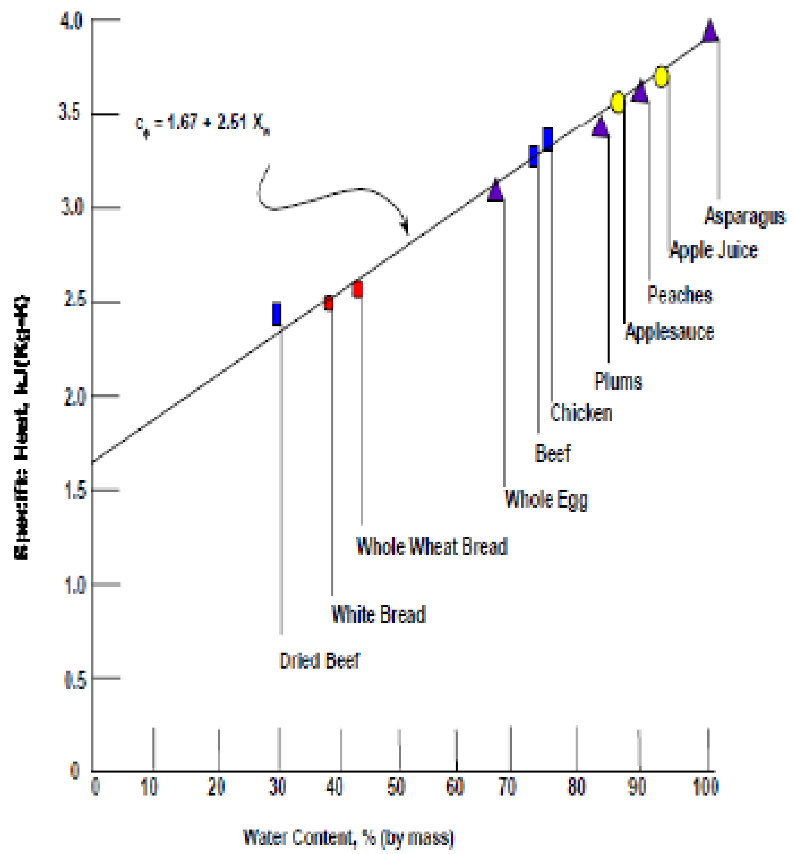


Figure 2.07. Specific heat of food products (at 0° to 20°C for meats, 4° to 32°C all others). Based upon ASHRAE data. (Courtesy of the American Society of Heating, Refrigeration and Air-Conditioning Engineers, 1989.)

While **water has the greatest effect** upon specific heat, other constituents, can also influence.

The empirical equation used for the specific heat of foods

$$Cp = 4.180\, X_w + 1.711\, X_p + 1.928\, X_f + 1.547\, X_c + 0.908\, X_a$$

where "w" is water, "p" is protein, "f" is fat, "c" is carbohydrate, and "a" is ash.

This equation takes into account the mass fraction (*X*) of all the solids that make up the food.

The specific heat calculation is expressed in kJ/(kg-K).

Thermal Conductivity

In steady state conduction through a solid-like material the important thermal property is **thermal conductivity** (*k*). Thermal conductivity is a measure of the ease with which heat flows through a material. It is defined as Rate of heat flow through unit thickness of material per unit area normal to the direction of heat flow per unit time for unit temperature difference.

The following equation relates the thermal conductivity to the amount of heat that flows through the material per unit of time (dQ/dt), the cross sectional area of the material through which the heat flows (A), and the temperature difference per unit of length of the conducting material (dT/dx).

$$(dQ/dt) = k\ A\ (dT/dx).$$

Thermal conductivity can be greatly influenced by a number of factors such as the water content, porosity, and even fiber orientation of the material.

Heat is conducted quickly through a metal like copper, hence its thermal conductivity value is high. Heat flows more slowly through materials like wood or fiberglass insulation; their thermal conductivity is low. The thermal conductivity of most food materials is in a relatively narrow range between 0.2 and 0.5 W/m K.

The equation based upon the overall food composition to estimate thermal conductivity:

$$k = 0.58X_W + 0.155X_p + 0.16X_f + 0.25X_c + 0.135X_a$$

where the parameters of the equations are as defined for Sp heat

Enthalpy

Total heat content of a material

$$h_2 - h_1 = m\, c_p\, (T_2 - T_1) + m\, X_w\, L$$

Where:

$h_2 - h_1$ = enthalpy difference
m = mass of product
X_w = water fraction
$T_2 - T_1$ = temperature difference
L = latent heat

Thermal diffusivity

In transient heat transfer, where temperature varies with time and location, the relevant thermal property is thermal diffusivity. **Thermal diffusivity** (α, m^2/s) is a combination of three basic thermal properties, defined as The rate at which heat is diffused out of the material. This quantity reveals the material's ability to conduct heat relative to its ability to store heat.

Mathematically , Thermal diffusivity =

Thermal conductivity/(density × specific heat) or $\alpha = k/\rho C_p$.

When these three basic properties are known, the diffusivity can be readily computed.

Values of thermal diffusivity for food products range from

1×10^{-7} to 2×10^{-7} m^2/s.

Convective heat transfer coefficient

The thermal property associated with convective heat transfer is the **convective heat transfer coefficient** (*h*); it also goes by the names *surface heat transfer coefficient*, unit surface conductance or *film coefficient*. Unlike thermal conductivity, which depends only upon the particular material, the convective heat transfer coefficient depends upon fluid velocity, fluid properties, surface characteristics of the solid, and the geometry of each situation.

It is defined as the rate of heat transfer per degree of temp diff across the solid fluid interface per unit of the solid's surface area.

$Q = h\,A\ \Delta t$

The convective heat transfer coefficient varies widely from about W/m2 °C for still air next to a flat surface to 100,000 W/m2 °C for steam condensing on a metal pipe.

Heat transfer may involve either sensible energy or latent energy.

If the temperature of an object is changed due to the heat transfer, then the heat transfer involves a transfer of **sensible heat**.

The exchange of energy that occurs during a change in phase is called the latent heat. **Latent heat** involves heat exchange without a temperature change.

The heat exchange during the phase change from liquid to solid is the **heat of fusion** or heat of solidification. Freezing water into ice or the opposite, thawing, is a common example of heat of fusion.

The energy to change a liquid to vapor is the latent heat of vaporization. **Latent heat of vaporization** is useful in applications involving drying or evaporation where a liquid is vaporized for ease of separation from the mixture. Vaporizing water is commonly done to dry food materials.

Latent heat (L) is the heat that is exchanged with a material during a phase change, when the heat exchanged does not result in a change in the temperature of the material. The units for latent heat are kJ/kg. Latent heat is usually subdivided into latent heat of freezing and latent heat of vaporization.

Latent heat of freezing is the 335 kJ that 1 kg of water releases while maintaining its temperature at 0 ^{0}C when changing from the liquid to the solid state. **Latent heat of vaporization** is represented by the 2257 kJ that 1 kg of water must absorb while temperature remains constant at 100 ^{0}C to evaporate from liquid into vapor.

Latent heat can represent a huge expenditure of energy in food processing when freezing or evaporation is involved. Latent heat is best determined through experimentation, but it also can be estimated based on the mass fraction of water in the product.

$$L = 335X_w \qquad\qquad L = 2257X_w$$

Heat of Respiration

Fruit and vegetable products are living organisms. To maintain their life processes, they must consume energy. They do this by a "combustion" process that "burns" sugar to produce CO_2 and heat. The heat produced by this process is commonly called the **heat of respiration**.

$$C_6H_{12}O_6\,(aq) + 6\,O_2\,(g) \rightarrow 6\,CO_2\,(g) + 6\,H_2O\,(l) + \text{heat energy}$$

While small for any single item such as an apple or an ear of sweet corn, the heat of respiration can become a significant source of heat when large quantities of material are present. High respiration rates also cause rapid deterioration in food quality.

Heats of respiration vary greatly among products and increase exponentially with temperature. It is also affected by maturity and storage time

Table 4.4: Thermal properties of grains

Grains	Moisture content (%, db)	Specific heat (KJ / Kg K)	Thermal conductivity (W / m K)	Thermal Diffusivity (10^{-7} m^2/s)
Wheat	10-20	1.09	0.139	0.91
Rice	10-20	1.33	0.087	1.00
Corn	10-20	1.20	0.165	0.89
Pigeon pea	8-22	1.50	0.153	0.94
Soyabean	8-10	2.01	0.116	0.54
Bengal gram	10-20			17.1
Mustard	8-12	2.56	0.175	0.73
Sorghum	8-12	1.69	0.124	0.85

Source: Engg. properties of Food materials (1980) CIAE Publication /80/15