FDE 449
Physical properties of Foods

Density, specific gravity and porosity

Density

- The quality of foods can be determined by measuring their density.

Data on the densities of foods are required in:

- separation processes such as centrifugation and sedimentation, and in pneumatic (air pressure) and hydraulic transport of powdered or particulate foods.

- measuring the density of liquid foods is used to calculate the power required for pumping to transport them by pumping.

Density

- The density of liquids is fairly straightforward, but solids in particulate form, such as peas or powders, have a bulk density as well as a solid density to consider.

- Gases and vapours, unlike solids and liquids, are considered to be compressible.

Density

- The density of a substance is equal to the mass of the substance divided by the volume that it occupies:

  Symbol ρ (rho)

$$density = \frac{mass}{volume} = \frac{m}{V}$$

ρ: density, kg/m^3, g/cm^3, g/mL, (lb/ft^3)

m: mass (kg, g, lb)

V: volume (m^3, cm^3 , ft^3)

Water has its maximum density of 1000 kg/ m3 at 4 oC:

$$10^3 kg/m^3 = \frac{10^3 x\, 10^3 g}{10^6 ml} = 1\ g/ml$$

Density units

	kg / m^3 (SI system)	g / cm^3 (cgs system)	lb / ft^3 *(Imp. System)	lb / in^3 *
1 kg / m^3 =	1	0.001	6.243×10^{-2}	3.613×10^{-5}
1 g / cm^3 =	1000	1	62.43	3.613×10^{-2}
1 lb / ft^3 =	16.02	1.602×10^{-2}	1	5.787×10^{-4}
1 lb / in^3	2.768×10^{4}	27.68	1728	1

* Not common.

Density of some common solid materials

Material	Density, kg/m^3	Temperature, ^oC
Aluminium	2640	0
Cast iron	7210	0
Copper	8900	0
Stainless steel	7950	20
Brick	1760	20
Concrete	2000	20
Glass soda	2240	20
Wood	200	30

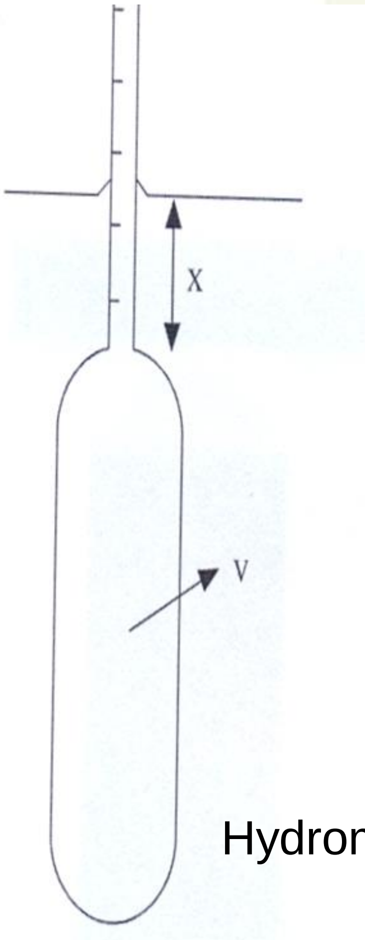
Density of some selected fluids

Fluid	Density, kg/ m^3	Temperature, ^oC
Acetone	792	20
Carbon tetrachloride	1595	20
Glycerol	1260	0
Mercury	13600	-
Milk	1028-1035	-
Acetic acid	1050	20
Olive oil	910	20
Tallow	900	65
Cream (%20 fat)	1010	3

Density of liquids

- can be determined by using a pycnometer.
- Wide-mouthed bottles can be used for very viscous materials such as tomato paste, batter, or honey.
- Liquid density can also be measured by placing a hydrometer in a beaker filled with the liquid sample.

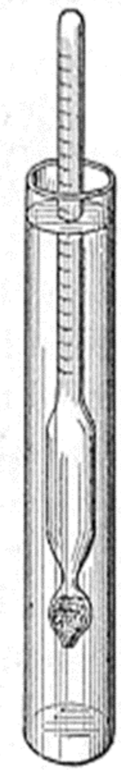
Pycnometer



Hydrometer

Hydrometer

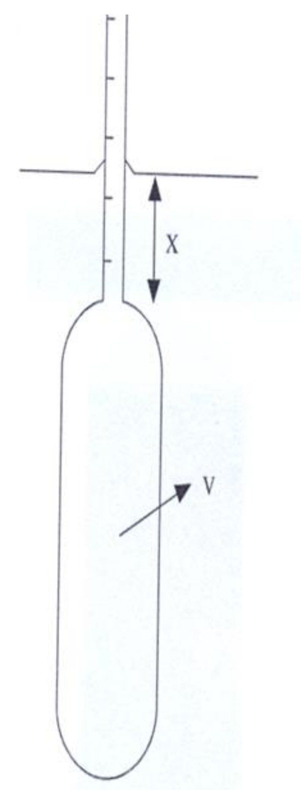
- The hydrometer has a stem that extends from a tubular shaped bulb.
- The diameter of the stem is approximately equal to the diameter of thermometer.
- The bulb may be filled with a dense material to give it an appropriate weight so that the whole hydrometer sinks in the test liquid to such a depth that the upper calibrated and marked stem is partly above the liquid.
- The depth to which the hydrometer sinks depends on the density of the fluid displaced.
- The deeper the hydrometer sinks, the lower the density of the solution.
- The constant weight hydrometer works on the principle that a floating body displaces its own weight of fluid.



Hydrometer

- The density of liquid is calculated from the ratio of weight of the hydrometer to the volume of the displaced liquid:

$$\rho_l = \frac{W}{AX+V}$$



where

W = weight of hydrometer (kg),

A = cross-sectional area of stem (m^2),

X = the length of the stem immersed (m),

V = Volume of the bulb (m^3).

Hydrometer

- Density hydrometers are sometimes prepared for a narrow range of measurement and therefore are sensitive to small changes in density.
- Specific names are given to these kinds of hydrometers such as **lactometers for milk** and oleometers for oil.

An *oleometer* is used for vegetable oils; the scale is from 50 to 0 and corresponds to a specific gravity of from 0.870 to *0.970.*

- **The Twaddell hydrometer** is used for liquids denser than water.
- **The Baume scale** has two scales, one of which is for fluids heavier than water and the other one is for lighter fluids.
- A variety of hydrometers are also available for specific purposes other than density such as;
- **The Brix saccharometer** shows directly the percentage sucrose by weight in the solution, at the temperature indicated on the instrument.
- **An *alcoholometer*** is used for testing alcoholic solutions, the scale shows the amount of alcohol by volume (0-100%).
- **Salometers** for determination of the percent saturation of salt solutions.

Density of solids

True density (ρ_T) is the density of a pure substance or a composite material calculated from the densities of its components considering conservation of mass and volume.

Density of solids

- If the densities and volume or mass fractions of constituents are known, density can be determined from:

$$\rho_T = \sum_{i=1}^{n} X_i^v \rho_i = \frac{1}{\sum_{i=1}^{n} X_i^w / \rho_i}$$

where

ρ_i = density of i th component (kg/m^3),

X_i^v = volume fraction of *i* th component,

X_i^w = mass fraction of *i* th component,

n = number of components.

We can write the formula also as follows:

In theory, if the composition of the food is known, the density ρ_f can be estimated from

- $$\rho_f = \frac{1}{m_1/\rho_1 + m_2/\rho_2 + m_3/\rho_3 \ldots m_n/\rho_n}$$

where

ρ_f = the density of the food,

m_1, to m_n = the mass fractions of constituents 1 to n and

ρ_1, to ρ_n = the densities of constituents 1 to n (n is the number of constituents).

The most commonly used definitions:

- ***Solid density (ρ_s)*** is the density of the solid material (including water), excluding any interior pores that are filled with air. It can be calculated by dividing the sample weight by solid volume determined by the gas displacement method in which gas is capable of penetrating all open pores up to the diameter of the gas molecule.
- ***Material (substance) density (ρ_m)*** is the density of a material measured when the material has been broken into pieces small enough to be sure that no closed pores remain.
- ***Particle density (ρ_p)*** is the density of a particle that has not been structurally modified. It includes the volume of all closed pores but not the externally connected ones. It can be calculated by dividing the sample weight by particle volume determined by a gas pycnometer.
- ***Apparent density (ρ_{app})*** is the density of a substance including all pores within the material (internal pores). Apparent density of regular geometries can be determined from the volume calculated using the characteristic dimensions and mass measured. Apparent density of irregularly shaped samples may be determined by solid or liquid displacement methods.

The most commonly used definitions:

- ***Bulk density (ρ_{bulk})*** is the density of a material when packed or stacked in bulk.
- Bulk density of particulate solids is measured by allowing the sample to pour into a container of known dimensions.
- Special care should be taken since the method of filling and the container dimensions can affect the measurement.
- It depends on the solid density, geometry, size, surface properties, and the method of measurement. It can be calculated by dividing the sample weight by bulk volume.
- When mixing, transporting, storing and packaging particulate matter, e.g. peas and flour, it is important to know the properties of the bulk material.
- When such solids are poured into a container, the total volume occupied will contain a substantial proportion of air.

Bulk density

- The porosity ε of the packed material is that fraction of the total volume which is occupied by the air, i.e.

$$\varepsilon = \frac{volume\ of\ air}{total\ volume}$$

- The porosity will be affected by the geometry, size and surface properties of the material. In addition, if this container is tapped, the total volume and hence the porosity will decrease, until eventually the system reaches an equilibrium volume.
- The density of the bulk material under these conditions is generally known as the bulk density.

Bulk densities of a variety of powders

Food	Bulk density Kg/m^3	Food	Bulk density Kg/m^3
Oat	513	Milk powder	610
Wheat	785	Salt (granulated)	960
Flour	449	Sugar (granulated)	800
Cocoa	480	Sugar (powdered)	480
Coffee (instant)	330	Wheat flour	480
Coffe (ground and roasted)	330	Yeast (bakers)	520
Corn starch	560	Egg (whole)	340

Bulk densities of some fruit and vegetables

Fruit or vegetable	Bulk density (kg/ m^3)
Apple	544-608
Carror	640
Grape	368
Lemon	768
Orange	768
Peach	608
Onion	640-736
Tomatoes	672

Moisture contents, solid densities and bulk densities of different cereals

Grain	Moisture (%)	Solid density, (kg/ m^3)	Bulk density (kg/ m^3)
Barley	7.5-8.2	1374-1415	565-650
Oat	8.5-8.8	1350-1378	358-511
Rice	8.6-9.2	1358-1386	561-591
Wheat	6.2-8.5	1409-1430	790-819

The solid or particle density will refer to the density of an individual unit. This unit may or may not contain internal pores. The solid density is defined as the mass of particles divided by the volume of particles and will take into account the presence of such pores.

The densities of solid constituents, disregarding any internal pores, are shown in Table.

Densities of solid constituents

Constituent	Density (kg/m^3)	Constituent	Density (kg/m^3)
Glucose	1560	Fat	900-950
Sucrose	1590	Salt	2160
Starch	1500	Citric acid	1540
Cellulose	1270-1610	Water	1000
Protein	1400		

Example 1

An apple contains 84.4% moisture, 14.55% sugar, 0.6% fat and 0.2% protein (densities are in kg/m^3; see Table)

- Solution:

Moisture contents, solid and bulk densities of some grains

Grain	moisture,%	Solid density, Kg/ m^3	Bulk density, Kg/ m^3
Barley	7.5-8.2	1374-1415	565-650
Oat	8.5-8.8	1350-1378	358-511
Rice	8.6-9.2	1358-1386	561-591
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Density-temperature relationship

- The densities of water and other substances change with temperature.
- As the temperature increases, the density decreases, and as the temperature decreases, the density increases.

E.g;

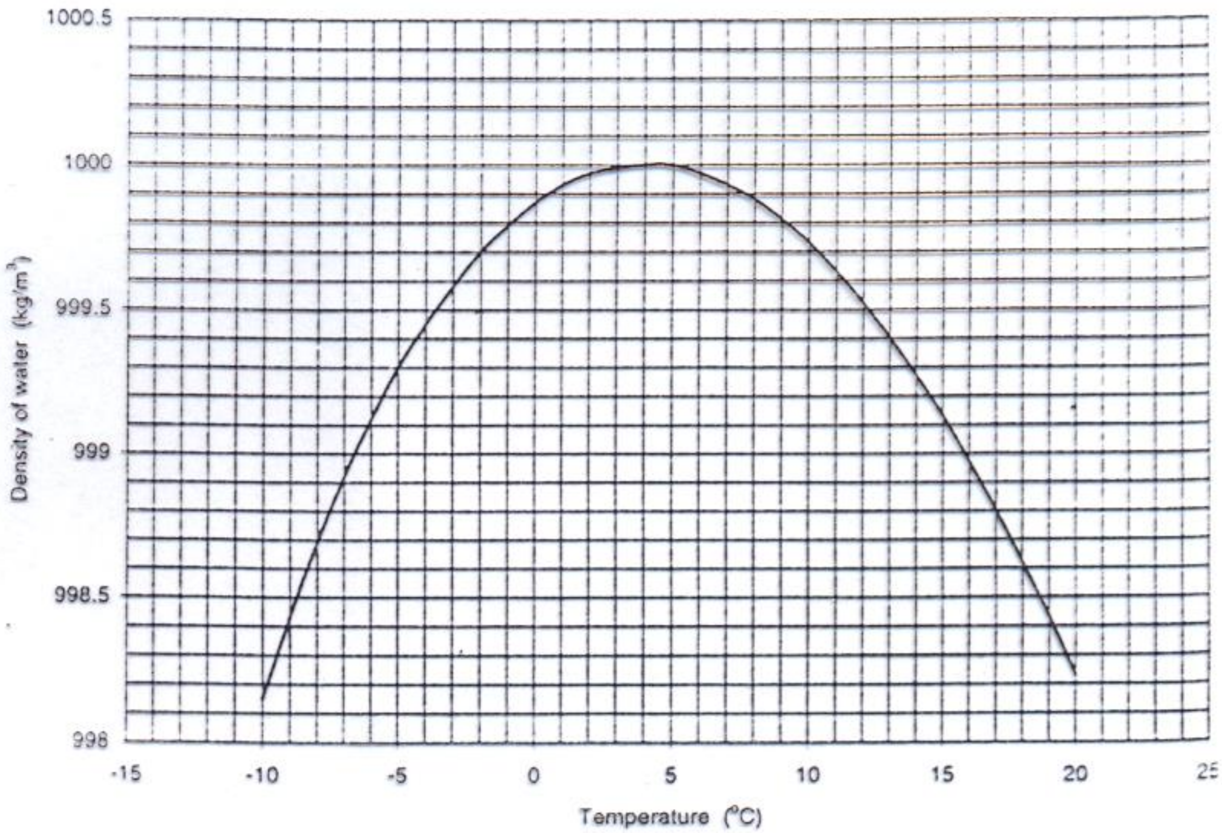
- Density of water at 20^{o}C 998.2 kg/ m^3
- The density of water at 0^{o}C is 999.8 kg/ m^3
- When water turns into ice at 0^{o}C, its density decreases to 916.8 kg/ m^3.

- Oil, which are viscous at normal temperatures, density decreases when heated.

- Density of sunflower oil, 916 kg/ m^3 at 20^{o}C
- When sunflower oil is heated to 80^{o}C, its density decreases to 876

kg/ m^3.

The density of water at 4^oC is 1000 kg/m^3.



- Water reaches its maximum density at 4^{o}C and is 1000 kg/ m^3.
- As the temperature rises above 4^{o}C, the density decreases.
- Adding solids to water (except oils) increases their density.

Effect of temperature on the densities of some liquids (kg/m^3)

Temperature °C	Water	Ethyl alcohol	Corn oil	Sunflower oil	Sesame oil	Soy oil	Palm oil
-20	993.5		947	944	946	947	949
-10	998.1		940	937	939	941	942
0	999.1	806.3	933	930	932	934	935
4	1000	802.9					
10	999.7	792.9	927	923	925	927	928
20	998.2	789.5	920	916	918	920	921
40	992.2		906	903	905	907	908
60	983.2		893	899	891	893	894
80	971.8		879	876	878	879	881

Equations developed by taking into account the effect of temperature in calculating the densities of components in foods:

- The density of food materials depends on temperature and the temperature dependence of densities of major food components [pure water, carbohydrate (CHO), protein, fat, ash and ice] has been presented by Choi and Okos (1986) as follows:

$\rho_{water} = 997.18 + 0.0031439\ T - 0.0037574\ T^2$

$\rho_{protein} = 1329.9 - 0.5184\ T$

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

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

$\rho_{cellulose} = 1311.5 - 0.36589\ T$

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

$\rho_{ice} = 916.89 - 0.13071\ T$

where densities (ρ) are in kg/m^3 and temperatures (T) are in ◦C and varies between −40 and 150◦C.

Example 2: Calculate the true density of spinach at 20◦C having the composition given in Table.

Composition of spinach

Component	Composition (%)
Water	91.57
Protein	2.86
Fat	0.35
Carbohydrate	1.72
Ash	3.50

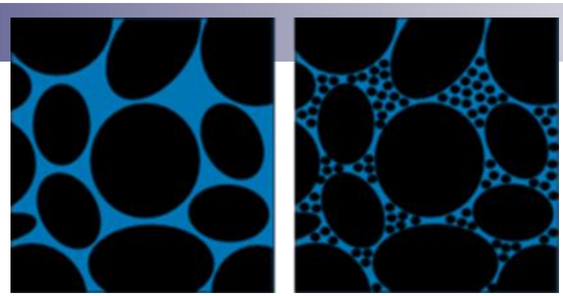
Solution 2:

Example 3:Find the density of the homogenized mixture given below at 20^{o}C.

Component	**Content (g)**	**Density at 20^{o}C (kg/m^{3})**
Salt	2	2160
Starch	20	1500
Sugar	35	1590
Olive oil	15	910
Water	50	998.2

Solution: Homework

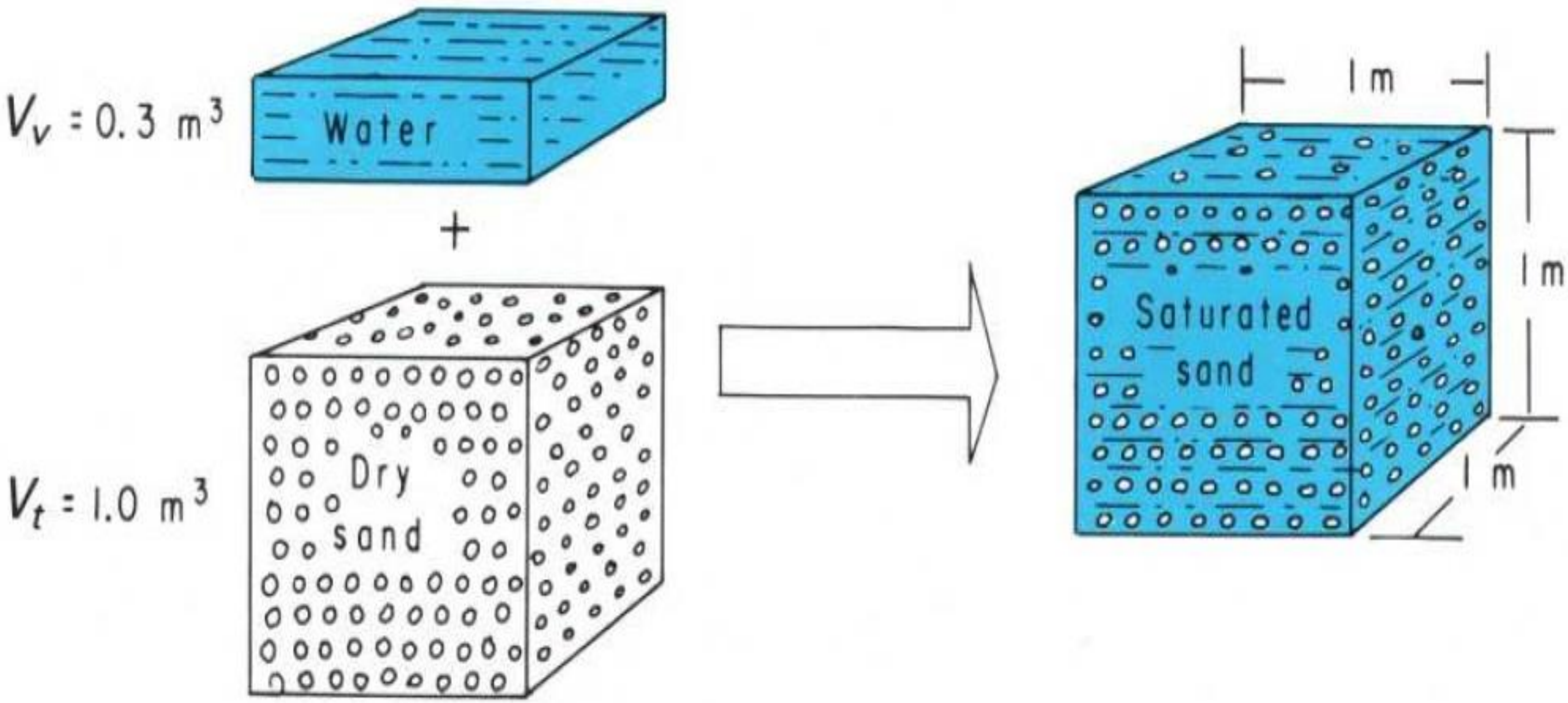
Porosity



- Porosity is an important physical property characterizing the texture and the quality of dry and intermediate moisture foods.
- Porosity data is required in modeling and design of various heat and mass transfer processes such as drying, frying, baking, heating, cooling, and extrusion.
- It 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:

$$Porosity = \frac{void\ volume}{total\ volume}$$

Porosity



$$\text{Porosity} = \frac{\text{Volume of voids } (V_v)}{\text{Total volume } (V_t)} = \frac{0.3\ m^3}{1.0\ m^3} = 0.30$$

Porosity

- Porosity is affected by the geometric shape, size and surface properties of the material.

- The bulk density of a food will decrease when the container in which it is emptied is closed, until the total volume, and thus the porosity, reaches equilibrium.

Relationship between porosity, bulk density and solid density

- Porosity due to the enclosed air space within the particles is named apparent porosity (ε_{app}) and defined as the ratio of total enclosed air space or voids volume to the total volume.
- It can also be named internal porosity. Apparent porosity is calculated from the measured solid (ρs) and apparent density (ρ_{app}) data as:

$$\text{Porosity } (\epsilon_{app}) = \frac{\text{volume of air}}{\text{volume of bulk sample}}$$

$$= \frac{\text{volume of bulk sample- true solid volume}}{\text{volüme of bulk sample}}$$

$$= 1 - \frac{\text{solid volume}}{\text{bulk volume}}$$

Apparent porosity is calculated from the measured solid (ρ_s) and apparent density (ρ_{app}) data as:

- $$\varepsilon_{app} = 1 - \frac{\rho_{app}}{\rho_s}$$

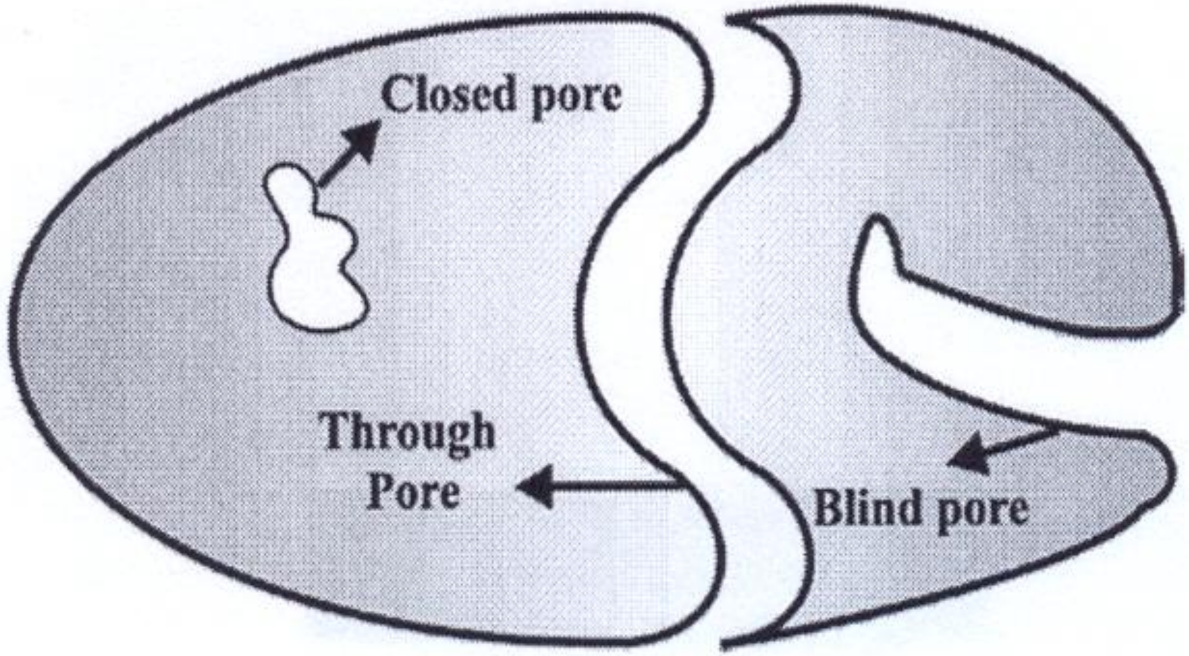
- Bulk porosity (εbulk), which can also be called external or interparticle porosity, includes the void volume outside the boundary of individual particles when stacked as bulk and calculated using bulk and apparent densities as:

$$\varepsilon_{bulk} = 1 - \frac{\rho_{bulk}}{\rho_{app}}$$

Then, total porosity when material is packed or stacked as bulk is:

$$\epsilon_{total} = \epsilon_{app} + \epsilon_{bulk}$$

Different kinds of pores



Example 4. Rice is packed in 20x15x4 cm cardboard boxes for marketing. When the box is filled, it holds 900 g of rice. According to this;

a) Calculate the bulk density of rice in g/mL.

b) If the porosity of rice is 0.15, determine its apparent density as kg/m^3

Solution:

Example 5. The porosity of granular salt is 0.41. The manufacturer wants to pack 340 g of salt into 250 mL glass jars. Can the manufacturer do this?

Apparent density of salt is 2.16 g/mL

Solution:

Liquid density and specific gravity

- Water has its maximum density of l000 kg/ m^3 at 4^oC. As the temperature increases above 4^oC, the density will decrease.The addition of all solids, with the exception of fat, to water will increase its density.
- Density measurement can be used for pure substance as an indication of total solids.
- However, it is often more convenient to measure the specific gravity SG of a liquid, where:

$$SG = \frac{\text{mass of liquid } (m)}{\text{mass of equal volüme of water } (m_1)} = \frac{\text{density of } \rho_L \text{ of liquid}}{\text{density } \rho_w \text{ of water}} = \frac{m/V}{m_1/V_1}$$

Specific gravity

- Note that this can also be used for solids as well as liquids.
- Specific gravity is dimensionless. The specific gravity of a fluid changes less than the density, as temperature changes.
- For example, maize oil has densities of 927 kg/m^3 and 893 kg/m^3 at 10^oC and 60 ^{o} C, respectively.
- However, the specific gravity only decreases from 0.927 to 0.908. When specific gravities are quoted, it is normally at a particular temperature.
- If the specific gravity of a material is known at a temperature T ^{o} C, its density at T ^{o} C will be given by

$$\rho_L = (SG)_T \times \rho_w$$

where

ρ_L = the density of liquid at T^{o}C,

(SG) = the specific gravity at T^{o}C

ρ_w = the density of water at T^{o}C (obtained from tables).