Chapter 2

PROPERTIES OF MILK

(Important constituents of milk, Important properties of milk, Why these properties are important for us, Selection of metals for dairy industry)

IMPORTANT CONSTITUENTS OF MILK

The different constituents of milk can be shown as in Fig. 2.1

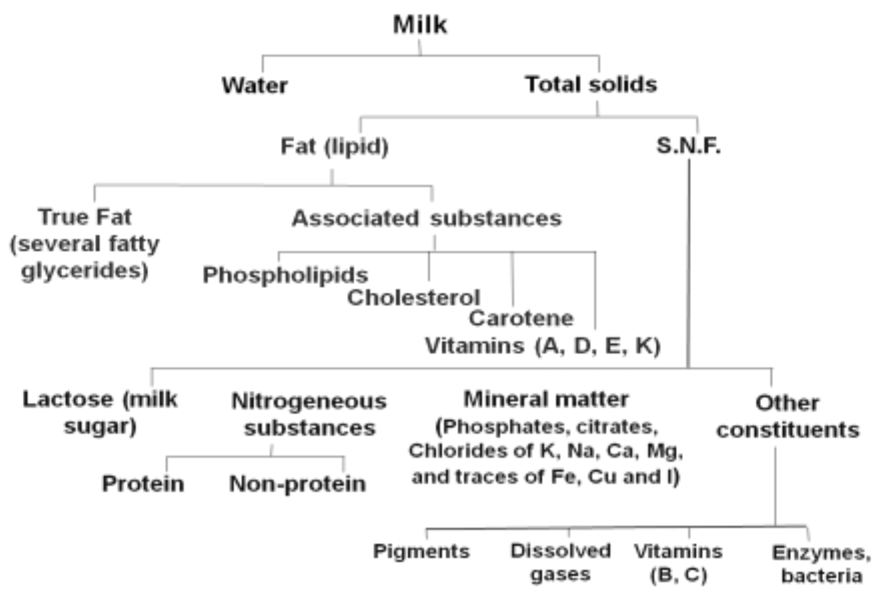

Fig. 2.1 Constituents of milk

Remember…….

- Milk contains all essential amino acids in fairly large quantities.
- It is an excellent source of Ca and P, both of which together with vit D are essential for bone formation.
- It is a good source of vit A (provided the cow is given sufficient green feed and fodder), vit D (provided the cow is exposed to enough sunlight), thiamine, riboflavin, etc. But milk is deficient in vit C.
- Milk fat, besides giving energy contains significant amount of essential fatty acids (linoleic and arachidonic), which give the characteristic flavor.
- Lactose (carbohydrate) provides energy. It also helps to establish a mild acidic reaction in the intestine (which checks the growth of proteolytic bacteria and facilitates assimilation).

The composition of milk varies with many factors, the most important of them being the species and breed of the animal. Table 2.1 gives an idea of the variations in major constituents of milk.

Table 2.1 Variation in major constituents of different milk

Source of Milk	Water	Fat	Protein	Lactose	Ash
Buffalo	84.2	6.6	3.9	5.2	0.8
Camel	86.5	3.1	4.0	5.6	0.8
Cow (Indian)	86.07	4.9	3.42	4.91	0.7
Cow (Foreign)	86.6	4.6	3.4	4.9	0.7
Goat	86.5	4.5	3.5	4.7	0.8
Human	87.7	3.6	1.8	6.8	0.1
Skim milk	90.6	0.1	3.6	5.0	0.7
Butter milk	91.0	0.4	3.4	4.5	0.7

Factors affecting composition of milk

- Species
- Breed: In general breeds giving more amount of milk yield a lower percentage of fat.
- Individuality
- Interval of milking (Longer interval implies more milk with a lower fat test).
- Completeness of milking: If the cow is completely milked the test is normal, or else, the test is lower.
- Irregularity of milking
- Disease and abnormal conditions
- Portion of milking: Fore-milk is low in fat content (less than 1%), while strippings are the highest close to 10%. Other milk constituents are slightly affected on a fat free basis.
- Stage of lactation: The change from colostrum to milk takes place within few days.
- Yield: For a single cow, there is a tendency for increased yields to be accompanied by a lower fat percentage and vice versa.
- Feeding: Has temporary effects.
- Season: The percentage of both fat and solids-not-fat (SNF) show slight but well defined variations during the course of year.
- Age: The fat per cent in milk declines slightly as the cow grows older.

- Condition of cow at calving: A cow would yield milk with higher fat per cent if it is healthy.
- Excitement
- Administration of drugs and hormones

There may also be variations in composition of milk obtained from a specific animal in day to day milking.

Energy values of different milk constituents

As mentioned above, the milk is a rich source of energy. The energy values of different milk constituents are as follows.

- Milk fat : 9.3 Cal/g,
- Milk protein : 4.1 Cal/g,
- Milk sugar : 4.1 Cal/g

Thus, with the available constituents, 100 g of cow milk usually gives 75 Cal and that of buffalo milk gives 100 Cal.

What is colostrum

During approximately the first three days of lactation, the buffalo/ cow secretes colostrum. This is very vital for the newborn calf and its composition reflects the calf's need. Colostrum contains the important proteins; the immuno-globulins, which are the newborn calf's source of antibodies. The content of iron and copper is markedly higher in the colostrum as compared to normal milk.

The average composition of colostrum is as follows.

Water: 73%	Fat: 9.55%
Total Protein: 9.59%	Lactose: 7.54%
Vitamin A: 1.8µg/kg	

Changes of milk due to boiling

When the milk is boiled there are several changes in it due to the presence of different constituents. These changes are mainly in the following form.

- Decrease in the percentage of cream
- Decrease in curd tension
- Decomposition of proteins
- Destruction of enzymes
- Darkening of the color of milk
- Coagulation of albumin and formation of a scum on the surface
- Acquiring a cooked taste
- Precipitation of Ca and Mg salts

- Breaking up of fat globules
- There may be stone formation in milk during heating.

Stone formation in milk

If the milk being processed has had no previous heat treatment, there are two types of deposits on the heat exchanger/ container surface. This is known as stone formation in milk or fouling.

1. <u>Fouling at low temperatures</u>
   - The soft, voluminous, curd-like material, which starts to form when the temperature exceeds about 75°C.
   - It is at its maximum in the temperature range 95-110°C, and then reduces in amount at higher temperature.
   - This type of deposit restricts the flow passages area and causes increase in the operating pressure.
   - It has high protein content (50-70%), and a lower mineral content (30-40%).

<u>2.Fouling at high temperatures</u>

- Deposits formed at higher temperatures
- Increases in quantity up to the highest temperature reached in the heat exchanger.
- Hard and granular in structure containing mineral (70-80%) and protein (10-20%).
- This deposit interferes more with heat transfer than with flow, and hence to reach the required processing temperature, the temperature of the heating medium has to be increased to an undesirable extent.

Both types (1 & 2) of deposit contain negligible amount of fat (about 5%), and protein and minerals are the main constituents. The amount of fouling depends greatly on the pH of raw milk. As the pH falls below about 6.5, a large amount of deposit is formed. Milk with high contents of β-casein are more prone to deposit formation. but the addition of pyrophosphates to milk brings about a significant improvement.

IMPORTANT PROPERTIES OF MILK

The knowledge of different properties of milk and milk products are required to design the processing and storage structures for milk. The important properties are discussed below.

Density and specific gravity

The knowledge of density is important to

- monitor changes during processing
- check adulteration
- separate the different constituents of milk (by methods such as centrifugation, cyclone separation, etc.)

- transport liquid milk as well as processed milk products (by different methods as pneumatic/ hydraulic transportation, etc.)
- design and develop storage structures for milk and milk products

The density and specific gravity of milk is usually given at 15.6°C (60° F). (The specific gravity of water is usually expressed at 4°C).

The specific gravity of some major milk constituents are: water: 1.00; fat: 0.93, protein: 1.346, lactose: 1.666, salts: 4.23, and SNF: 1.616. As we have already discussed that the milks obtained from different animals vary in composition, the densities will also vary.)

The density of milk of different animals are given below.

- Cow milk : 1.028-1.03
- Buffalo milk : 1.03-1.032
- Skim milk : 1.035-1.037
- Milk powder (bulk density) : 0.83

  (Milk powder has a porosity of 43-51%)

Though the buffalo milk contains higher fat, still due to higher SNF, the specific gravity is more than cow milk.

Determination of specific gravity of milk by Lactometer

Fig. 2.2 A lactometer immersed in a cylinder

- A lactometer (or galactometer) is a hydrometer used to test milk.
- The specific gravity of milk does not give a conclusive indication of its composition since milk contains a variety of substances that are either heavier or lighter than water. Additional tests for fat content are necessary to determine overall composition.

- The specific gravity of milk should not be determined for at least one hour after it is drawn from the animal, or else, a lower than normal value will be obtained.
- Quevenne is an arbitrary scale used with hydrometers or lactometers in the determination of the specific gravity of milk. degrees Quevenne = 1000 (specific gravity - 1).
- The specific gravity of milk is calculated by dividing the Quevenne's degree by 1,000 and adding 1. i.e. if the Quevenne reading is 31, then

specific gravity = (31/1000)+1= 1.0031

Correction for temperature

The lactometers are normally standardized at a particular temperature (say (60°F or 15.6° C). If the temperature is above or below the standard temperature of 60°F, the lactometer reading should be corrected by adding 0.1 to the lactometer reading or 0.0001 to the specific gravity for each °F above 60°F and vice versa for lower temperatures.

Example: If the meter reading becomes 31.0 at 66^{o}F, what is the specific gravity of milk?

Solution:

The corrected lactometer reading is 31.0+0.6= or 31.6

Specific gravity: 1+31.6/1000 = 1.0316

In another method, the instrument is graduated into a hundred parts. Milk is poured in and allowed to stand until cream has formed. The depth of the cream deposit in degrees determines the quality of the milk.

Another instrument, invented by Doeffel, is two inches long, divided into 40 parts, beginning at the point to which it sinks when placed in water.

Some other types of hydrometers

- Alcoholometer : to measure alcoholic strength of liquids
- Saccharometer : to measure amount of sugar in a solution
- Thermohydrometer : that has a thermometer enclosed in the float section
- Barkometer : to measure strength of tanning liquors used in tanning leather
- Battery hydrometer : charge of a lead-acid battery can be estimated from the density of the sulfuric acid solution used as electrolyte.
- Antifreeze tester : to test the quality of the antifreeze solution used for engine cooling.

Total solids and total SNF

The total solids and solids not fat (SNF) are determined as follows (The method is known as Gerber method).

Percentage total solids = 0.25 D +1.22 F+0.72

Percentage SNF = 0.25 D +0.22 F+0.72,

In the above equations, D=1000(d-1), where d= specific gravity of sample of milk at 20°C, and F is the fat percentage in sample.

Case I: What is the amount of total solids and SNF with a milk having 3% fat and density of milk is 1016 kg/m³ (@20°C).

Solution:

$D = 1000(1.016-1.00)= 16$

Per cent total solids = $0.25(16) +1.22(3)+0.72 = 8.38$

Per cent SNF = $0.25(16) +0.22(3)+0.72 = 5.38$

Freezing point

Due to the dissolved solids in liquid milk and milk products, the freezing points are normally lower than the freezing point of pure water. In fact, more the concentration of solids, more will be the freezing point depression. The freezing points of different types of milk are as given in Table 2.2.

Table 2.2. Freezing points of different types of milk

Type of milk	**Freezing point**
Fresh whole milk	-0.506°C to –0.504°C
Indian cow milk	-0.547°C
Buffalo milk	-0.549°C
Evaporated milk	-1.4°C
Sweetened milk	-15.12°C to –12.04°C

Souring results lowering in freezing point due to increase in the amount of soluble molecules. Hence unsoured samples should be tested for determination of freezing point. Another important point is that the volume of milk is always increased when it is frozen.

The knowledge of freezing point of milk is important as it is employed for detection of adulteration.

Boiling point

As mentioned above, the boiling point of milk is also little higher than that of pure water due to the dissolved solids.

For normal milk at atmospheric pressure, the boiling point is around 100.5°C (100.2-101°C). As a thumb rule, when the concentration is doubled, the boiling point rises by about 0.5°C, and if the concentration is 3:1, the boiling point rise is 0.8°C.

The addition of solids, salts, sugars, acids, etc. raises the boiling point. The boiling point also varies with composition and pressure.

Specific heat

The specific heat of milk varies depending upon the fat content and temperature. The general values are as follows.

Whole milk : 3.89-3.93 kJ/ kg-°K (0.93-0.94 kCal/kg-°K);

Skim milk : 3.97 kJ/kg-°K (0.95 kCal/kg°K)

Thermal conductivity

The thermal conductivity of milk is found out by Lamb's equation, which is as follows:

$$K=0.0801 + 0.568\, M_w$$

Here M_w is the moisture fraction (i.e. expressed in decimals)

Acidity and pH

The milk is acidic and the average natural acidity is as follows.

Cow milk : 0.13 to 0.14% (natural acidity)

Buffalo milk : 0.14 to 0.15%

The developed or real acidity is due to lactic acid formed as a result of bacterial action on lactose on milk. The titrable acidity is the sum of developed and natural acidity.

The pH is another measure of acidity and the pH values of milk are as follows.

Normal fresh sweet cow milk : 6.4-6.6

Buffalo milk : 6.7-6.8

Higher pH value of milk indicates udder infection and the lower value indicates bacterial action.

The acidity and pH of fresh milk varies with species, breed, individuality and stage of lactation and as well on health of animal.

Viscosity

The materials of high viscosity would require a large surface, slow moving type agitator to move them properly. Besides, viscous materials cause a slow moving film on heating and cooling surfaces, and thereby reduce the rate of heat transfer. The pump pressure for forcing the liquid through pipe lines will also increase. Table 2.3 gives the average values of viscosity of milk at different temperatures.

Table 2.3 Viscosity of milk forms (Viscosity in Pa.s)

Type of Milk	Temperature, °C			
	10	20	40	80
Whole milk	2.79	2.12	1.24	0.68
Skim milk	2.44	1.74	1.03	0.53
Whey	1.71	1.26	0.82	0.68

The above table is a representative one and there can be variations. The viscosity of milk also varies according to composition, age and treatment.

The viscosity of milk can increase during processing and storage. In particular, the increase of viscosity is observed during

- Increase in concentration
- Homogenization
- Ageing at low temperature.

The milk and milk forms can be categorized as Newtonian and Non-Newtonian fluids as follows.

Newtonian fluids: **m**ilk, skim milk, cheese, whey permeate, etc.

Non-Newtonian fluids : **s**uspensions, pastes, emulsion, etc.

Surface tension

Surface tension is the force per unit length acting on a length of surface of a body or the work done in increasing its surface area under isothermal conditions. The surface tension forces are responsible for the finely dispersed liquids to form spherical droplets (minimum surface area to volume ratio).

Table 2.4 Surface tension of some commodities

Material	Surface tension, mN/m
Water	72.6
Cow milk	52
Buffalo milk	50.5
Whey	0.68

Color of milk

- The color of milk is a blend of individual effects produced by: (1) colloidal casein particles and dispersed fat globules, both of which scatter light, and (2) carotene (to some extent xanthophylls), which imparts a yellowish tint.
- Thus, the color of milk ranges from yellowish creamy white (cow milk) to creamy white (buffalo milk).
- The intensity of the yellow color of the cow milk depends on the factors such as breed, feed, size of fat globules, fat per cent in the milk, etc.
- Greater intake of green feed results in deeper yellow color of milk.
- Larger the fat globules and higher fat percentage will impart a greater intensity of yellow color.
- Skim milk has a bluish and whey a greenish yellow color.

Refractive index

- The average refractive index of cow milk and buffalo milk at 40°C are as follows.
  - cow milk : 1.3461
  - buffalo Milk : 1.3477
- Total refraction is sum of individual refractions of the constituents present in the solution.
- The measure of refractive index can be used to determine adulteration, especially watering. However, the freezing point is more reliable than refractive index for determination of adulteration.

Flavor

- It is composed of smell (odor) and taste.
- The flavor of milk is a blend of sweet taste of lactose and salty taste of minerals, both of which are damped down by proteins.
- The phospholipids, fatty acids and fat of milk also contribute to the flavor.

Usually the changes in flavor/ abnormal flavor in milk occur due to:

- Type of feed
- Chemical composition as well as chemical changes
- Season
- Stage of lactation
- Condition of udder
- Sanitation and other conditions during milking and subsequent handling of milk, during storage
- Bacterial growth
- Addition of foreign material
- Absorbed materials

Agitation

The agitation of dairy products containing butter fat should be gentle but complete and uniform. Severe agitation causes clumping and churning of butter fat and disturbances in cream formation. Insufficient agitation will cause localized overheating and burning of products. Pressure intensifies the churning effect of agitation.

Expansion of milk

Milk product which have entrapped air in them greatly increase in volume as the temperature rises. The expansion of milk is of practical significance because of its bearing on the capacity of tanks.

Overrun

When air is incorporated into a whipped or frozen product, the density decreases. The amount of entrapped air incorporated is measured as overrun.

$$\text{Overrun} = \frac{\text{Wt of original liq} - \text{Wt of same vol of aerated prod}}{\text{Wt of original liquid}} \text{x100}$$

$$\text{Overrun} = \frac{\text{Increase in volume}}{\text{Original volume}} \text{x100}$$

Overrun of 2-3 times the total solid contents are recommended. Too low overrun yields a heavy product. Too high overrun gives too light and fluffy product.

Foaming of milk

Pure liquids do not foam and the foaming of solution is correlated with the surface activity of the solutes. The following table shows the different types of materials/ constituents forming the foam.

Less Foam	Transient Foam	Persistent foams
Mixtures of liquids of similar chemical type and surface tension Aqueous solutions of highly hydrophilic solutes, e.g. sucrose.	Solutes, which lower the surface tension moderately	Solutes, which lower the surface tension strongly in dilute solution, e.g. proteins.

Effect of Metal on Milk

Milk reacts on certain metals, so that a small amount of the metal is dissolved in it. The metallic salts thus formed may give rise to a "metallic" taste in the milk.

Factors influencing the degree of action by milk on metal

- Temperature of milk
- Period of contact
- Cleanliness and polish of metal
- Amount of free air in milk
- Acidity of milk
- Presence of sugar

Desirable characteristics of metals for dairy equipment

- Non-toxic
- Insoluble (in milk or its products)
- Non-absorbent
- Highly resistant to corrosion
- Good agents of heat transfer
- Easy to clean and keep bright
- Low cost

- Durable
- Light, yet strong

SELECTION ON METALS FOR DAIRY EQUIPMENT

Many types of materials can be used for the milk handling and processing equipment, but the main consideration should be that the metal should not adversely affect the quality of milk. The following points will help in understanding some basic considerations for selection of metals for milk processing equipment.

- Most dairy equipment are made up of 18:8 (18 Cr and 8 Ni) stainless steel (s.s.).
- Copper is used for brines as brine frequently corrodes the 18:8 metal and holes may form.
- A nickel alloy called Inconel (80 Ni, 14 Cr and 6 Fe) is preferred to s.s. in that it can be more readily soldered where soldering is preferred to welding. However, this is not used with brine (salt solution).
- Aluminum also has considerable uses. But it is corroded by ordinary alkaline dairy cleaners and sterilizers. (So plants using aluminum equipments have to use an aluminum cleanser throughout the plant, which is somewhat expensive.)
- Soldering is widely used in fabrication of dairy equipments (½ tin and ½ lead). Welding is used to join s.s. parts.
- Small traces of copper, iron and zinc induce oxidized flavor.
- Iron induces fishy flavor in butter.
- Also the presence of iron metal acts as a catalyzer, which accelerates the rate of oxidation of the butter fat in the milk.
- For freedom from metallic off-flavors, there must be no exposed copper or copper containing alloy. A perfectly tinned surface or some of the s.s. of the same composition are safe.
- Silver, lead and mercury are poisonous.
- Tin is quite soluble in milk, but luckily it does not cause off flavors. It can be removed by refining.
- Aluminum is moderately soluble, but does not affect flavor materially. It can be easily repaired.
- Corrosion passivity of metals are also required.

CHECK YOUR PROGRESS

1. What are the important properties of milk, which affect the processing?
2. How the density and viscosity of milk affect the milk processing operations?
3. What are the factors that affect the flavor and color of milk ?
4. Why the freezing temperature of the milk is slightly lower than water ?
5. Why the boiling temperature of the milk is slightly higher than that of water ?
6. Name the desirable characteristics of metals to be used in milk processing equipment.
7. Explain the working principle of a lactometer ?