PHSICAL AND CHEMICAL PROPERTIES OF MILK

1. Introduction

The dictionary defines milk as a whitish liquid consisting of milk proteins, fats, lactose and various vitamins and minerals that has been produced by the adult female mammals after childbirth by stimulation of their mammary glands. This milk serves as food for their young.

Milk is also defined as a complex colloidal dispersion having fat globules, casein and whey proteins in an aqueous suspension consisting of lactose, minerals and vitamins and minerals. Milk is an emulsion or colloid of butterfat globules within a water-based fluid that contains dissolved carbohydrates and protein aggregates with minerals. Because it is produced as a food source for the young, all of its contents provide benefits for the growth. The principal requirements are energy which is obtained from the lipids, lactose and protein present in milk. Biosynthesis of amino acids which is supplied by proteins (essential amino acids and amino groups), essential fatty acids, vitamins and other inorganic elements also supply energy.

The physical and chemical properties of milk depend the intrinsic compositional factors. Also contributing extrinsic factors such as temperature and post-milking treatments. Assessment of some of the physico-chemical properties of milk is used as a parameter to know the quality of milk.

2. Physical properties of milk

Data on the physical properties of milk (such as thermal conductivity or viscosity) serve as parameters that can be used to design dairy processing equipments. Some physical properties such as freezing point and specific gravity can be used to determine the concentration of specific components in milk or in the estimation of solids-not-fat. Assessment of the extent of biochemical changes happening in milk during processing can be known by extent of acidification by starter or the development of a rennet coagulum.

3. Important physical properties of milk have been described in detail below:

1. Density

The density of a substance is its mass per unit volume. The density of bulk milk (4% fat and 8.95% solids-not-fat) at 20^0c is approximately 1,030 kg m^{-3}. Milk fat has a density of approximately 902 kg m^{-3} at 40^0c. The storage conditions of the milk sample greatly influence its density. The density is also dependant on the liquid to solid fat ratio and the degree of hydration of proteins. In order to minimize the effect of thermal history on the density, milk is usually pre-warmed to $40\text{-}45^0$c which liquefies the milk fat and then cooled to the temperature at which the assay is carried out which is usually 20^0c.

The density of milk and milk products is used to convert volume into mass and vice versa and to estimate the content of solids present in milk. It is also used to calculate other physical properties such as kinematic viscosity.

Density is calculated by dividing the mass of a certain quantity of a material by its volume. Density is dependent on the temperature at the time of measurement, temperature history of the material, composition of the material (especially the fat content) and inclusion of air.

2. **Specific gravity**

Specific gravity or relative density is the ratio of the density of the substance to that of water at a specified temperature. The thermal expansion coefficient is the factor which governs the influence of temperature on density and hence it becomes necessary to specify temperature while elaborating on density or specific gravity. The density and specific gravity of milk tend to vary with the breed of cow or buffalo. For instance, milk from Ayrshire cows has a mean specific gravity of 1.0317 while that of Jersey and Holestein milk is 1.0330.

3. **Appearance**

The opacity of milk is due to the presence of suspended particles such as fat, proteins and minerals. The color of milk tends to vary from white to yellow depending on the carotene content of the fat. Skim milk is visibly much more transparent and has a slightly bluish color.

4. **Freezing point**

The freezing point of milk is lower than the freezing point of water because of the dissolved components present in milk. Determination of the freezing point of milk is used as a legal standard to determine if milk has been diluted with water. It can also be used to determine the lactose content in milk, estimate the whey powder contents in skim milk powder and to determine the water activity of cheese. The freezing point of milk is -0.552^{0}c or 31^{0}F.

Correct interpretation of the freezing point of milk with respect to the added water content depends on a good understanding of the factors affecting freezing point depression. With respect to interpretation of freezing points for added water determination, the most significant variables are the nutritional status of the herd and water access. Under-feeding causes increased freezing point. Large temporary increase in freezing point occur after consumption of large amounts of water as the milk is iso-osmotic with blood.

5. **Viscosity**

Viscosity is a measure of thickness of milk. Determination of viscosity of milk and milk products is important to know the rate of creaming, the rate of mass and heat transfer, the flow conditions in dairy process.

Milk and skim milk exhibit Newtonian behavior, in which the viscosity is independent of the rate of shear. The viscosity of these products depend on the temperature. A cooler temperature increases the viscosity due the increase in volume of casein micells. Temperature above 65^0c increases viscosity owing to the denaturation of whey proteins. Also, an increase or decrease in pH of milk is also capable of causing an increase in casein micelle voluminosity.

Cooled raw milk and cream exhibit non-Newtonian behavior. In this case, viscosity is dependant on the shear rate. Partial coalescence of fat globule might be caused due to agitation which increases the viscosity. Fat globules that have undergone cold agglutination may get dispersed due to agitation, causing a decrease in viscosity.

6. Surface and Interfacial tension

In the interface between liquid and air, the behavior of molecules of the liquid is different from that of similar molecules in the bulk phase. Molecules in the bulk phase are subjected to attractive forces equally in all directions by other molecules of the liquid whereas molecules at the surface or interface experience a net attractive force directed towards the bulk phase. The forces that cause a decrease in the surface or interfacial area are referred to as surface tension or interfacial tension. The presence of surface-active agents i.e. surfactants, influences the surface tension of water.

The surface tension of milk is a fundamental physical property that relates to the stability of foams, emulsions and films. The surface tension affects fractionation, concentration and drying process. Casein micells, phospholipids, whey proteins and fatty acids are the surface-active components present in milk. These surfactants can readily absorb at an air-water interface and reduce surface tension. Salts and lactose do not contribute to surface tension. Surface tension of milk can be determined by increase in the height of liquid in a capillary, the weight or volume of drops formed when a given amount of liquid is allowed to flow from a capillary tip, the pressure required to force a bubble of gas through a nozzle immersed in the liquid and the force required to pull a ring or plate free from the surface of a liquid.

7. Optical properties: Light absorption and scattering

Milk is a complex colloidal dispersion of fat globules, casein micells and whey proteins in an aqueous solution of lactose, salts and other compounds. Because of this, milk not only absorbs light at several wavelengths but also scatters light because of the presence of large particles such as casein micells and fat globules.

8. Refractive index

The refractive index of a transparent material is defined as the ratio of the velocity of light in air to the velocity of light in the medium. When a ray of light passes at an angle through the interface between two transparent media of different densities, an abrupt change in direction, i.e. refraction of the ray of light is observed.

The refractive index of bovine milk is in the range of 1.3440 – 1.3485. The refractive index of water at 20^0c is 1.3330. The difference between the values in the refractive index of water and milk is due to the presence of dissolved substances such as minerals, lactose, whey proteins and casein micells in milk. Presence of large colloidal substances such as fat globules and air bubbles do not contribute to the refractive index of milk.

9. Rheology

When milk is concentrated by procedures such as heat evaporation, ultrafiltration of reverse osmosis, the density increases. This is because of the effect per se and the particle-particle interactions increase due to the smaller inter-particle distance. These interactions lead to aggregate formation. The effects on rheological behavior of aggregate formation are essentially the same as the effects of concentrating only the fat globules, as in the case of cream.

Rheological properties can be measured with a wide range of viscometers and rheometers, varying in sophistication and versatility. Many equipments available now are equipped with computerized control, data acquisition and data analysis which allows for the rapid and accurate measurement of rheological properties.

10. Specific heat capacity and Enthalpy

The specific heat capacity of a material is defined as the quantity of thermal energy required to raise the temperature of unit mass of the material by 1^0c. The apparent specific heat capacity of milk fat is markedly temperature dependant at temperatures > 40^0c because of latent heat of fusion effects. A maximum is exhibited between the range of 15 – 20^0c. The precise shape of the apparent specific heat-capacity temperature curve depends on the milk fat solid-liquid ration that existed at each temperature during measurement.

4. Chemical properties of milk

1. Titratable Acidity

Titratable acidity is a measure of the buffering of milk between pH 6.6 and 8.3 (which is the phenolphthalein end point). The titratable acidity is mainly due to the presence of phosphates, proteins, citrate and carbon-di-oxide in milk.

Titratable acidity is determined mainly for two reasons:

- To check the freshness of milk and milk products
- To control the manufacture of fermented dairy products

Titratable acidity serves as a quality index owing to its simplicity and speed of measurement. The titratable acidity of milk is usually expressed in terms of percentage lactic acid. The acidity of milk and milk products is usually determined by titration with sodium hydroxide (NaOH) to the phenolphthalein end point (pH 8.3).

If a high initial acidity in milk is observed in the absence of formation of lactic acid, it is indicative of that milk being rich in proteins and other inherent buffering components. The titrable acidity of fresh bulk milk is between the range of 0.14 to 0.16%. The titratable acidity of milk varies slightly with different breeds of cows. The liberation of fatty acid from milk fat by the action of the enzyme lipase can result in some acidity being developed in cream and high-fat dairy products.

Titratable acidity can also be explained as the amount of alkali required to bring the pH to neutrality. This property of milk is used to determine bacterial growth during fermentations, such as cheese and yogurt making, as well as compliance with cleanliness standards. Naturally, there is no lactic acid in fresh bovine milk, however, lactic acid can be produced by bacterial contamination, but this is uncommon. The titratable acidity is due to the casein and phosphates.

2. **pH or Acid-base equilibria**

It is an indicator of the acidity of milk. The pH of bovine milk at 25^0c is between 6.5 and 6.7. Compositional variations are mainly responsible for the differences in pH and buffering between individual lots of fresh milk. The pH of colustrum is lower, which is about 6.0 and that of mastitic milk or end-of-lactation milk is higher at 7.5. This is higher than the pH of mid-lactation milk.

Milk consists of many acid and base groups which result in buffering action over a wide pH range. The important buffering components in milk are soluble phosphate, colloidal calcium phosphate, citrate, bicarbonate and casein. Quantitative evaluation of the buffering ability of each of these individual component is difficult. Three approaches have been used in attempts to account for the buffering activity of milk in terms of the properties of its constituents: calculation, titration of artificial mixtures and fractionation.

It has been estimated that the contribution of casein, whey protein and milk salts to the buffering of skim milk is 36.0, 5.4 and 58.6% respectively.

Calculation from titration curves depends on the method used such as the forward and back-titration curves of milk. In this case the titration curve does not coincide. For example, when milk is acidified, maximum buffering occurs at approximately pH 5.1 but when acidified milk is back-titrated with base, there is low buffering at pH 5.1 and maximum buffering at pH 6.3.

The pH and buffering properties of milk are also influenced by a number of compositional and processing factors, including temperature, pH, heat treatment, concentration, presence of carbon-di-oxide and concentrations of proteins and salts.

Speed of titration, mainly attributed to the precipitation of calcium phosphate which causes the release of H^+ affects the titratable acidity of milk. This is because there is a decrease in pH owing to the release of H^+. This phenomenon is described as 'fading of phenolphthalein end-point'.

The pH of milk is higher, or more alkaline, outside of the cow than inside the cow due to loss of carbon dioxide to the air. The pH of milk is never determined immediately after milking because the processing milk goes through removes dissolved gasses. The pH is determined after processing the milk to assure that lactic acid is being produced at the desired rate by added microorganisms during the preparation of cheeses and fermented milk. The casein in milk forms into a curd or a gel at a pH of 4.6.

3. Dielectric property of milk

The dielectric property of a material is its permittivity and the dielectric loss factor are the real and imaginary parts, respectively, of the complex permittivity.

This property is frequency dependant. Dielectric property is a measure of the material to store electromagnetic energy. It is a measure of the material's ability to dissipate electromagnetic energy as heat. The measurement of dielectric property spectra could be useful to know the gross composition of large quantities of milk in real time.

4. Oxidation – Reduction Equilibria

Oxidation is defined as the loss of electrons by a substance while reduction is defined as gain of electrons. The major components of milk other than water, i.e. fat, lactose and protein do not have any effect on its redox potential. The redox system in milk is due to lactate-pyruvate, ascorbate and riboflavin.

The content of ascorbic acid in fresh milk is about 11.2 to 17.3 mg/l. As milk is drawn from the udder, all ascorbate is in the reduced form, but reversible oxidation to dehydroascorbate occurs at a rate which is dependent on the temperature and concentration of copper, iron and oxygen.

The redox potential of milk is strongly influenced by heat treatment, bacterial activity, contamination with metal ions such as copper, concentration of oxygen and exposure to light. The redox potential of milk decreases on heating because of the liberation of active sulphydryl group of β-lactoglobulin, which is oxidized by atmospheric oxygen. High-temperature short-time heating of milk results in lowered redox values because of the les oxidation of ascorbic acid and greater retention of disulphide-reducing substances in milk. The removal of oxygen before heating also lowers the redox value. Bacterial activity also brings down the redox potential because of the consumption of the available oxygen for bacterial metabolism. Also, contamination of milk with metal ions such as Copper or Iron increases the redox value.Addition of dyes such as Methylene blue serves as a good indicator to identify the decrease or increase in redox potential. These dyes get reduced to colourless forms with time as the bacteria grow and metabolize in milk. Such changes in colour can be used as an index of microbial contamination and form the basis of the methylene blue and resazurin reduction tests for the bacterial quality of milk.

Summary

Here is a brief summary of our learning in this session, wherein we understood in detail about the milk and the physical and chemical properties of milk.

Milk is defined as a complex colloidal dispersion having fat globules, casein and whey proteins in an aqueous suspension consisting of lactose, minerals and vitamins and minerals. Milk is an emulsion or colloid of butterfat globules within a water-based fluid that contains dissolved carbohydrates and protein aggregates with minerals. Because it is produced as a food source for the young, all of its contents provide benefits for the growth. The principal requirements are energy which is obtained from the lipids, lactose and protein present in milk. Biosynthesis of amino acids which is supplied by proteins (essential amino acids and amino groups), essential fatty acids, vitamins and other inorganic elements also supply energy.

The physical and chemical properties of milk depend the intrinsic compositional factors. Also contributing extrinsic factors such as temperature and post-milking treatments. Assessment of some of the physico-chemical properties of milk is used as a parameter to know the quality of milk.

We discussed about the various physical properties such as viscosity, density, surface tension, refractive index etc. Also, we studied the chemical properties such as pH or acid-base equilibria, isoelectric point, titrable acidity etc.

We also understood the definitions, property and applications of the physical and chemical properties of milk.