LECTURE 1

Milk

Milk is defined as the secretion of the mammary glands of mammals, its primary natural function being nutrition of the young. Milk of some animals, especially cows, buffaloes, goats and sheep, is also used for human consumption, either as such or in the form of a range of dairy products. In this book, the word milk will be used for the ‘normal’ milk of healthy cows, unless stated otherwise. Occasionally, a comparison will be made with human milk.

COMPOSITION AND STRUCTURE

PRINCIPAL COMPONENTS
The principal chemical components or groups of chemical components are those present in the largest quantities. Of course, the quantity (in grams) is not paramount in all respects. For example, vitamins are important with respect to nutritive value; enzymes are catalysts of reactions; and some minor components contribute markedly to the taste of milk.

Lactose or milk sugar is the distinctive carbohydrate of milk. It is a disaccharide composed of glucose and galactose. Lactose is a reducing sugar. The fat is largely made up of triglycerides, constituting a very complicated mixture. The component fatty acids vary widely in chain length (2 to 20 carbon atoms) and in saturation (0 to 4 double bonds). Other lipids that are present include phospholipids, cholesterol, free fatty acids, monoglycerides, and diglycerides. About four fifths of the protein consists of casein, actually a mixture of four proteins: a S1 - , a - , β - , and κ-casein. The caseins are typical for milk and have some rather specific properties: They are to some extent phosphorylated and have little or no secondary structure. The remainder consists, for the most part, of the milk serum proteins, the main one being β-lactoglobulin. Moreover, milk contains numerous minor proteins, including a wide range of enzymes.

The mineral substances — primarily K, Na, Ca, Mg, Cl, and phosphate — are not equi-valent to the salts. Milk contains numerous other elements in trace quantities. The salts are only partly ionized. The organic acids occur largely as ions or as salts; citrate is the principle one.

Furthermore, milk has many miscellaneous components, often in trace amounts. The total content of all substances except water is called the content of dry matter. Furthermore, one distinguishes solids-not-fat and the content of fat in the dry matter. The chemical composition of milk largely determines its nutritional value; the extent to which microorganisms can grow in it; its flavor; and the chemical reactions that can occur in milk. The latter include reactions that cause off-flavours.

MILK FORMATION
Milk components are for the most part formed in the mammary gland (the udder) of a cow, from precursors that are the results of digestion. Digestion. Mammals digest their food by the use of
enzymes to obtain simple, soluble, low-molar-mass components, especially monosaccharides; small peptides and amino acids; and fatty acids and monoglycerides. These are taken up in the blood, together with other nutrients, such as various salts, glycerol, organic acids, etc. The substances are transported to all the organs in the body, including the mammary gland, to provide energy and building blocks (precursors) for metabolism, including the synthesis of proteins, lipids, etc.

In ruminants like the cow, considerable predigestion occurs by means of microbial fermentation, which occurs for the most part in the first stomach or rumen. The latter may be considered as a large and very complex bio-fermenter. It contains numerous bacteria that can digest cellulose, thereby breaking down plant cell walls, providing energy and liberating the cell contents. From cellulose and other carbohydrates, acetic, propionic, butyric and lactic acid are formed, which are taken up in the blood. The composition of the organic acid mixture depends on the composition of the feed. Proteins are broken down into amino acids. The rumen flora uses these to make proteins but can also synthesize amino acids from low-molar-mass nitrogenous components. Further on in the digestive tract the microbes are digested, liberating amino acids. Also, food lipids are hydrolyzed in the rumen and partly metabolized by the microorganisms. All these precursors can reach the mammary gland.

**Milk Synthesis.** The synthesis of milk components occurs for the greater part in the secretory cells of the mammary gland. At the basal end precursors of milk components are taken up from the blood, and at the apical end milk components are secreted into the lumen. Proteins are formed in the endoplasmic reticulum and transported to the Golgi vesicles, in which most of the soluble milk components are collected. The vesicles grow in size while being transported through the cell and then open up to release their contents in the lumen. Triglycerides are synthesized in the cytoplasm, forming small globules, which grow while they are transported to the apical end of the cell. They become enrobed by the outer cell membrane (or plasmalemma) while being pinched off into the lumen. This type of secretion is called merocrine, which means that the cell remains intact.

**Fat globules.** To a certain extent, milk is an oil-in-water emulsion. But the fat globules are more complicated than emulsion droplets. In particular, the surface layer or membrane of the fat globule is not an adsorption layer of one single substance but consists of many components; its structure is complicated. The dry mass of the membrane is about 2.5% of that of the fat. A small part of the lipids of milk is found outside the fat globules. At temperatures below 35°C, part of the fat in the globules can crystallize. Milk minus fat globules is called milk plasma, i.e., the liquid in which the fat globules float.

**Casein micelles** consist of water, protein, and salts. The protein is casein. Casein is present as a caseinate, which means that it binds cations, primarily calcium and magnesium. The other salts in the micelles occur as a calcium phosphate, varying somewhat in composition and also containing a small amount of citrate. This is often called colloidal phosphate. The whole may be called calcium-caseinate/calcium-phosphate complex. The casein micelles are not micelles in the colloid-chemical sense but just ‘small particles.’ The micelles have an open structure and, accordingly, contain much water, a few grams per gram of casein. Milk serum, i.e., the liquid in which the micelles are dispersed, is milk minus fat globules and casein micelles.
Serum proteins are largely present in milk in molecular form or as very small aggregates.

Lipoprotein particles, sometimes called milk microsomes, vary in quantity and shape. Presumably, they consist of remnants of mammary secretory cell membranes. Few definitive data on lipoprotein particles have been published.

SOME PROPERTIES OF MILK

Milk as a solution.
Milk is a dilute aqueous solution and behaves accordingly. Because the dielectric constant is almost as high as that of pure water, polar substances dissolve well in milk and salts tend to dissociate (although this dissociation is not complete). The ionic strength of the solution is about 0.073 M. The pH of milk is about 6.7 at room temperature. The viscosity is low, about twice that of water, which means that milk can readily be mixed, even by convection currents resulting from small temperature fluctuations. The dissolved substances give milk an osmotic pressure of about 700 kPa (7 bar) and a freezing-point depression close to 0.53 K. The water activity is high, about 0.995. Milk density (\( \rho \)) equals about 1029 kg·m\(^{-3}\) at 20°C; it varies especially with fat content.

Milk as a Dispersion.
The fat globules have a membrane, which acts as a kind of barrier between the plasma and the core lipids. The membrane also protects the globules against coalescence. The various particles can be separated from the rest. The fat globules can be concentrated in a simple way by creaming, which either occurs due to gravity or — more efficiently — is induced by centrifugation. In this way cream and skim milk are obtained. Skim milk is not identical to milk plasma, though quite similar, because it still contains some small fat globules. Cream can be churned, leading to butter and buttermilk; the latter is rather similar in composition to skim milk. Likewise, casein micelles can be concentrated and separated from milk, for instance, by membrane filtration. The solution passing through the membrane is then quite similar to milk serum. If the pores in the membrane are very small, also the serum proteins are retained. When adding rennet enzyme to milk, as is done in cheese making, the casein micelles start to aggregate, forming a gel; when cutting the gel into pieces, these contract, expelling whey. Whey is also similar to milk serum but not quite, because it contains some of the fat globules and part of the \( \kappa \)-casein split off by the enzyme. Casein also aggregates and forms a gel when the pH of the milk is lowered to about 4.6. Moreover, water can be removed from milk by evaporation. Altogether, a range of liquid milk products of various compositions can be made.

Flavor. The flavor of fresh milk is fairly bland. The lactose produces some sweetness and the salts some saltiness. Several small molecules present in very small quantities also contribute to flavor. The fat globules are responsible for the creaminess of whole milk.
**Nutritional value.** Milk is a complete food for the young calf, and it can also provide good nutrition to humans. It contains virtually all nutrients, most of these in significant quantities. However, it is poor in iron and the vitamin C content is not high. It contains no antinutritional factors, but it lacks dietary fibre.

**Milk as a Substrate for bacteria.** Because it is rich in nutrients, many microorganisms, especially bacteria, can grow in milk. Not all bacteria that need sugar can grow in milk, some being unable to metabolize lactose. Milk is poor in iron, which is an essential nutrient for several bacteria, and contains some antibacterial factors, such as immunoglobulins and some enzyme systems. Moreover, milk contains too much oxygen for strictly anaerobic bacteria. Altogether, the growth of several bacteria is more or less restricted in raw milk, but several others can proliferate, especially at high ambient temperatures.

**CHANGES IN MILK**

Milk is not a system in equilibrium. It changes even while in the udder. This is partly because different components are formed at various sites in the mammary secretory cell and come into contact with one another after their formation. Furthermore, several changes can occur due to the milking, the subsequent lowering of the temperature, and so on. Changes may be classified as follows:

1. **Physical changes occurring**, for instance, when air is incorporated during milking: Because of this, additional dissolution of oxygen and nitrogen occurs in milk. Moreover, a new structural element is formed: air bubbles. Milk contains many surface-active substances, predominantly proteins, which can become attached to the air–water interface formed. Furthermore, by contact with the air bubbles, fat globules may become damaged, i.e., lose part of their membrane. Fat globules may cream. Creaming is most rapid at low temperature because the globules aggregate to large flocs during the so-called cold agglutination. On cooling, part of the milk fat starts to crystallize, the more so at a lower temperature. But even at 0°C part of the fat remains liquid. The presence of fat crystals can strongly diminish the stability of fat globules against clumping.

2. **Chemical changes** may be caused by the presence of oxygen: Several substances may be oxidized. In particular, light may induce reactions, often leading to off-flavors. Composition of salts can vary, for example, with temperature.

3. **Biochemical changes** can occur because milk contains active enzymes: Examples are lipase, which causes lipolysis; proteinases, which cause proteolysis; and phosphatases, which cause hydrolysis of phosphoric acid esters.

4. **Microbial changes** are often the most conspicuous: The best-known effect is production of lactic acid from lactose, causing an obvious decrease in pH. Numerous other changes, such as lipolysis and proteolysis, may result from microbial growth.
Milk Processing

Milk fresh from the cow is virtually a sterile product. All post-milking handling must maintain the milk’s nutritional value and prevent deterioration caused by numerous physical and biological factors. In addition, equipment on the farm must be maintained to government and industry standards. Most cows are milked twice a day, although some farms milk three or four times per day. The milk is immediately cooled from body temperature to below 40°F (5°C), then stored at the farm under refrigeration until picked up by insulated tanker trucks at least every other day. The milk tanker driver records the amount of milk and notes the temperature and the presence of any off-odors. If the milk is too warm or has an off-odor, it will not be picked up, and the farmer will have to feed it to his animals or dump it. When the milk is pumped into the tanker, a sample is collected for later lab analysis.

When the milk arrives at the milk plant, it is checked to make sure it meets the standards for temperature, total acidity, flavor, odor, tanker cleanliness, and the absence of antibiotics. The butterfat and solids-not-fat content of this raw milk is also analyzed. The amounts of butterfat (BF) and solids-not-fat (SNF) in the milk will vary according to time of year, breed of cow, and feed supply. Butterfat content, solids-not-fat content, and volume are used to determine the amount of money paid the farmer.

Once the load passes these receiving tests, it is then pumped into large refrigerated storage silos (nearly half-million pounds capacity) at the processing plant.

All raw milk must be processed within 72 hours of receipt at the plant. Milk is such a nutritious food that numerous naturally occurring bacteria are always present. The milk is pasteurized, which is a process of heating the raw milk to kill all "pathogenic" bacteria that may be present. A pathogen is a bacteria that could, if allowed to grow and multiply, make humans sick. It should be noted that pasteurization is not sterilization (sterilization eliminates all viable life forms, while pasteurization does not). After pasteurization, some harmless bacteria may survive the heating process. It is these bacteria that will cause milk to "go sour." Keeping milk refrigerated is the best way to slow the growth of these bacteria. Some bacteria do not cause spoilage, but are actually added to milk or cream after pasteurization to make "cultured" products such as cheese, cottage cheese, yogurt, buttermilk, acidophilus milk and sour cream.

There are different ways to pasteurize milk. The "batch" method heats the milk to at least 145° and holds it at that temperature for at least 30 minutes.

Since this method may cause a "cooked" flavor, it is not used by some milk plants for fluid milk products.

High Temperature/Short Time (HTST) pasteurization heats the milk to at least 161° for at least 15 seconds. The milk is immediately cooled to below 40° and packaged into plastic jugs or plastic-coated cartons. Most milk plants have at least one HTST processor. This piece of equipment is considered the "heart" of the plant.
Butterfat content accounts for several different types of products. Whole milk, 2%, 1%, Nonfat, and Half & Half are some examples. A machine called a separator separates the cream and skim portions of the milk. A separator is really a large centrifuge that spins about 2,000 rotations per minute. The different types of milk products are then "standardized" by blending the components (skim milk, raw milk, cream) in the correct proportions to yield the desired end-products. Water is never added to lower the butterfat content of fluid milk. Excess cream is used to make ice cream and butter.

Milk is homogenized to prevent the cream portion from rising to the top of the package. The expression "cream rises to the top." is accurate because cream is lighter in weight than milk. The cream portion of un-homogenized milk would form a cream layer at the top of the carton. A "homogenizer" forces the milk under high pressure through a valve that breaks up the butterfat globules to such small sizes they will not "coalesce" (stick together). Homogenization does not affect the nutrition or quality of the product; it is done entirely for aesthetic purposes.

Vitamin quantities may be reduced by the heating process and removal of the butterfat. Therefore, to replace the natural nutrition of nature's perfect food, liquid vitamins are added to fortify most fluid milk products. Many states have milk standards that require the addition of milk solids. These solids represent the natural mineral (i.e. calcium, iron), protein (casein), and sugar (lactose) portion of nonfat dry milk. You will see this shown as an ingredient on those products needing fortification.

Quality Control personnel conduct numerous tests on the raw and pasteurized products to insure optimum quality and nutrition. A sample is analyzed for the presence of microbiological organisms with a standard plate count (SPC) and ropey milk test. The equipment used to analyze butterfat and solids-not-fat is calibrated on a regular basis to insure a consistent, quality product that meets or exceeds government requirements.

All milk products have a sell-by date printed on the package. This is the last day the item should be offered for sale. However, most companies guaranty the quality and freshness of the product for at least 7 days past the date printed on the package. Samples of each product packaged each day are saved to confirm that they maintain their freshness 7 days after the sell-by date.

Once the milk has been separated, standardized, homogenized and pasteurized, it is held below 40°F in insulated storage tanks, then packaged into gallon, half-gallon, quart, pint, and half-pint containers. The packaging machines are maintained under strict sanitation specifications to prevent bacteria from being introduced into the pasteurized product. All equipment that comes into contact with product (raw or pasteurized) is washed daily. Sophisticated automatic Clean-in-Place (CIP) systems guarantee consistent sanitation with a minimum of manual handling, reducing the risk of contamination.

Once packaged, the products are quickly conveyed to a cold storage warehouse. They are stored there for a short time and shipped to the supermarket on refrigerated trailers. Once at the store, the milk is immediately placed into a cold storage room or refrigerated display case.

Food Safety
Food safety is a very broad topic. Pesticides, herbicides, chemical additives, and spoilage are all of concern, but food scientists, food processors, and consumers focus most on microbiological quality. **Microorganisms** pose a challenge to the food industry and most food processes are designed with microbial quality in mind. Microorganisms are often too small to be seen with the unaided eye and have the ability to reproduce rapidly. Many of them produce toxins and can cause infections. For all of these reasons, the microbiological quality of the food we eat is scrutinized closely.

Centuries ago, Genghis Khan was able to rule vast stretches of land through the mobility of his army. With very little food, he was able to engage in swift attacks over long periods of time. As the story goes, each horseman carried two leather bags. The larger one held dry milk produced by drying fluid milk in the sun during periods of rest. The smaller bag was used to rehydrate some of the milk powder with water, which was consumed during an offensive. The lightly equipped army of Khan thus could cover long distances in weeks, and eventually controlled most of the Asian continent. Yet, one has to wonder how many people suffered food-borne illness in those days.

Today, **food-borne illness** is of serious concern. Its frequency is not known because a great majority of the cases go unreported. Reporting **food-borne diseases** to public health authorities is not required in the United States. Estimates claim as many as 200 million cases in the U.S. per year. Only a small percentage of these are hospitalized. Most are passed off as traveler's diarrhea, 24 hour flu, or upset stomach. **Salmonellosis**, one of the more serious food-borne diseases, is said to be reported only about 1% of the time. About 42,000 cases of salmonellosis are reported in the U.S. annually, with about 150 deaths. So, there are potentially 4.2 million cases of **Salmonella** food poisoning annually despite the fact that the U.S. food supply is considered very safe and processed under the best conditions available.

Testing the foods we consume for the presence of pathogenic microorganisms is very important. Although 100% of the food cannot be tested, it can be deemed "safe" through proper audit of the food supply. In many instances, the pathogenic microorganisms are present in very small numbers, but for many of these pathogens, small numbers are all that are necessary to transmit disease or illness. For that reason, the presence of other microorganisms is monitored. These microorganisms provide an index of the sanitary quality of the product and may serve as an indicator of potential for the presence of pathogenic species. **Escherichia coli** (E. coli) is commonly employed as an indicator microorganism. Because E. coli is a coliform bacteria common to the intestinal tract of humans and animals, its relationship to intestinal food-borne pathogens is high.

Total counts of microorganisms are also an indication of the sanitary quality of a food. Referred to as the **Standard Plate Count** (SPC), this total count of viable microbes reflects the handling history, state of decomposition or degree of freshness of the food. Total counts may be taken to indicate the type of sanitary control exercised in the production, transport, and storage of the food. Most foods have standards or limits for total counts. This is especially true for milk.

It must be remembered that a low SPC does not always represent a safe product. It is possible to have low-count foods in which toxin-producing organisms have grown. These organisms
produce toxins that remain stable under conditions that may not favor the survival of the microbial cell.

In adopting microbiological standards to milk, the first concern is product safety, followed by shelf-life. The following bacterial counts are standards for milk as recommended by the U.S. Public Health Service:

**Grade A raw milk for pasteurization** Not to exceed 100,000 bacteria per milliliter (ml) prior to commingling with other produced milk; and not exceeding 300,000 per ml as commingled milk prior to pasteurization.

**Grade A pasteurized milk** Not over 20,000 bacteria per ml, and not over 10 coliforms per ml.

The objective of pasteurization is to reduce the total microbial load, or SPC. In addition, pasteurization must destroy all pathogens that may be carried in the milk from the cow, particularly undulant fever, tuberculosis, Q-fever, and other diseases transmittable to humans. This is accomplished by setting the time and temperature of the heat treatment so that certain heat-resistant pathogens, specifically *Mycobacterium tuberculosis* and *Coxiella burnetii* (causative agents of Q-fever and tuberculosis, respectively) would be destroyed if present. Milk pasteurization temperatures are sufficient to destroy all yeasts, mold, and many of the spoilage bacteria.

**Quality Assurance**

Of all functions in the food industry, Quality Assurance (QA) requires many diverse technical and analytical skills. QA personnel continually monitor incoming raw milk and finished milk products to insure compliance with compositional standards, microbiological standards, and various government regulations. A QA manager can halt production, refuse acceptance of raw material, or stop the shipment if specifications for a product or process are not met. This department does not usually have control over the product unless something has gone wrong.

The major functions of the QA Department are:

**Compliance with specifications** Legal requirements, industry standards, internal company standards, shelf-life tests, customers' specifications.

**Test procedures** Testing of raw materials, finished products, and in-process tests.

**Sampling schedules** Utilize a suitable sampling schedule to maximize the probability of detection while minimizing workload.

**Records and reporting** Maintain all QA records so that customer complaints and legal problems can be dealt with.
Trouble shooting Solve various problems caused by poor quality raw materials, erratic supplies and malfunctioning process equipment; and investigate reasons for poor quality product to avoid repetition.

Special problems Customer complaints, production problems, personnel training, short courses, etc.

A typical QA Department may have a chemistry lab, a raw materials inspection lab, a sensory lab and a microbiology lab. All of these disciplines work together to assure that the food we consume is of the highest quality. After all, it is quality which will bring a customer back again and again.