Dairy Science and Technology

UNIVERSITY of GUELPH

Education Series

Welcome to Dairy Science and Technology.

This site was developed and is mainatined by Professor Doug Goff of the University of Guelph, Canada. It originated in 1995 with the funding assistance of the Ontario Milk Marketing Board (now the Dairy Farmers of Ontario), and credit is given to Jane Ellenton for much of the original creative and development work. It has been edited and updated many times since. Please feel free to use this site for reference, teaching, or training. Contact me if I can help you to tailor it to your specific needs. Send me your comments as to how it can be improved (email to dgoff@uoguelph.ca).

Introduction to Dairy Science and Technology: Milk History, Composition, Production and Consumption Data and Trends

Milk Production and Biosynthesis

Milk Grading and Defects

Dairy Chemistry and Physics

Dairy Microbiology

Dairy Processing

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Dairy Products

- Overview and Fluid Milk Products
- Concentrated and Dried Milk Products
- **Cultured Dairy Products**
    - Cheese
    - Yogurt and Fermented Beverages
- Ice Cream
- Butter

Structure of Milk and Dairy Products

This is a link to an absolutely marvellous website developed by my good friend Dr. Milos Kalab, entitled "Foods Under the Microscope", with many high-quality images of the structure of milk and dairy products obtained during Dr. Kalab's long and outstanding career as a food microscopist with Agriculture and Agri-Food Canada in Ottawa.

Glossary of Terms

(Terms that appear as an italicized hot-link will take you to the definition in the glossary)

Dairy Science and Technology General References

About the Author

Introduction to Dairy Science and Technology: Milk History, Consumption, Production, and Composition

Introduction

This course is about the study of milk and milk-derived food products from a food science perspective. It focusses on the biological, chemical, physical, and microbiological aspects of milk itself, and on the technological (processing) aspects of the transformation of milk into its various consumer products, including beverages, fermented products, concentrated and dried products, butter and ice cream.

Milk is as ancient as mankind itself, as it is the substance created to feed the mammalian infant. All species of mammals, from man to whales, produce milk for this purpose. Many centuries ago, perhaps as early as 6000-8000 BC, ancient man learned to domesticate species of animals for the provision of milk to be consumed by them. These included cows (genus Bos), buffaloes, sheep, goats, and camels, all of which are still used in various parts of the world for the production of milk for human consumption.

Fermented products such as cheeses were dicovered by accident, but their history has also been documented for many centuries, as has the production of concentrated milks, butter, and even ice cream.

Technological advances have only come about very recently in the history of milk consumption, and our generations will be the ones credited for having turned milk processing from an art to a science. The availability and distribution of milk and milk products today in the modern world is a blend of the centuries old knowledge of traditional milk products with the application of modern science and technology.

The role of milk in the traditional diet has varied greatly in different regions of the world. The tropical countries have not been traditional milk consumers, whereas the more northern regions of the world, Europe (especially Scandanavia) and North America, have traditionally consumed far more milk and milk products in their diet. In tropical countries where high temperatures and lack of refrigeration has led to the inability to produce and store fresh milk, milk has traditionally been preserved through means other than refrigeration, including immediate consumption of warm milk after milking, by boiling milk, or by conversion into more stable products such as fermented milks.

World-wide Milk Consumption and Production

The total milk consumption (as fluid milk and processed products) per person averages 107 kg world-wide, but varies from 380 kg in Europe and 280 kg in North America and Oceania, to 50 kg in Southern Asia and 20 kg in Eastern Asia. As the various regions of the world become more integrated through travel and migration, these trends are changing, a factor which needs to be considered by product developers and marketers of milk and milk products in various countries of the world.

Even within regions such as Europe, the custom of milk consumption has varied greatly. Table 1 illustrates milk per capita consumption information from various countries of the world. Several trends can be observed from these data. Consider for example the high consumption of beverage milk and fermented products in Finland, Norway, and Sweden (the Scandanavian countries) compared to France, Germany, Italy and Greece where cheeses have tended to dominate milk consumption. When you also consider the climates of these regions, it would appear that the culture of producing more stable products (cheese) in hotter climates as a means of preservation is evident.

Table 1. Per Capita Consumption of Milk and Milk Products in Various Countries.

Country	Beverage Milk	Flavoured Milk	Fermented Products	Cheeses	Cream	Butter
Finland	186.3		37.1	11.8	1.9	16.0
Norway	164.7		14.7	13.5	2.4	8.6
Sweden	145.1		27.2	15.4	2.9	8.7
Netherlands	91.2	21.0	19.1	14.9	1.0	7.2
France	78.1	6.0	13.6	21.8	0.9	14.1
Germany	70.1	8.6	10.5	16.8	1.7	14.9
Austria	134.1	2.5	9.5	9.6	1.2	8.8
Italy	79.5		3.3	17.5	0.8	2.3
Greece	54.2	1.7	6.0	22.2	0.3	2.7
UK	123.4	0.7	3.6	7.5	0.8	8.4
Ireland	182.7		3.2	4.9	0.7	11.8
USA	96.9	4.4	2.1	10.9	0.6	3.8
Canada	102.6	4.2	3.2	11.7	1.0	7.8
India	48.3		4.2	0.2	0.02	1.1
Australia	96	9.7	3.0	8.5	1.2	6.4
Japan	38.0	6.2	7.2	1.0	0.1	1.1

Source: International Dairy Federation

The next table shows the quantity of raw milk produced around the world. Over half of the milk produced comes from Europe while fully 3/4 of the world milk is produced in Europe and North America.

Table 2. Raw Milk Produced in 1993 in Various Regions of the World (`000 tonnes).

Europe	217,500
North America	87,000
South America	25,600
India	30,500
Oceania	16,200

Africa	2,400
China	5,500
Japan	8,600
Total	410,665

Source: United States Department of Agriculture

Milk Composition

The role of milk in nature is to nourish and provide immunological protection for the mammalian young. Milk and honey are the only articles of diet whose sole function in nature is food. It is not surprising, therefore, that the nutritional value of milk is high.

Table 3. Composition of Milk from Different Mammalian Species (per 100 g fresh milk).

	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)
Cow	3.2	3.7	4.6	66
Human	1.1	4.2	7.0	72
Water Buffalo	4.1	9.0	4.8	118
Goat	2.9	3.8	4.7	67
Donkey	1.9	0.6	6.1	38
Elephant	4.0	5.0	5.3	85
Monkey, rhesus	1.6	4.0	7.0	73
Mouse	9.0	13.1	3.0	171
Whale	10.9	42.3	1.3	443
Seal	10.2	49.4	0.1	502

Table 4. Gross composition of milk of various breeds, g/100g.

	Body Wt. (kg)	Milk Yield (kg)	Fat (%)	Protein (%)	Lactose (%)	Ash (%)	Total Solids (%)
Holstein	640	7360	3.54	3.29	4.68	0.72	12.16
Brown Swiss	640	6100	3.99	3.64	4.94	0.74	13.08
Ayrshire	520	5760	3.95	3.48	4.60	0.72	12.77
Guernsey	500	5270	4.72	3.75	4.71	0.76	14.04
Jersey	430	5060	5.13	3.98	4.83	0.77	14.42
Shorthorn	530	5370	4.0	3.32	4.89	0.73	12.9

Holstein: 12.16% T.S. x 7360 kg/lactation = 895 kg of total solids produced/lactation (140% of her body wt.!)
Jersey: 14.42% T.S. x 5060 kg/lactation = 730 kg of total solids produced/lactation (170% of her body wt.!)

Now you can return to the home page and work through the various topics within this Education Series systematically, or you can select any topic of interest for further, in-depth information. I hope you enjoy!

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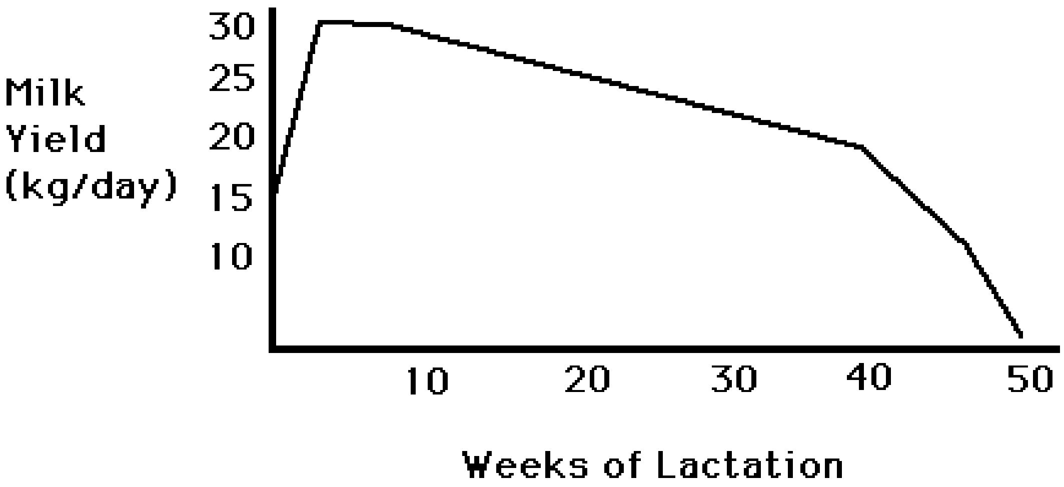
Milk Production and Biosynthesis

Milk Production

Milk is the source of nutrients and immunological protection for the young cow. The gestation period for the female cow is 9 months. Shortly before calving, milk is secreted into the udder in preparation for the new born. At parturition, fluid from the mammary gland known as **colostrum** is secreted. This yellowish coloured, salty liquid has a very high serum protein content and provides antibodies to help protect the newborn until its own immune system is established. Within 72 hours, the composition of colostrum returns to that of fresh milk, allowing to be used in the food supply.

The period of **lactation**, or milk production, then continues for an average of 305 days, producing 7000 kg of milk. This is quite a large amount considering the calf only needs about 1000 kg for growth.

Within the lactation, the highest yield is 2-3 months post- parturition, yielding 40-50 L/day. Within the milking lifetime, a cow reaches a peak in production about her third lactation, but can be kept in production for 5-6 lactations if the yield is still good.



About 1-2 months after calving, the cow begins to come into heat again. She is usually inseminated about 3 months after calving so as to come into a yearly calving cycle. Heifers are normally first inseminated at 15 months so she's 2 when the first calf is born. About 60 days before the next calving, the cow is **dried off**. There is no milking during this stage for two reasons:

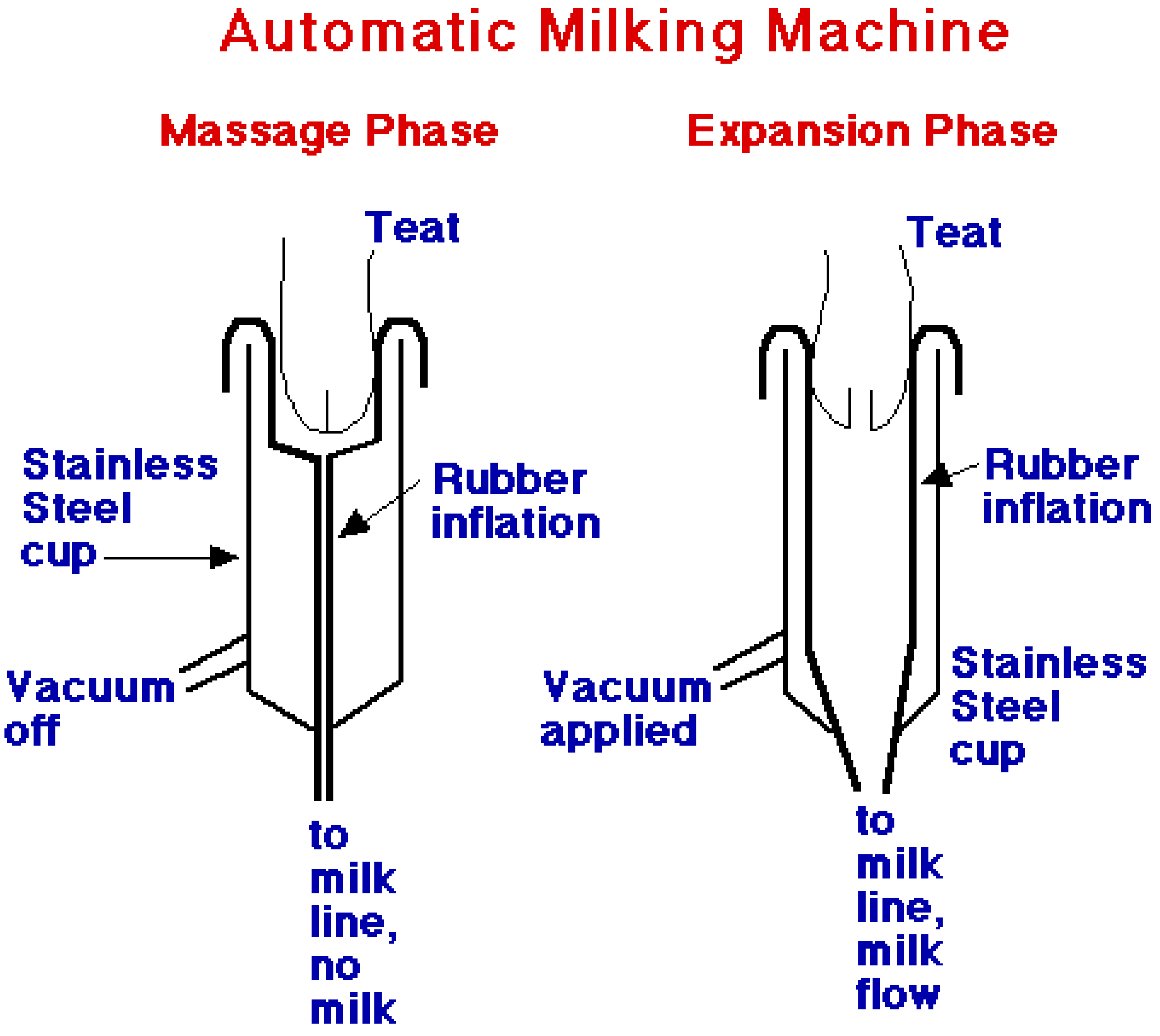
1. milk has tapered off because of maternal needs of the fetus
2. udder needs time to prepare for the next milking cycle

The life of a female cow can be summerized as follows:

Age	
0	Calf born
15 mos	Heifer inseminated for first calf
24 mos	First calf born - starts milking
27 mos	Inseminated for second calf
34 mos	Dried off
36 mos	Second calf born - starts milking

Cycle repeats for 5-6 lactations

Automatic Milking



Effects of Milk Handling on Quality and Hygiene

Cleanliness

The environment of production has a great effect on the quality of milk produced. From the food science perspective, the production of the highest quality milk should be the goal. However, this is sometimes not the greatest concern of those involved in milk production. Hygienic quality assessment tests include sensory tests, dye reduction tests for microbial activity, total bacterial count (standard plate count), sediment, titratable acidity, somatic cell count, antibiotic residues, and added water.

The two common dye reduction tests are methylene blue and resazurin. These are both synthetic compounds which accept electrons and change colour as a result of this reduction. As part of natural metabolism, active microorganisms transfer electrons, and thus rate at which dyes added to milk are reduced is an indication of the level of microbial activity. Methylene blue turns from blue to colorless, while resazurin turns from blue to violet to pink to colourless. The reduction time is inversely correlated to bacterial numbers. However, different species react differently. Mesophilics are favoured over pscchrotrophsa, but psychrotrophic organisms tend to be more numerous and active in cooled milk.

Temperature

Milk production and distribution in the tropical regions of the world is more challenging due to the requirements for low-temperature for milk stability. Consider the following chart illustraing the numbers of bacteria per millilitre of milk after 24 hours:

5°C	2,600
10°C	11,600
12.7°C	18,800
15.5°C	180,000
20°C	450,000

Traditionally, this has been overcome in tropical countries by stabilizing milk through means other than refrigeration, including immediate consumption of warm milk after milking, by boiling milk, or by conversion into more stable products such as fermented milks.

Mastitis and Antibiotics

Mastitis is a bacterial and yeast infection of the udder. Milk from mastitic cows is termed abnormal. Its SNF, especially lactose, content is decreased, while Na and Cl levels are increased, often giving mastitic milk a salty flavour. The presence of mastitis is also accompanied by increases in bacterial numbers, including the possibility of human pathogens, and by a dramatic increase in somatic cells. These are comprised of leukocytes (white blood cells) and epithelial cells from the udder lining. Increased somatic cell counts are therefore indicative of the presence of mastitis. Once the infection reaches the level known as "clinical' mastitis, pus can be observed in the teat canal just prior to milking, but at sub-clinical levels, the presence of mastitis is not obvious.

Somatic Cell Count (000's/ml)	Daily Milk Yield (kg): 1st Lactation	Older Lactations
0-17	23.1	29.3
18-34	23.0	28.7
35-70	22.6	28.0
71-140	22.4	27.4
141-282	22.1	27.0
282-565	21.9	26.3
566-1130	21.4	25.4
1131-2262	20.7	24.6
2263-4525	20.0	23.6
>4526	19.0	22.5

Antibiotics are frequently used to control mastitis in dairy cattle. However, the presence of antibiotic residues in milk is very problematic, for at least three reasons. In the production of fermented milks, antibiotic residues can slow or destry the growth of the fermentation bacteria. From a human health point of view, some people are allergic to specific antibiotics, and their presence in food consumed can have severe consequences. Also, frequent exposure to low level antibiotics can cause microorganisms to become resistant to them, through mutation, so that they are ineffective when needed to fight a human infection. For these reasons, it is extremely important that milk from cows being treated with antibiotics is withheld from the milk supply.

The withdrawal time after final treatment for various antibiotics is shown below:

Amoxcillin 60 hrs.
Cloxacillin 48 hrs.
Erythromicin 36 hrs.
Novobiocin 72 hrs.
Penicillin 84 hrs.
Sulfadimethozine 60 hrs.
Sulfabromomethozine 96 hrs.
Sulfaethoxypyridozine 72 hrs.

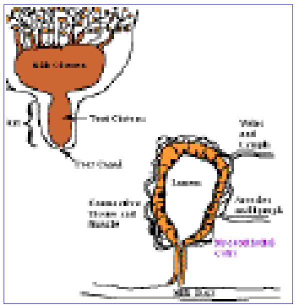
Anti-Microbial Systems in Raw Milk

There exists in milk a number of natural anti-microbial defense mechanisms. These include:

- lysozyme - an enzyme that hydrolyses glycosidic bonds in gram positive cell walls. However, its effect as a bacteriostatic mechanism in milk is probably negligible.
- lactoferrin - an iron binding protein that sequesters iron from microorganisms, thus taking away one of their growth factors. Its effect as a bacteriostatic mechanism in milk is also probably negligible.
- lactoperoxidase - an enzyme naturally present in raw milk that catalyzes the conversion of hydrogen peroxide to water. When hydrogen peroxide and thiocyanate are added to raw milk, the thiocyanate is oxidized by the enzyme/ hydrogen peroxide complex producing bacteriostatic compounds that inhibit Gram negative bacteria, E. coli , Salmonella spp , and streptococci. This technique is being used in many parts of the world, especially where refrigeration for raw milk is not readily available, as a means of increasing the shelf life of raw milk.

Milk Biosynthesis

Milk is synthesized in the **mammary gland**. Within the mammary gland is the milk producing unit, the **alveolus**. It contains a single layer of epithelial secretory cells surrounding a central storage area called the **lumen**, which is connected to a duct system. The secretory cells are, in turn, surrounded by a layer of myoepithelial cells and blood capillaries.



Udder, Alveolus, Secretory Cell: 26 KB

The raw materials for milk production are transported via the bloodstream to the secretory cells. It takes 400-800 L of blood to deliver components for 1 L of milk.

- **Proteins:** building blocks are amino acids in the blood. Casein submicelles may begin aggregation in Golgi vesicles within the secretory cell.
- **Lipids:**
  - C4-C14 fatty acids are synthesized in the cells
  - C16 and greater fatty acids are preformed as a result of rumen hydrogenation and are transported directly in the blood
- **Lactose:** milk is in osmotic equilibrium with the blood and is controlled by lactose, K, Na, Cl; lactose synthesis regulates the volume of milk secreted

The milk components are synthesized within the cells, mainly by the **endoplasmic reticulum (ER)** and its attached ribosomes. The energy for the ER is supplied by the mitochondria. The components are then passed along to the **Golgi apparatus**, which is responsible for their eventual movement out of the cell in the form of vesicles. Both vesicles containing aqueous non-fat components, as well as liquid droplets (synthesized by the ER) must pass through the cytoplasm and the apical plasma membrane to be deposited in the lumen. It is thought that the milk fat globule membrane is comprised of the apical plasma membrane of the secretory cell.

Milking stimuli, such as a sucking calf, a warm wash cloth, the regime of parlour etc., causes the release of a hormone called **oxytocin**. Oxytocin is relased from the pituitary gland, below the brain, to begin the process of **milk let-down**. As a result of this hormone stimulation, the muscles begin to compress the alveoli, causing a pressure in the udder known as letdown reflex, and the milk components stored in the lumen are released into the duct system. The milk is forced down into the teat cistern from which it is milked. The let-down reflex fades as the oxytocin is degraded, within 4-7 minutes. It is very difficult to milk after this time.

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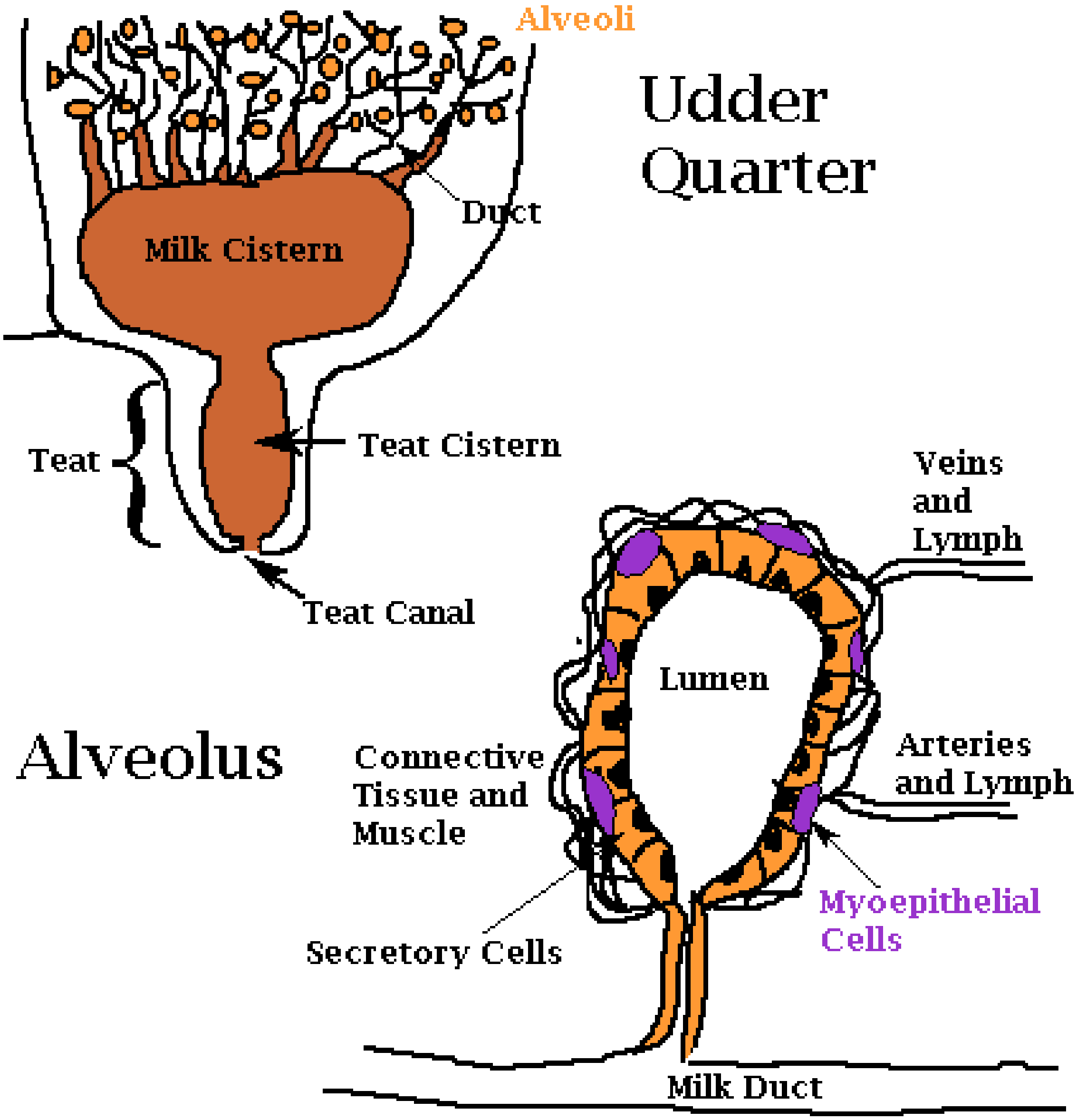
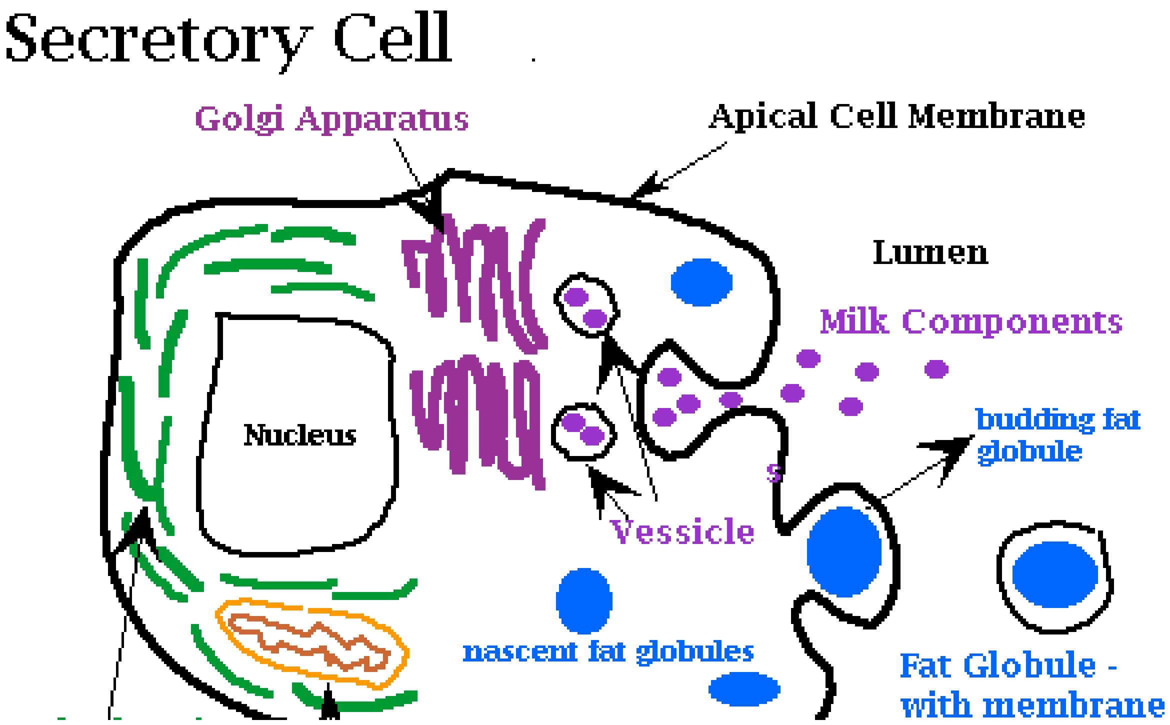

Alveoli
Udder Quarter
Duct
Milk Cistern
Teat
Teat Cistern
Teat Canal
Veins and Lymph
Lumen
Alveolus
Connective Tissue and Muscle
Arteries and Lymph
Myoepithelial Cells
Secretory Cells
Milk Duct


Secretory Cell
Golgi Apparatus
Apical Cell Membrane
Lumen
Milk Components
Nucleus
budding fat globule
Vessicle
nascent fat globules
Fat Globule - with membrane

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Dairy Chemistry and Physics

Composition and Structure

- Overview
- **Milk Lipids**
    - Chemical Properties
    - Physical Properties
    - **Structure:** The Milk Fat Globule
    - Functional Properties
- **Milk Proteins**
    - Introduction
    - Caseins
    - **Structure:** The Casein Micelle
    - Whey Proteins
    - Enzymes
- Lactose
- Vitamins
- Minerals

Physical Properties

- Density
- Viscosity
- Freezing Point
- Acid-Base Equilibria
- Optical Properties

Composition and Structure: Overview

The role of milk in nature is to nourish and provide immunological protection for the mammalian young. Milk has been a food source for humans since prehistoric times; from human, goat, buffalo, sheep, yak, to the focus of this section - domesticated cow milk (genus *Bos*). Milk and honey are the only articles of diet whose sole function in nature is food. It is not surprising, therefore, that the nutritional value of milk is high. Milk is also a very complex food with over 100,000 different molecular species found. There are many factors that can affect milk composition such as breed variations (see introduction, cow to cow variations, herd to herd variations - including management and feed considerations, seasonal variations, and geographic variations. With all this in mind, only an approximate composition of milk can be given:

- 87.3% water (range of 85.5% - 88.7%)
- 3.9 % milkfat (range of 2.4% - 5.5%)
- 8.8% solids-not-fat (range of 7.9 - 10.0%):
    - protein 3.25% (3/4 casein)
    - lactose 4.6%
    - minerals 0.65% - Ca, P, citrate, Mg, K, Na, Zn, Cl, Fe, Cu, sulfate, bicarbonate, many others
    - acids 0.18% - citrate, formate, acetate, lactate, oxalate
    - enzymes - peroxidase, catalase, phosphatase, lipase
    - gases - oxygen, nitrogen
    - vitamins - A, C, D, thiamine, riboflavin, others

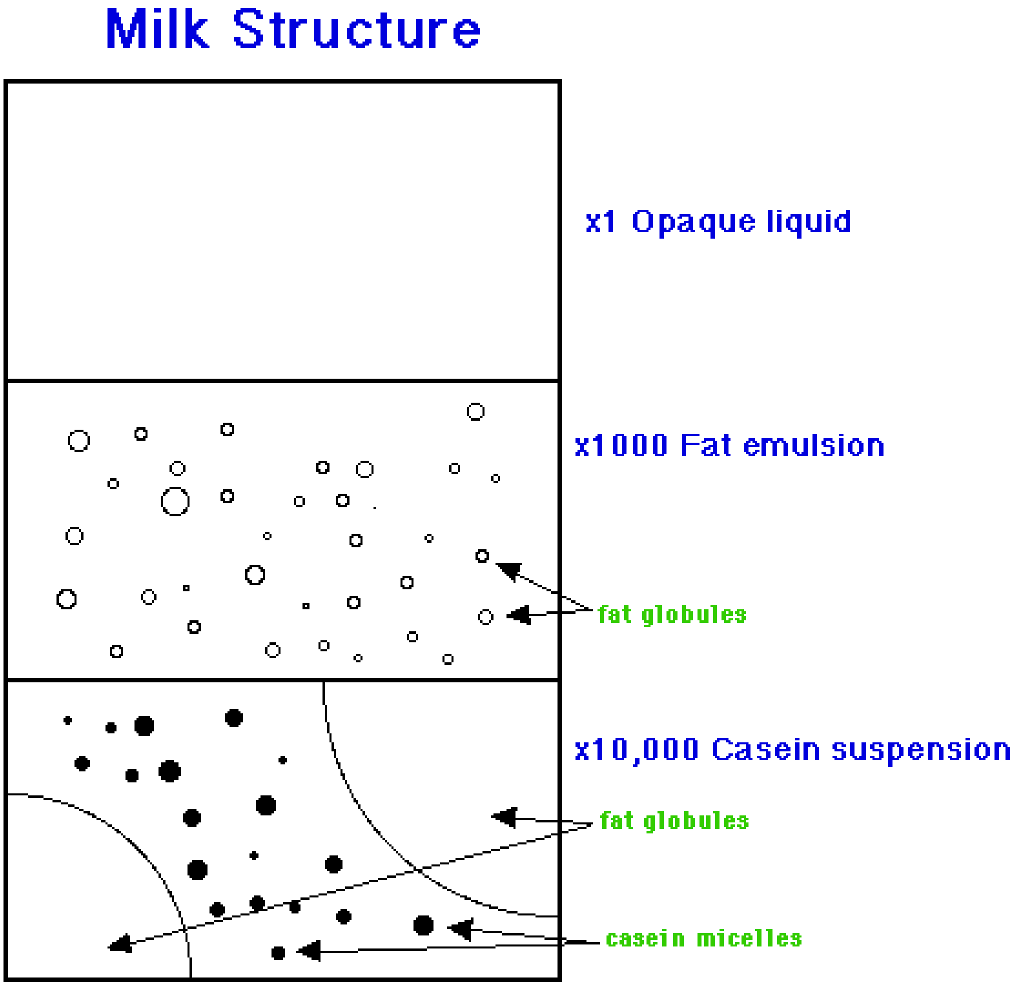
The following terms are used to describe milk fractions:

- **Plasma** = milk - fat (skim milk)
- **Serum** = plasma - casein micelles (whey)
- **solids-not-fat (SNF)** = proteins, lactose, minerals, acids, enzymes, vitamins
- **Total Milk Solids** = fat + SNF

Not only is the composition important in determining the properties of milk, but the physical structure must also be examined. Due to its role in nature, milk is in a liquid form. This may seem curious if one takes into consideration the fact that milk has less water than most fruits and vegetables. Milk can be described as:

- an **oil-in-water emulsion** with the fat globules dispersed in the continuous serum phase
- a **colloid suspension** of casein micelles, globular proteins and lipoprotein partilcles
- a **solution** of lactose, soluble proteins, minerals, vitamins other components.

Looking at milk under a microscope, at low magnification (5X) a uniform but turbid liquid is observed. At 500X magnification, spherical droplets of fat, known as fat globules, can be seen. At even higher magnification (50,000X), the casein micelles can be observed. The main structural components of milk, fat globules and casein micelles, will be examined in more detail later.



Milk Lipids - Chemical Properties

The fat content of milk is of economic importance because milk is sold on the basis of fat. Milk fatty acids originate either from microbial activity in the rumen, and transported to the secretory cells via the blood and lymph, or from synthesis in the secretory cells. The main milk lipids are a class called **triglycerides** which are comprised of a glycerol backbone binding up to three different fatty acids. The fatty acids are composed of a hydrocarbon chain and a carboxyl group. The major fatty acids found in milk are:

Long chain

- C14 - myristic 11%
- C16 - palmitic 26%
- C18 - stearic 10%
- C18:1 - oleic 20%

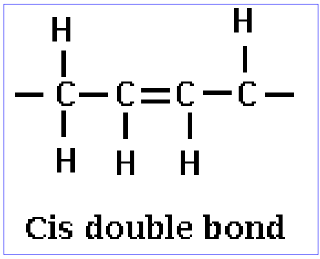
Short chain (11%)

- C4 - butyric*
- C6 - caproic
- C8 - caprylic
- C10 - capric

* butyric fatty acid is specific for milk fat of ruminant animals and is resposible for the rancid flavour when it is cleaved from

glycerol by lipase action.

Saturated fatty acids (no double bonds), such as myristic, palmitic, and stearic make up two thirds of milk fatty acids. Oleic acid is the most abundant **unsaturated fatty acid** in milk with one double bond. While the **cis** form of geometric isomer is the most common found in nature, approximately 5% of all unsaturated bonds are in the **trans** position as a result of rumen hydrogenation.



Lipid structures: 17 KB

Triglycerides account for 98.3% of milkfat. The distribution of fatty acids on the triglyceride chain, while there are hundreds of different combinations, is not random. The fatty acid pattern is important when determining the physical properties of the lipids. In general, the SN1 position binds mostly longer carbon length fatty acids, and the SN3 position binds mostly shorter carbon length and unsaturated fatty acids. For example:

- C4 - 97% in SN3
- C6 - 84% in SN3
- C18 - 58% in SN1

The small amounts of mono- , diglycerides, and free fatty acids in fresh milk may be a product of early lipolysis or simply incomplete synthesis. Other classes of lipids include **phospholipids** (0.8%) which are mainly associated with the fat globule membrane, and **cholesterol** (0.3%) which is mostly located in the fat globule core.

Milk Lipids - Physical Properties

The physical properties of milkfat can be summerized as follows:

- density at 20° C is 915 kg m(-3)*
- refractive index (589 nm) is 1.462 which decreases with increasing temperature
- solubility of water in fat is 0.14% (w/w) at 20° C and increases with increasing temperature
- thermal conductivity is about 0.17 J m(-1) s(-1) K(-1) at 20° C
- specific heat at 40° C is about 2.1kJ kg(-1) K(-1)
- electrical conductivity is <10(-12) ohm(-1) cm(-1)
- dielectric constant is about 3.1

*the brackets around numbers denote superscript

At room temperature, the lipids are solid, therefore, are correctly referred to as "fat" as opposed to "oil" which is liquid at room temperature. The **melting points** of individual triglycerides ranges from -75° C for tributyric glycerol to 72° C for tristearin. However, the final melting point of milkfat is at 37° C because higher melting triglycerides dissolve in the liquid fat. This temperature is significant because 37° C is the body temperature of the cow and the milk would need to be liquid at this temperature. The melting curves of milkfat are complicated by the diverse lipid composition:

- trans unsaturation increases melting points
- odd-numbered and branched chains decrease melting points

Crystallization of milkfat largely determines the physical stability of the fat globule and the consistency of high-fat dairy products, but crystal behaviour is also complicated by the wide range of different triglycerides. There are four forms that milkfat crystals can occur in; **alpha, ß , ß ' 1**, and **ß ' 2**, however, the alpha form is the least stable and is rarely observed in slowly cooled fat.

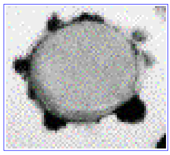
Milkfat Structure - Fat Globules

More than 95% of the total milk lipid is in the form of a globule ranging in size from 0.1 to 15 m in diameter. These liquid fat droplets are covered by a thin membrane, 8 to 10 nm in thickness, whose properties are completely different from both milkfat and plasma. The **native fat globule membrane** (FGM) is comprised of apical plasma membrane of the secretory cell which continually envelopes the lipid droplets as they pass into the lumen. The major components of the native FGM, therefore, is protein and phospholipids. The phospholipids are involved in the oxidation of milk. There may be some rearrangement of the membrane after release into the lumen as amphiphilic substances from the plasma adsorb onto the fat globule and parts of the membrane dissolve into either the globule core or the serum. The FGM decreases the lipid-serum interface to very low values, 1 to 2.5 mN/m, preventing the globules from immediate flocculation and coalescence, as well as protecting them from enzymatic action.

It is well known that if raw milk or cream is left to stand, it will separate. ***Stokes' Law*** predicts that fat globules will cream due to the differences in densities between the fat and plasma phases of milk. However, in cold raw milk, creaming takes place faster than is predicted from this fact alone. **IgM**, an immunoglobulin in milk, forms a complex with lipoproteins. This complex, known as **cryoglobulin** precipitates onto the fat globules and causes flocculation. This is known as **cold agglutination**. As fat globules cluster, the speed of rising increases and sweeps up the smaller globules with them. The cream layer forms very rapidly, within 20 to 30 min., in cold milk.

Homogenization of milk prevents this creaming by decreasing the diameter and size distribution of the fat globules, causing the speed of rise to be similar for the majority of globules. As well, homogenization causes the formation of a recombined membrane which is much similar in density to the continuous phase.

Recombined membranes are very different than native FGM. Processing steps such as homogenization, decreases the average diameter of fat globule and significantly increases the surface area. Some of the native FGM will remain adsorbed but there is no longer enough of it to cover all of the newly created surface area. Immediately after disruption of the fat globule, the surface tension raises to a high level of 15 mN/m and amphiphilic molecules in the plasma quickly adsorb to the lipid droplet to lower this value. The adsorbed layers consist mainly of serum proteins and casein micelles.


Electron Micrograph of Homogenized Milkfat Globules 77 KB

Fat Destabilization

While homogenization is the principal method for acheiving stabilization of the fat emulsion in milk, **fat destabilization** is necessary for butter, whipping cream and ice cream. Fat destabilization refers to the process of clustering and clumping (partial coalescence) of the fat globules which leads to the development of a continuous internal fat network or matrix structure in the product. In order to understand this concept, the different kinds of **fat globule aggregates** must be examined:

Floccules:

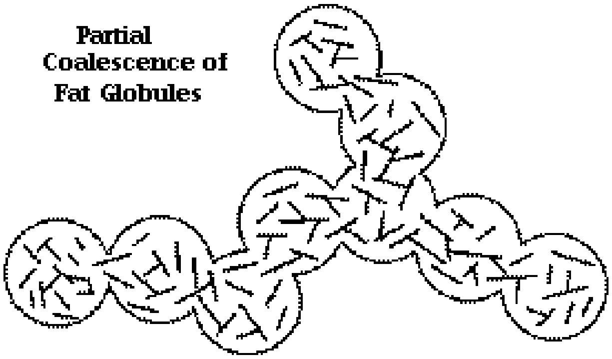
the fat globules that flocculate keep their identity and are held together by weak forces; they are easily redispersed

Clusters:

fat globules may share part of their interfacial layers; they are bound together by stronger forces and are harder to redisperse

Clumps:

fat globules that are partially solid/partially liquid can form clusters if brought into contact; very difficult to redisperse



A good reference for more information on fat globules can be found in Mulder and Walstra.

Milk Lipids - Functional Properties

Like all fats, milkfat provides lubrication. They impart a creamy mouth feel as opposed to a dry texture. Butter flavour is unique and is derived from low levels of short chain fatty acids. If too many short chain fatty acids are hydrolyzed (separated) from the triglycerides, however, the product will taste rancid. Butter fat also acts as a reservoir for other flavours, especially in aged cheese. Fat globules produce a 'shortening' effect in cheese by keeping the protein matrix extended to give a soft texture. Fat substitutes are designed to mimic the globular property of milk fat. The spreadable range of butter fat is 16-24° C. Unfortunately butter is not spreadable at refrigeration temperatures. Milk fat provides energy (1g = 9 cal.), and nutrients (essential fatty acids, fat soluble vitamins).

Milk Proteins

Introduction and Review

The **primary structure** of proteins consists of a polypeptide chain of amino acids residues joined together by peptide linkages, which may also be cross-linked by disulphide bridges. **Amino acids** contain both a weakly basic amino group, and a weakly acid carboxyl group both connected to a hydrocarbon chain, which is unique to different amino acids. The three-dimensional organization of proteins, or **conformation**, also involves secondary, tertiary, and quaternary structures. The **secondary structure** refers to the spatial arrangement of amino acid residues that are near one another in the linear sequence. The alpha-helix and ß -pleated sheat are examples of secondary structures arising from regular and periodic stearic relationships. The **tertiary structure** refers to the spatial arrangement of amino acid residues that are far apart in the linear sequence, giving rise to further coiling and folding. If the protein is tightly coiled and folded into a somewhat spherical shape, it is called a **globular** protein. If the protein consists of long polypeptide chains which are intermolecularly linked, they are called **fibrous** proteins. **Quaternary structure** occurs when proteins with two or more polypeptide chain subunits are associated.

Milk Protein Fractionation

The nitrogen content of milk is distributed among caseins (76%), whey proteins (18%), and non-protein nitrogen (NPN) (6%). This does not include the minor proteins that are associated with the FGM. This nitrogen distribution can be determined by the **Rowland fractionation** method:

1. Precipitation at pH 4.6 - separates caseins from whey nitrogen
2. Precipitation with sodium acetate and acetic acid (pH 5.0) - separates total proteins from whey NPN

The **concentration of proteins in milk** is as follows:

	grams/ litre	% of total protein

Total Protein	33	100
Total Caseins	26	79.5
alpha s1	10	30.6
alpha s2	2.6	8.0
beta	9.3	28.4
kappa	3.3	10.1
Total Whey Proteins	6.3	19.3
alpha lactalbumin	1.2	3.7
beta lactoglobulin	3.2	9.8
BSA	0.4	1.2
Immunoglobulins	0.7	2.1
Proteose peptone	0.8	2.4

Caseins, as well as their structural form - casein micelles, whey proteins, and milk enzymes will now be examined in further detail.

Caseins

The casein content of milk represents about 80% of milk proteins. The principal casein fractions are **alpha(s1)** and **alpha(s2)-caseins, ß -casein**, and **kappa-casein**. The distinguishing property of all caseins is their low solubility at pH 4.6. The common compositional factor is that caseins are **conjugated proteins**, most with phosphate group(s) esterified to serine residues. These phosphate groups are important to the structure of the casein micelle. Calcium binding by the individual caseins is proportional to the phosphate content.

The conformation of caseins is much like that of denatured globular proteins. The high number of **proline residues** in caseins causes particular bending of the protein chain and inhibits the formation of close-packed, ordered secondary structures. As well, the lack of tertiary structure accounts for the stability of caseins against heat denaturation because there is very little structure to unfold. Without a tertiary structure there is considerable exposure of hydrophobic residues. This results in strong association reactions of the caseins and renders them insoluble in water. Within the group of caseins, there are several distinguishing features based on their charge distribution and sensitivity to calcium precipitation:

alpha(s1)-casein:

Two hydrophobic regions, containing all the proline residues, separated by a polar region, which contains all but one of eight phophate groups. It can be precipitated at very low levels of calcium.

alpha(s2)-casein:

Concentrated negative charges near N-terminus and positive charges near C-terminus. It can also be precipitated at very low levels of calcium.

ß -casein:

Highly charged N-terminal region and a hydrophobic C-terminal region. Very amphiphilic protein acts like a detergent molecule. Self association is temperature dependant; will form a large polymer at 20° C but not at 4° C. Less sensitive to calcium precipitation.

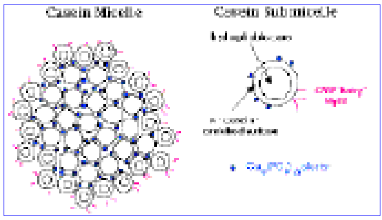
kappa-casein:

Very resistant to calcium precipitation, stabilizing other caseins. Rennet cleavage at the Phe105-Met106 bond eliminates the stabilizing ability, leaving a hydrophobic portion, para-kappa-casein, and a hydrophilic portion called kappa-casein glycomacropeptide (GMP), or more accurately, **caseinomacropeptide** (CMP).

Structure: The Casein Micelle

Most, but not all, of the casein proteins exist in a colloidal particle known as the **casein micelle**. Its biological function is to carry large amounts of highly insoluble CaP to mammalian young in liquid form and to form a clot in the stomach for more efficient nutrition. Besides casein protein, calcium and phosphate, the micelle also contains citrate, minor ions, lipase and plasmin enzymes, and entrapped milk serum. The "casein sub-micelle" model has been prominent for the last several years, and is illustrated and described here, but there is not universal acceptance of this model, and mounting research evidence to suggest that there is not a defined sub-micellar structure to the micelle at all.

In the submicelle model, it is throught that there are small aggregates of whole casein, containing 10 to 100 casein molecules, called **submicelles**. It is thought that there are two different kinds of submicelle; with and without kappa-casein. These submicelles contain a hydrophobic core and are covered by a hydrophilic coat which is at least partly comprised of the polar moieties of kappa-casein. The hydrophilic CMP of the kappa-casein exists as a flexible hair.



Casein Micelle Structure 17 KB

Colloidal calcium phosphate (CCP) acts as a cement between the hundreds or even thousands of submicelles that form the casein micelle. Binding may be covalent or electrostatic. Submicelles rich in kappa-casein occupy a surface position, whereas those with less are buried in the interior. The resulting hairy layer, at least 7 nm thick, acts to prohibit further aggregation of submicelles by **steric repulsion**. The casein micelles are not static; there are three dynamic equilibria between the micelle and its surroundings:

- the free casein molecules and submicelles
- the free submicelles and micelles
- the dissoved colloidal calcium and phosphate

The following factors must be considered when assessing the **stability of the casein micelle**:

Role of Ca++:

More than 90% of the calcium content of skim milk is associated in some way or another with the casein micelle. The removal of Ca++ leads to reversible dissociation of ß -casein without micellular disintegration. The addition of Ca++ leads to aggregation.

H Bonding:

Some occurs between the individual caseins in the micelle but not much because there is no secondary structure in casein proteins.

Disulphide Bonds:

alpha(s1) and ß-caseins do not have any cysteine residues. If any S-S bonds occur within the micelle, they are not the driving force for stabilization.

Hydrophobic Interactions:

Caseins are among the most hydrophobic proteins and there is some evidence to suggest they play a role in the stability of the micelle. It must be remembered that hydrophobic interactions are very temperature sensitive.

Electrostatic Interactions:

Some of the subunit interactions may be the result of ionic bonding, but the overall micellar structure is very loose and open.

van der Waals Forces:

No sucess in relating these forces to micellular stability.

Steric stabilization:

As already noted, the hairy layer interferes with interparticle approach.

There are several factors that will affect the stability of the casein micelle system:

Salt content:

affects the calcium activity in the serum and calcium phosphate content of the micelles.

pH:

lowering the pH leads to dissolution of calcium phosphate until, at the isoelectric point (pH 4.6), all phosphate is dissolved and the caseins precipitate.

Temperature:

at 4° C, beta-casein begins to dissociate from the micelle, at 0° C, there is no micellar aggregation; freezing produces a precipitate called cryo-casein.

Heat Treatment:

whey proteins become adsorbed, altering the behaviour of the micelle.

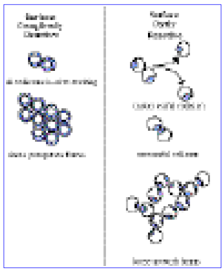
Dehydration:

by ethanol, for example, leads to aggregation of the micelles.

When two or more of these factors are applied together, the effect can also be additive.

Casein micelle aggregation

Caseins are able to aggregate if the surface of the micelle is reactive. The Schmidt model further illustrates this.



Casein micelle aggregation 17 KB

Although the casein micelle is fairly stable, there are four major ways in which aggregation can be induced:

1. chymosin - rennet or other proteolytic enzymes as in Cheese manufacturing
2. acid
3. heat
4. age gelation

Enzyme Coagulation

Chymosin, or **rennet**, is most often used for enzyme coagulation. During the **primary stage**, rennet cleaves the Phe(105)-Met(106) linkage of kappa-casein resulting in the formation of the soluble CMP which diffuses away from the micelle and para-kappa-casein, a distinctly hydrophobic peptide that remains on the micelle. The patch or reactive site, as illustrated in the above image, that is left on the micelles after enzymatic cleavage is necessary before aggregation of the paracasein micelles can begin.

During the **secondary stage**, the micelles aggregate. This is due to the loss of stearic repulsion of the kappa-casein as well as the loss of electrostatic repulsion due to the decrease in pH. As the pH approaches its isoelectric point (pH 4.6), the caseins aggregate. The casein micelles also have a strong tendency to aggregate because of hydrophobic interactions. Calcium assists coagulation by creating isoelctric conditions and by acting as a bridge between micelles. The temperature at the time of coagulation is very important to both the primary and secondary stages. With an increase in temperature up to 40° C, the rate of the rennet reaction increases. During the secondary stage, increased temperatures increase the hydrophobic reaction. The **tertiary stage** of coagulation involves the rearrangement of micelles after a gel has formed. There is a loss of paracasein identity as the milk curd firms and syneresis begins.

Acid Coagulation

Acidification causes the casein micelles to destabilize or aggregate by decreasing their electric charge to that of the isoelectric point. At the same time, the acidity of the medium increases the solubility of minerals so that organic calcium and phosphorus contained in the micelle gradually become soluble in the aqueous phase. Casein micelles disintegrate and casein precipitates. Aggregation occurs as a result of entropically driven hydrophobic interactions.

Heat

At temperatures above the boiling point casein micelles will irreversibly aggregate. On heating, the buffer capacity of milk salts change, carbon dioxide is released, organic acids are produced, and tricalcium phophate and casein phosphate may be precipitated with the release of hydrogen ions.

Age Gelation

Age gelation is an aggregation phenomenon that affects shelf-stable, sterilized dairy products, such as concentrated milk and UHT milk products. After weeks to months storage of these products, there is a sudden sharp increase in viscosity accompanied by visible gelation and irreversible aggregation of the micelles into long chains forming a three-dimensional network. The actual cause and mechanism is not yet clear, however, some theories exist:

1. Proteolytic breakdown of the casein: bacterial or native plasmin enzymes that are resistant to heat treatment may lead to the formation of a gel
2. Chemical reactions: polymerization of casein and whey proteins due to Maillard type or other chemical reactions
3. Formation of kappa-casein-ß -lactoglobulin complexes

An excellent source of information on casein micelle stability can be found in Walstra.

Whey Proteins

The proteins appearing in the supernatant of milk after precipitation at pH 4.6 are collectively called whey proteins. These globular proteins are more water soluble than caseins and are subject to heat denaturation. Native whey proteins have good gelling and whipping properties. Denaturation increases their water holding capacity. The principle fractions are **ß -lactoglobulins, alpha-lactalbumins, bovine serum albumin (BSA)**, and **immunoglobulins (Ig)**.

ß -Lactoglobulins: (MW - 18,000) This group, including eight genetic variants, comprises approximately half the total whey proteins. It has two internal disulfide bonds and one free thiol group. The conformation includes considerable secondary structures and exists naturally as a noncovalent linked dimer. At the isoelectric point (ph 3.5 to 5.2), the dimers are further associated to octamers but at pH below 3.4, they are dissociated to monomers.

alpha-Lactalbumins: (MW - 14,00) These proteins contain eight cysteine groups, all involved in internal disulfide bonds, and four tryptophan residues. It has a highly ordered secondary structure, and a compact, spherical tertiary structure. Thermal denaturation and pH <4.0 results in the release of bound calcium.

Enzymes

Enzymes are a group of proteins that have the ability to catalyze chemical reactions and the speed of such reactions. The action of enzymes is very specific. Milk contains both **indigenous** and **exogenous** enzymes. Exogenous enzymes mainly consist of heat-stable enzymes produced by psychrotrophic bacteria: lipases, and proteinases. There are many indigenous enzymes that have been isolated from milk. The most significant group are the hydrolases:

- lipoprotein lipase
- plasmin

- alkaline phosphatase

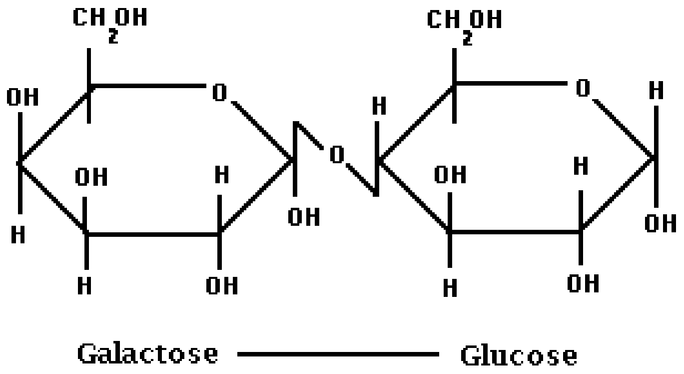
Lipoprotein lipase (LPL): A lipase enzyme splits fats into glycerol and free fatty acids. This enzyme is found mainly in the plasma in association with casein micelles. The milkfat is protected from its action by the FGM. If the FGM has been damaged, or if certain cofactors (blood serum lipoproteins) are present, the LPL is able to attack the lipoproteins of the FGM. Lipolysis may be caused in this way.

Plasmin: Plasmin is a proteolytic enzyme; it splits proteins. Plasmin attacks both ß -casein and alpha(s2)-casein. It is very heat stable and responsible for the development of bitterness in pasteurized milk and UHT processed milk. It may also play a role in the ripening and flavour development of certain cheeses, such as Swiss cheese.

Alkaline phosphatase: Phosphatase enzymes are able to split specific phosporic acid esters into phosphoric acid and the related alcohols. Unlike most milk enzymes, it has a pH and temperature optima differing from physiological values; pH of 9.8. The enzyme is destroyed by minimum pasteurization temperatures, therefore, a phosphatase test can be done to ensure proper pasteurization.

Lactose

Lactose is a disaccharide (2 sugars) made up of glucose and galactose (which are both monosaccharides).



It comprises 4.8 to 5.2% of milk, 52% of milk SNF, and 70% of whey solids. It is not as sweet as sucrose. When lactose is hydrolyzed by **ß -D-galactosidase (lactase)**, an enzyme that splits these monosaccharides, the result is increased sweetness, and depressed freezing point.

One of its most important functions is its utilization as a fermentation substrate. Lactic acid bacteria produce lactic acid from lactose, which is the beginning of many fermented dairy products. Because of their ability to metabolize lactose, they have a competitive advantage over many pathogenic and spoilage organisms.

Some people suffer from **lactose intolerance**; they lack the lactase enzyme, hence they cannot digest lactose, or dairy products containing lactose. Crystallization of lactose occurs in an alpha form which commonly takes a **tomahawk** shape. This results in the defect called sandiness. Lactose is relatively insoluble which is a problem in many dairy products, ice cream, sweetened condensed milk. In addition to lactose, fresh milk contains other carbohydrates in small amounts, including glucose, galactose, and oligosaccharides.

Vitamins

Vitamins are organic substances essential for many life processes. Milk includes fat soluble vitamins A , D, E, and K. Vitamin A is derived from retinol and ß -carotene. Because milk is an important source of dietary vitamin A, fat reduced products which have lost vitamin A with the fat, are required to supplement the product with vitamin A.

Milk is also an important source of dietary water soluble vitamins:

- B1 - thiamine
- B2 - riboflavin
- B6 - pyridoxine
- B12 - cyanocobalamin
- niacin
- pantothenic acid

There is also a small amount of vitamin C (ascorbic acid) present in raw milk but is very heat-labile and easily destroyed by pasteurization.

The vitamin content of fresh milk is given below:

Vitamin	Contents per litre
A (ug RE)	400
D (IU)	40
E (ug)	1000
K (ug)	50
B1 (ug)	450
B2 (ug)	1750
Niacin (ug)	900
B6 (ug)	500
Pantothenic acid (ug)	3500
Biotin (ug)	35
Folic acid (ug)	55
B12 (ug)	4.5
C (mg)	20

Minerals

All 22 minerals considered to be essential to the human diet are present in milk. These include three families of salts:

1. **Sodium (Na), Potassium (K) and Chloride (Cl):**These free ions are negatively correlated to lactose to maintain osmotic equilibrium of milk with blood
2. **Calcium (Ca), Magnesium (Mg), Inorganic Phosphorous (P(i)), and Citrate:** This group consits of 2/3 Ca, 1/3 Mg, 1/2 P(i), and less than 1/10 citrate in colloidal (nondiffusible) form and present in the casein micelle.
3. **Diffusible salts of Ca, Mg, citrate, and Ca++, and HPO42-:** These salts are very pH dependent and contribute to the overall acid-base equilibrium of milk

   The mineral content of fresh milk is given below:

Mineral	Content per litre
Sodium (mg)	350-900
Potassium (mg)	1100-1700
Chloride (mg)	900-1100
Calcium (mg)	1100-1300
Magnesium (mg)	90-140
Phosphorus (mg)	900-1000
Iron (ug)	300-600
Zinc (ug)	2000-6000
Copper (ug)	100-600
Manganese (ug)	20-50

Iodine (ug)	260
Fluoride (ug)	30-220
Selenium (ug)	5-67
Cobalt (ug)	0.5-1.3
Chromium (ug)	8-13
Molybdenum (ug)	18-120
Nickel (ug)	0-50
Silicon (ug)	750-7000
Vanadium (ug)	tr-310
Tin (ug)	40-500
Arsenic (ug)	20-60

Physical Properties

Density

The density of milk and milk products is used for the following;

- to convert volume into mass and vice versa
- to estimate the solids content
- to calculate other physical properties (e.g. kinematic viscosity)

Density, the mass of a certain quantity of material divided by its volume, is dependant on the following:

- temperature at the time of measurement
- temperature history of the material
- composition of the material (especially the fat content)
- inclusion of air (a complication with more viscous products)

With all of this in mind, the density of milk varies within the range of 1027 to 1033 kg m(-3) at 20° C.

The following table gives the density of various fluid dairy products as a function of fat and solids-not-fat (SNF) composition:

	Product Composition		Density (kg/m(2)) at:			
Product	Fat (%)	SNF (%)	4.4° C	10° C	20° C	38.9° C
Producer milk	4.00	8.95	1.035	1.033	1.030	1.023
Homogenized milk	3.6	8.6	1.033	1.032	1.029	1.022
Skim milk, pkg	0.02	8.9	1.036	1.035	1.033	1.026
Fortified skim	0.02	10.15	1.041	1.040	1.038	1.031
Half and half	12.25	7.75	1.027	1.025	1.020	1,010
Half and half, fort.	11.30	8.9	1.031	1.030	1.024	1.014
Light cream	20.00	7.2	1.021	1.018	1.012	1.000
Heavy cream	36.60	5.55	1.008	1.005	0.994	0.978

Viscosity

Viscosity of milk and milk products is important in determining the following:

- the rate of creaming
- rates of mass and heat transfer
- the flow conditions in dairy processes

Milk and skim milk, excepting cooled raw milk, exhibit Newtonian behavior, in which the viscosity is independent of the rate of shear. The viscosity of these products depends on the following:

- Temperature:
  - cooler temperatures increase viscosity due to the increased voluminosity of casein micelles
  - temperatures above 65° C increase viscosity due to the denaturation of whey proteins
- pH: an increase or decrease in pH of milk also causes an increase in casein micelle voluminosity

Cooled raw milk and cream exhibit **non-Newtonian** behavior in which the viscosity is dependant on the shear rate. Agitation may cause partial coalescence of the fat globules (partial churning) which increases viscocity. Fat globules that have under gone cold agglutination, may be dispersed due to agitation, causing a decrease in viscosity.

Freezing Point

Freezing point is a ***colligative property*** which is determined by the molarity of solutes rather than by the percentage by weight or volume. In the dairy industry, freezing point is mainly used to determine **added water** but it can also been used to determine lactose content in milk, estimate whey powder contents in skim milk powder, and to determine water activity of cheese. The freezing point of milk is usually in the range of -0.512 to -0.550° C with an average of about **-0.522° C**.

Correct interpretation of freezing point data with respect to added water 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 the access to water. Under feeding causes increased freezing points. Large temporary increases in freezing point occur after consumption of large amounts of water because milk is iso-osmotic with blood. The primary sources of non-intentional added water in milk are residual rinse water and condensation in the milking system.

Acid-Base Equilibria

Both ***titratable acidity*** and ***pH*** are used to measure milk acidity. The pH of milk at 25° C normally varies within a relatively narrow range of **6.5** to **6.7**. The normal range for titratable acidity of herd milks is **13 to 20 mmol/L**. Because of the large inherent variation, the measure of titratable acidity has little practical value except to measure changes in acidity (eg., during lactic fermentation) and even for this purpose, pH is a better measurement.
There are many components in milk which provide a buffering action. The major buffering groups of milk are caseins and phosphate.

Optical Properties

Optical properties provide the basis for many rapid, indirect methods of analysis such as proximate analysis by infrared absorbency or light scattering. Optical properties also determine the appearance of milk and milk products. Light scattering by fat globules and casein micelles causes milk to appear turbid and opaque. Light scattering occurs when the wave length of light is near the same magnitude as the particle. Thus, smaller particles scatter light of shorter wavelengths. Skim milk appears slightly blue because casein micelles scatter the shorter wavelengths of visible light (blue) more than the red. The carotenoid precursor of vitamin A, ß -carotene, contained in milk fat, is responsible for the 'creamy' colour of milk. Riboflavin imparts a greenish colour to whey.
Refractive index (RI) is normally determined at 20° C with the D line of the sodium spectrum. The refractive index of milk is 1.3440 to 1.3485 and can be used to estimate total solids.

More information on dairy chemistry can be found in Walstra and Jenness, Goff and Hill, and Wong et al.

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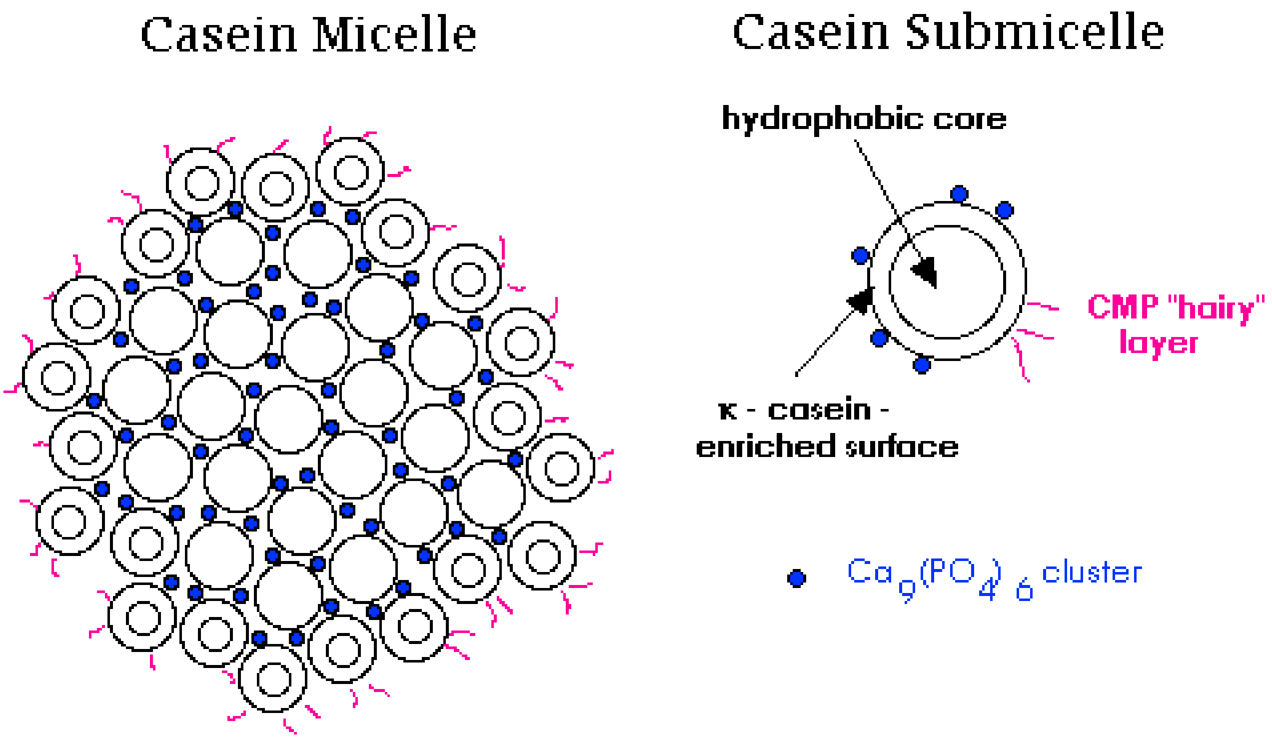
Casein Micelle structure

This model is that of the "casein sub-micelle" model. There is not universal acceptance of this model among dairy scientists, in fact there is mounting evidence that well-defined casein submicelles do not exist, rather the structure is more open and fluid, perhaps a "bowl-of-spaghetti" type of model. However, scientists do know a great deal about the micelle from its behaviour, and any model needs to account for all of the known facts. It may be many years yet before out visualizationtechniques allow us to know the true structure of the casein micelle.



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Milk Grading and Defects

The importance of milk grading lies in the fact that dairy products are only as good as the raw materials from which they were made. It is important that dairy personnel have a knowledge of sensory perception and evaluation techniques. The identification of off-flavours and desirable flavours, as well as knowledge of their likely cause, should enable the production of high quality milk, and subsequently, high quality dairy products.

Milk Grading

- Sense of Taste
- Sense of Smell
- Techniques

Milk Defects

- Lipolyzed
- Oxidiation
- Sunlight
- Cooked
- Transmitted
- Microbial

Milk Grading

An understanding of the principles of sensory evaluation are neccessary for grading. All five primary senses are used in the sensory evaluation of dairy products: sight, taste, smell, touch and sound. The greatest emphasis, however, is placed on taste and smell.

The Sense of Taste

Taste buds, or receptors, are chiefly on the upper surface of the tongue, but may also be present in the cheek and soft palates of young people. These buds, about 900 in number, must make contact with the flavouring agent before a taste sensation occurs. Saliva, of course, is essential in aiding this contact. There are four different types of nerve endings on the tongue which detect the four basic "mouth" flavours - **sweet, salt, sour, and bitter**. Samples must, therefore, be spread around in the mouth in order to make positive flavour identification. In addition to these basic tastes, the mouth also allows us to get such reactions as coolness, warmth, sweetness, astringency, etc.

The Sense of Smell

We are much more perceptive to the sense of smell than we are to taste. For instance, it is possible for an odouriferous material such as mercaptain to be detected in 20 billion parts of air. The centres of olfaction are located chiefly in the uppermost part of the nasal cavity. To be detectable by smell, a substance must dissolve at body temperature and be soluble in fat solvents.

Note: The sense of both taste and smell may become fatigued during steady use. A good judge does not try to examine more than one sample per minute. Rinsing the mouth with water between samples may help to restore sensitivity.

Milk Grading Techniques

Temperature should be between 60-70° F (15.5-21° C) so that any odour present may be detected readily by sniffing the container. Also, we want a temperature rise when taking the sample into the mouth; this serves to volatize any notable constituents.

Noting the odour by placing the nose directly over the container immediately after shaking and taking a full "whiff" of air. Any off odour present may be noted.

Need to make sure we have a representative sample; mixing and agitation are important.

Agitation leaves a thin film of milk on the inner surface which tends to evaporate giving off odour if present.

During sampling, take a generous sip, roll about the mouth, note flavour sensation, and expectorate. Swallowing milk is a poor practice.

Can enhance the after-taste by drawing a breath of fresh air slowly through the mouth and then exhale slowly through the nose. With this practice, even faint odours can be noted.

Milk has a flavour defect if it has an odour, a foretaste or an aftertaste, or does not leave the mouth in a clean, sweet, pleasant condition after tasting.

Characterization of Flavour Defects - ADSA

Lipolytic or Hydrolytic rancidity

Rancidity arises from the hydrolysis of milkfat by an enzyme called the lipoprotein lipase (LPL). The flavour is due to the short chain fatty acids produced, particularly **butyric acid**. LPL can be indigenous or bacterial. It is active at the fat/water interface but is ineffective unless the fat globule membrane is damaged or weakened. This may occur through agitation, and/or foaming, and pumping. For this reason, homogenized milk is subject to rapid lipolysis unless lipase is destroyed by heating first; the enzyme (protein) is denatured at 55-60° C. Therefore, always homogenize milk immediately before or after pasteurization and avoid mixing new and homogenized milk because it leads to rapid rancidity.

Some cows can produce spontaneous lipolysis from reacting to something indigenous to the milk. Late lactation, mastitis, hay and grain ratio diets (more so than fresh forage or silage), and low yielding cows are more suseptible.

Lipolysis can be detected by measuring the acid degree value which determines the presence of free fatty acids. Lipolytic or hydrolytic rancidity is distinct from oxidative rancidity, but frequently in other fat industries, rancid is used to mean oxidative rancidity; in dairy, rancidity means lipolysis.

Characterized: soapy, blue-cheese like aroma, slightly bitter, foul, pronounced aftertaste, does not clear up readily

Oxidation

Milk fat oxidation is catalysed by copper and certain other metals with oxygen and air. This leads to an autooxidation reaction consisting of initiation, propagation, termination.

RH --- R + H **initiation** - free radical

R + O2 ---- RO2 **propagation**

RO2 + RH --- ROOH + R

R + R --- R2 **termination**

R + RO2 --- RO2R

It is usually initiated in the phospholipid of the fat globule membrane. Propagation then occurs in triglycerides, primarily double bonds of unsaturated fatty acids. During propagation, peroxide derivatives of fatty acids accumulate. These undergo further reactions to form carbonyls, of which some, like aldehydes and ketones, have strong flavours. Dry feed, late lactation, added copper or other metals, lack of vit E (tocopherol) or selenium (natural antioxidates) in the diet all lead to spontaneous oxidation. It can be a real problem especially in winter. Exposure to metals during processing can also contribute.

Characterized: metallic, wet cardboard, oily, tallowy, chalky; mouth usually perceives a puckery or astringent feel

Sunlight

Often confused with oxidized, this defect is caused by UV-rays from sunlight or flourescent lighting catalyzing oxidation in unprotected milk. Photo-oxidation activates riboflavin which is responsible for catalyzing the conversion of methionine to methanal. It is, therefore, a protein reaction rather than a lipid reaction. However, the end product flavour notes are similar but tends to diminish after storage of several days.

Characterized: burnt-protein or burnt-feathers-like, "medicinal"-like flavour

Cooked

This defect is a function of the time-temperature of heating and especially the presence of any "burn-on" action of heat on certain proteins, particulary whey proteins. Whey proteins are a source of sulfide bonds which form sulfhydryl groups that contribute to the flavour. The defect is most obvious immediately after heating but dissipates within 1 or 2 days.

Characterized: slightly cooked or nutty-like to scorched or caramelized

Transmitted flavours

Cows are particulary bad for transmitting flavours through milk and milk is equally as susceptible to pick-up of off flavours in storage. Feed flavours and green grass can be problems so it is necessary to remove cows from feed 2-4 hrs before milking. Weeds, garlic/onion, and dandelions can tranfer flavours to the milk and even subsequent products such as butter. Barny flavours can be picked up in the milk if there is poor ventilation and the barn is not properly cleared and cows breathe the air. These flavours are volatile so can be driven off through vacuum de-aeration.

Characterization: hay/silage, cowy/barny

Microbial

There are many flavour defects of dairy products that may be caused by bacteria, yeasts, or moulds. In raw milk the **high acid/sour** flavour is caused by the growth of lactic acid bacteria which ferment lactose. It is less common today due to change in raw milk microflora. In both raw or processed milk, **fruity** flavours may arise due to psychrotrophs such as *Pseudomonas fragi*. **Bitter or putrid** flavours are caused by psychrotrophic bacteria which produce protease. It is the proteolytic action of protease that usually causes spoilage in milk. **Malty** flavours are caused by *S.lactis* var. *maltigenes* and is characterized by a corn flakes type flavour. Although more of a tactile defect, **ropy** milk is also caused by bacteria, specifically those which produce exopolysaccharides.

Miscellaneous Defects

- astringent
- chalky
- chemical/medicinal - disease - associated or adulteration
- flat - adulteration (water)
- foreign
- salty - disease associated
- bitter - adulteration

More information on off-flavours in milk can be found in Bassette et al., and Shipe et al.

Milk flavour is graded on a score of one to 10. Some flavour defects, even if only slightly present, can decrease the score drastically. The following are suggested flavour scores for milk with designated intensities of flavour defects.

Flavour		Intensity of Defect	
Criticisms	Slight	Definite	Pronounced
Astringent	8	7	5
Barny	7	5	3
Bitter	7	5	3
Cooked	9	8	6
Cowy	6	4	1
Feed	9	7	5
Flat	9	8	7
Foreign	5	3	0
Garlic/onion	5	3	1
High acid	3	1	0
Bacterial	5	3	0
Lacks Freshness	7	5	3
Malty	7	5	3
Oxidized	7	5	3
Rancid	7	5	3
Salty	8	6	4
Unclean	7	5	3

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Glossary of Terms

Boiling Point Elevation: One of the colligative properties. The boiling point of a solution is increased over that of water by the presence of solutes, and the extent of the increase is a function of both concentration and molecular weight.

Colligative Properties: Properties which depend on the number of molecules in solution, a function of concentration and molecular weight, rather than just on the total percent concentration. Such properties include boiling point elevation, freezing point depression, and osmotic concentration.

Emulsion: liquid droplets dispersed in another immiscible liquid. The dispersed phase droplet size ranges from 0.1 - 10 μ m. Important oil-in-water food emulsions, ones in which oil or fat is the dispersed phase and water is the continuous phase, include milk, cream, ice cream, salad dressings, cake batters, flavour emulsions, meat emulsions, and cream liquers. Examples of food water-in-oil emulsions are butter or margarine. Emulsions are inherently unstable because free energy is associated with the interface between the two phases. As the interfacial area increases, either through a decrease in particle size or the addition of more dispersed phase material, i.e. higher fat, more energy is needed to keep the emulsion from coalescing. Some molecules act as surface active agents (called surfactants or emulsifiers) and can reduce this energy needed to keep these phases apart.

Foam: a gas dispersed in a liquid where the gas bubbles are the discrete phase. There are many food foams including whipped creams, ice cream, carbonated soft drinks, mousses, meringues, and the head of a beer. A foam is likewise unstable and needs a stabilizing agent to form the gas bubble membrane.

Freezing point depression: of a solution is a colligative property associated with the number of dissolved molecules. The lower the molecular weight, the greater the ability of a molecule to depress the freezing point for any given concentration. For example, in ice cream manufacturing, monosaccharides such as fructose or glucose produce a much softer ice cream than disaccharides such as sucrose, if the concentration of both is the same.

Osmotic pressure: A chemical force caused by a concentration gradient. It is a colligative property and the principle behind membrane processing.

pH: pH is a measure of the activity of the hydronium ion (H3O+) which, according to the Debye-Huckel expression, is a function of the concentration of the hydronium ion [H3O+], the effective diameter of the hydrated ion and the ionic strength (µ m) of the solvent. For solutions of low ionic strength (µ m < 0.1) hydronium ion activity is nearly equivalent to [H3O+] which is normally abbreviated to [H+]. Then, for a weak acid (HA) dissociating to H+ and A- with a dissociation constant, Ka and pKa equal to -log10 Ka, the most important relationships are defined the following two equations:

$$Ka = [H+]\ [A-] / [HA]$$

$$pH = \log\ 1 / [H+] = pKa + \log [A-] / [HA]$$

Reynold's Number: a dimensionless expression used in predicting flow patterns:

$$\boxed{N_{Re} = \frac{D\,V\,C}{\eta}}$$

D = inside pipe diameter

V = average velocity

C = density

η = absolute viscosity

Stoke's Law: The velocity at which a sphere will rise or fall in a liquid varies as the square of its diameter:

$$V = \frac{d^2 (ld - lc) rw^2}{18 n}$$

V = particle velocity
d = particle diameter
ld = discreter phase density
lc = continuous phase density
r = separation radius from axis of rotation
w = angular velocity
n = continuous phase viscocity

For example, a fat globule with a diameter of 2 microns will rise 4 times faster than a fat globule with a diameter of 1 micron.

Titratable acidity: A measure of titaratable hydrogen ions. Includes H+ ions free in solution and those associated with acids and proteins.

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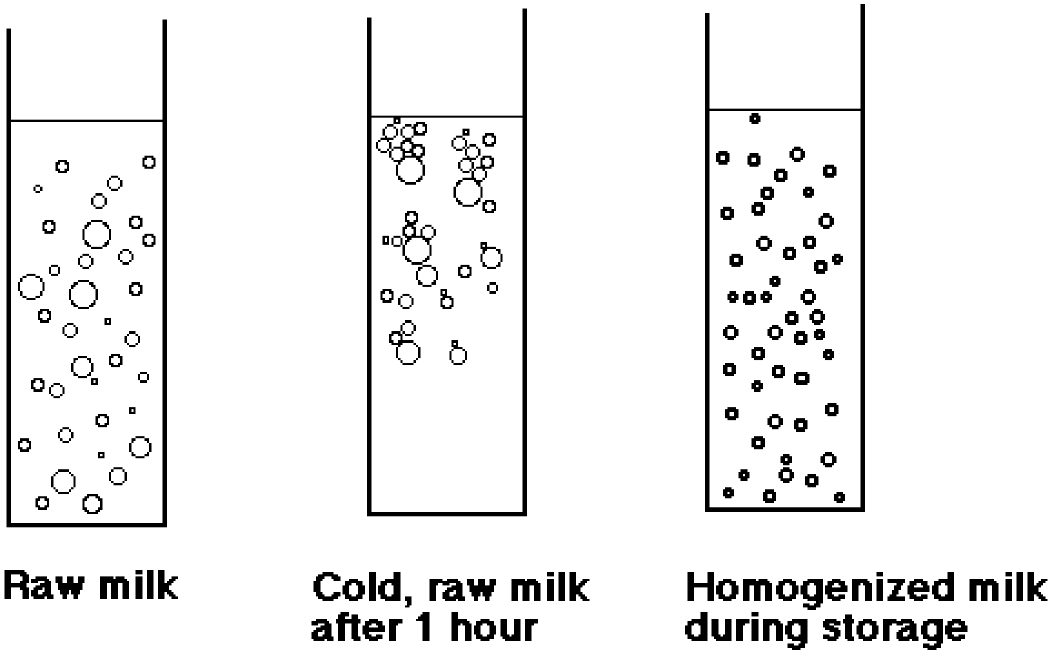
Homogenization of Milk and Milk Products

The following topics will be covered in this section:

- Introduction
- Homogenization Mechanism
    - turbulence
    - cavitation
- Effect Of Homogenization
    - fat globule properties
    - surface layers

Introduction

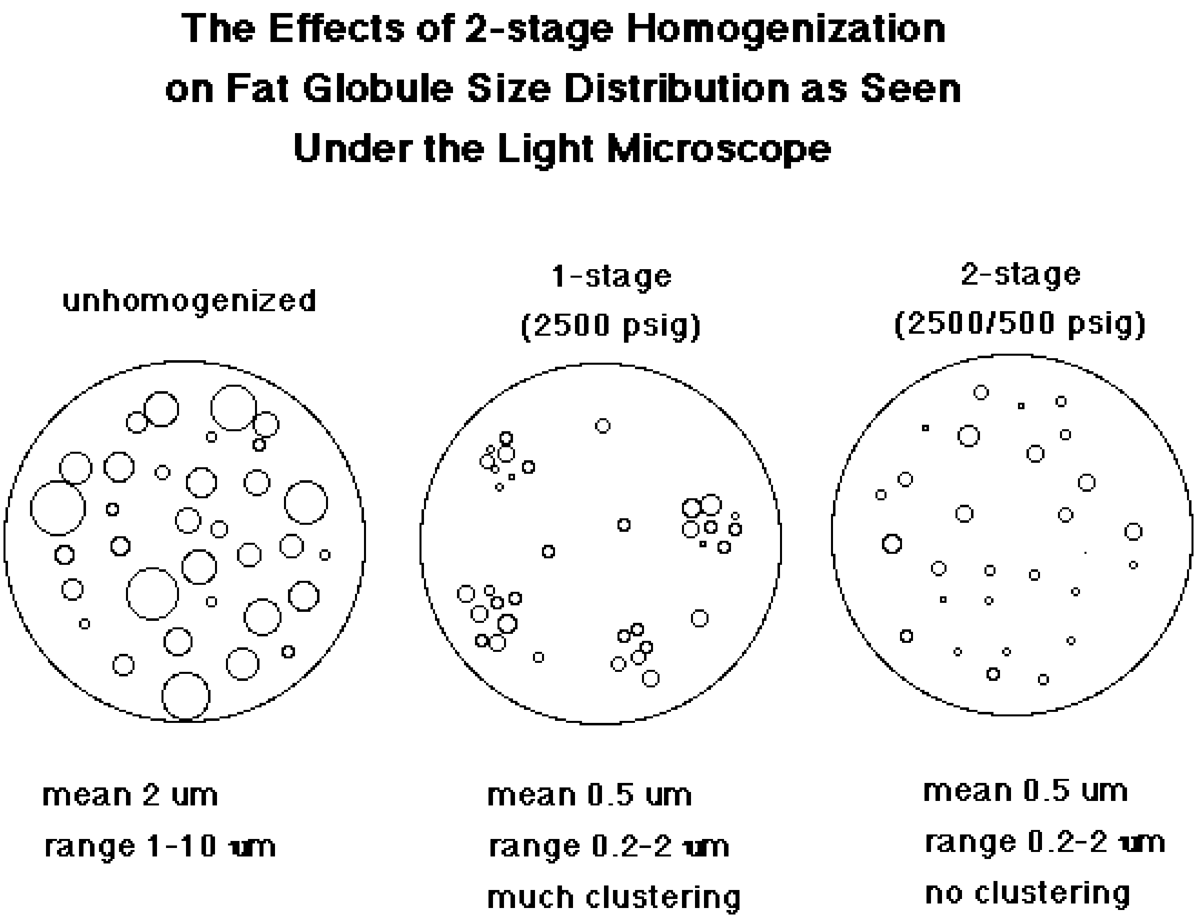
Milk is an oil-in-water ***emulsion***, with the fat globules dispersed in a continuous skimmilk phase. If raw milk were left to stand, however, the fat would rise and form a cream layer. Homogenization is a mechanical treatment of the fat globules in milk brought about by passing milk under high pressure through a tiny orifice, which results in a decrease in the average diameter and an increase in number and surface area, of the fat globules. The net result, from a practical view, is a much reduced tendency for creaming of fat globules. Three factors contribute to this enhanced stability of homogenized milk: a decrease in the mean diameter of the fat globules (a factor in Stokes Law), a decrease in the size distribution of the fat globules (causing the speed of rise to be similar for the majority of globules such that they don't tend to cluster during creaming), and an increase in density of the globules (bringing them closer to the continuous phase) oweing to the adsorption of a protein membrane. In addition, heat pasteurization breaks down the cryo-globulin complex, which tends to cluster fat globules causing them to rise.

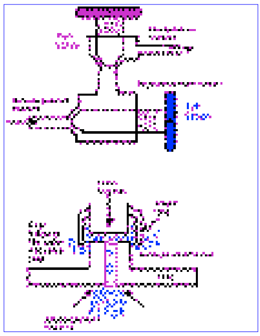


Homogenization Mechanism

Auguste Gaulin's patent in 1899 consisted of a 3 piston pump in which product was forced through one or more hair like tubes under pressure. It was discovered that the size of fat globules produced were 500 to 600 times smaller than tubes. There have been over 100 patents since, all designed to produce smaller average particle size with expenditure of as little energy as possible. The homogenizer consists of a 3 cylinder positive piston pump (operates similar to car engine) and homogenizing valve. The pump is turned by electric motor through connecting rods and crankshaft.

To understand the mechanism, consider a conventional homogenizing valve processing an emulsion such as milk at a flow rate of 20,000 l/hr. at 14 MPa (2100 psig). As it first enters the valve, liquid velocity is about 4 to 6 m/s. It then moves into the gap between the valve and the valve seat and its velocity is increased to 120 meter/sec in about 0.2 millisec. The liquid then moves across the face of the valve seat (the land) and exits in about 50 microsec. The homogenization phenomena is completed before the fluid leaves the area between the valve and the seat, and therefore emulsification is initiated and completed in less than 50 microsec. The whole process occurs between 2 pieces of steel in a steel valve assembly. The product may then pass through a second stage valve similar to the first stage. While most of the fat globule reduction takes place in the first stage, there is a tendency for clumping or clustering of the reduced fat globules. The second stage valve permits the separation of those clusters into individual fat globules.




Homogenizer and Valve 17 KB

It is most likely that a combination of two theories, turbulence and cavitation, explains the reduction in size of the fat globules during the homogenization process.

Turbulence

Energy, dissipating in the liquid going through the homogenizer valve, generates intense turbulent eddies of the same size as the average globule diameter. Globules are thus torn apart by these eddie currents reducing their average size.

Cavitation

Considerable pressure drop with charge of velocity of fluid. Liquid cavitates because its vapor pressure is attained. Cavitation generates further eddies that would produce disruption of the fat globules.

The high velocity gives liquid a high kinetic energy which is disrupted in a very short period of time. Increased pressure increases velocity. Dissipation of this energy leads to a high energy density (energy per volume and time). Resulting diameter is a function of energy density.

In summary, the homogenization variables are:

- type of valve
- pressure
- single or two-stage
- fat content
- surfactant type and content
- viscosity
- temperature

Also to be considered are the droplet diameter (the smaller, the more difficult to disrupt), and the log diameter which decreases linearly with log P and levels off at high pressures.

Effect of Homogenization:

Fat globule

	No Homogenization	15 MPa (2500 psig)
Av. diam. (μ m)	3.3	0.4
Max. diam. (μ m)	10	2
Surf. area (m^2/ml of milk)	0.08	0.75
Number of globules (μ m^{-3})	0.02	12

Surface layer

The milk fat globule has a native membrane, picked up at the time of secretion, made of amphiphilic molecules with both hydrophilic and hydrophobic sections. This membrane lowers the interfacial tension resulting in a more stable emulsion. During homogenization, there is a tremendous increase in surface area and the native milk fat globule membrane (MFGM) is lost. However, there are many amphiphilic molecules present from the milk plasma that readily adsorb: casein micelles (partly spread) and whey proteins. The interfacial tension of raw milk is 1-2 mN/m, immediately after homogenization it is unstable at 15 mN/m, and shortly becomes stable (3-4 mN/m) as a result of the adsorption of protein. The transport of proteins is not by diffusion but mainly by convection. Rapid coverage is achieved in less than 10 sec but is subject to some rearrangement.

Surface excess is a measure of how much protein is adsorbed; for example 10 mg/m^2 translates to a thickness of adsorbed layer of approximately 15 nm.

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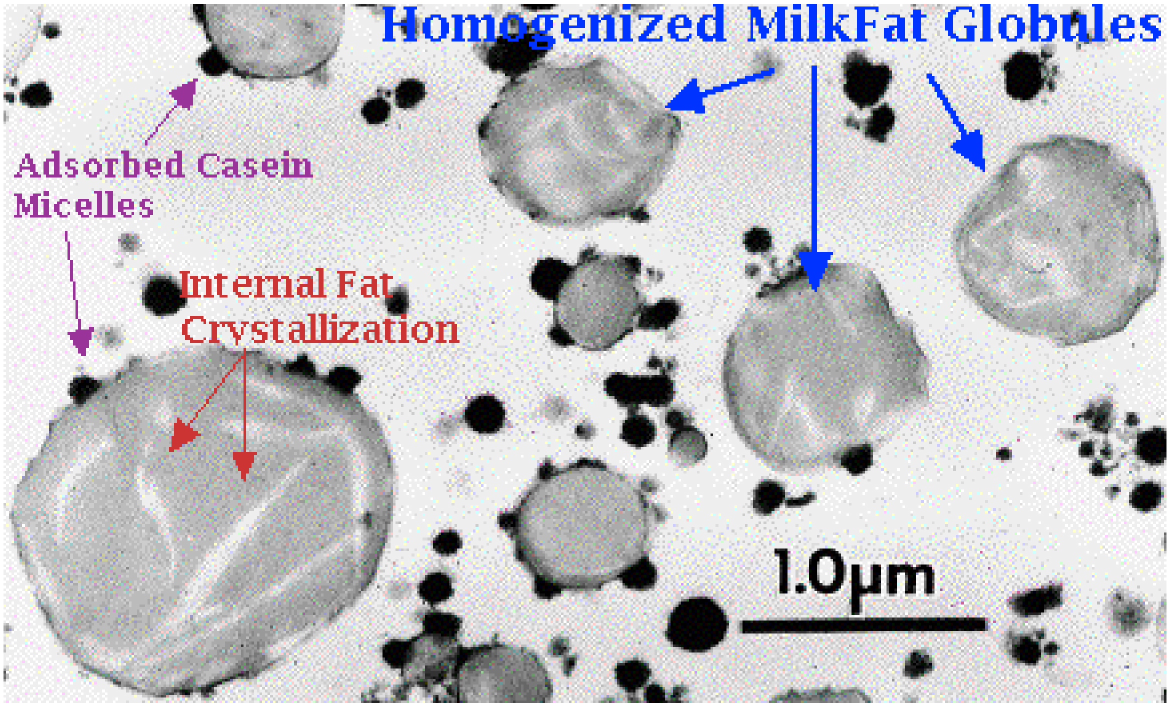

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Dairy Microbiology

Basic Microbiology

- Microorganisms: Bacteria, Yeasts, Moulds
- Microbial Growth
- Detection and Enumeration

Microorganisms in Milk

- Spoilage Microorganisms
- Pathogenic Microorganisms

HACCP

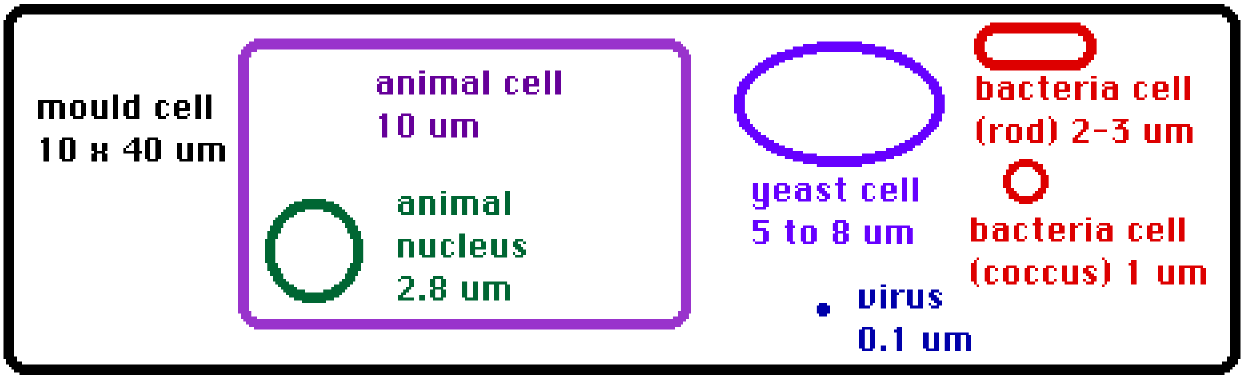
Starter Cultures

- Mesophilic and Thermophilic
- Bacteriophages
- Starter Culture Preparation

Basic Microbiology

Microorganisms

Microorganisms are living organisms that are individually too small to see with the naked eye. The unit of measurement used for microorganisms is the micrometer (μ m); 1 μ m = 0.001 millimeter; 1 nanometer (nm) = 0.001 μ m. Microorganisms are found everywhere (ubiquitous) and are essential to many of our planets life processes. With regards to the food industry, they can cause spoilage, prevent spoilage through fermentation, or can be the cause of human illness.



There are several classes of microorganisms, of which **bacteria** and **fungi** (yeasts and moulds) will be discussed in some detail. Another type of microorganism, the bacterial viruses or **bacteriophage**, will be examined in a later section.

Bacteria

Bacteria are relatively simple single-celled organisms. One method of classification is by shape or morphology:

- **Cocci:**

  - spherical shape

  - 0.4 - 1.5 µ m

  Examples: **staphylococci** - form grape-like clusters; **streptococci** - form bead-like chains
- **Rods:**

  - 0.25 - 1.0 µ m width by 0.5 - 6.0 µ m long

  Examples: **bacilli** - straight rod; **spirilla** - spiral rod

There exists a bacterial system of taxonomy, or classification system, that is internationally recognized with family, genera and species divisions based on genetics.

Some bacteria have the ability to form resting cells known as **endospores**. The spore forms in times of environmental stress, such as lack of nutrients and moisture needed for growth, and thus is a survival strategy. Spores have no metabolism and can withstand adverse conditions such as heat, disinfectants, and ultraviolet light. When the environment becomes favourable, the spore germinates and giving rise to a single vegetative bacterial cell. Some examples of spore-formers important to the food industry are members of ***Bacillus*** and ***Clostridium*** generas.

Bacteria reproduce asexually by **fission** or simple division of the cell and its contents. The doubling time, or **generation time**, can be as short as 20-20 min. Since each cell grows and divides at the same rate as the parent cell, this could under favourable conditions translate to an increase from one to 10 million cells in 11 hours! However, bacterial growth in reality is limited by lack of nutrients, accumulation of toxins and metabolic wastes, unfavourable temperatures and dessication. The maximum number of bacteria is approximately 1 X 10e9 CFU/g or ml.
Note: Bacterial populations are expressed as **colony forming units (CFU)** per gram or millilitre.

Bacterial growth generally proceeds through a series of phases:

- **Lag phase:** time for microorganisms to become accustomed to their new environment. There is little or no growth during this phase.

- **Log phase:** bacteria logarithmic, or exponential, growth begins; the rate of multiplication is the most rapid and constant.
- **Stationary phase:** the rate of multiplication slows down due to lack of nutrients and build-up of toxins. At the same time, bacteria are constantly dying so the numbers actually remain constant.
- **Death phase:** cell numbers decrease as growth stops and existing cells die off.

The shape of the curve varies with temperature, nutrient supply, and other growth factors.

Yeasts

Yeasts are members of a higher group of microorganisms called fungi . They are single-cell organisms of spherical, elliptical or cylindrical shape. Their size varies greatly but are generally larger than bacterial cells. Yeasts may be divided into two groups according to their method of reproduction:

1. **budding:** called Fungi Imperfecti or false yeasts
2. **budding and spore formation:** called Ascomycetes or true yeasts

Unlike bacterial spores, yeast form spores as a method of reproduction.

Moulds

Moulds are filamentous, multi-celled fungi with an average size larger than both bacteria and yeasts (10 X 40 µ m). Each filament is referred to as a **hypha**. The mass of hyphae that can quickly spread over a food substrate is called the **mycelium**. Moulds may reproduce either asexually or sexually, sometimes both within the same species.

Asexual Reproduction:

- fragmentation - hyphae separate into individual cells called arthropsores
- spore production - formed in the tip of a fruiting hyphae, called **conidia**, or in swollen structures called **sporangium**

Sexual Reproduction: sexual spores are produced by nuclear fission in times of unfavourable conditions to ensure survival.

Microbial Growth

There are a number of factors that affect the survival and growth of microorganisms in food. The parameters that are inherent to the food, or **intrinsic factors**, include the following:

- nutrient content
- moisture content
- pH

- available oxygen
- biological structures
- antimicrobial constituents

Nutrient Requirements: While the nutrient requirements are quite organism specific, the microorganisms of importance in foods require the following:

- water
- energy source
- carbon/nitrogen source
- vitamins
- minerals

Milk and dairy products are generally very rich in nutrients which provides an ideal growth environment for many microorganisms.

Moisture Content: All microorganisms require water but the amount necessary for growth varies between species. The amount of water that is available in food is expressed in terms of water activity (aw), where the aw of pure water is 1.0. Each microorganism has a maximum, optimum, and minimum aw for growth and survival. Generally bacteria dominate in foods with high aw (minimum approximately 0.90 aw) while yeasts and moulds, which require less moisture, dominate in low aw foods (minimum 0.70 aw). The water activity of fluid milk is approximately 0.98 aw.

pH: Most microorganisms have approximately a neutral pH optimum (pH 6-7.5). Yeasts are able to grow in a more acid environment compared to bacteria. Moulds can grow over a wide pH range but prefer only slightly acid conditions. Milk has a pH of 6.6 which is ideal for the growth of many microoorganisms.

Available Oxygen: Microorganisms can be classified according to their oxygen requirements necessary for growth and survival:

- Obligate Aerobes: oxygen required
- Facultative: grow in the presence or absence of oxygen
- Microaerophilic: grow best at very low levels of oxygen
- Aerotolerant Anaerobes: oxygen not required for growth but not harmful if present
- Obligate Anaerobes: grow only in complete absence of oxygen; if present it can be lethal

Biological Structures: Physical barriers such as skin, rinds, feathers, etc. have provided protection to plants and animals against the invasion of microorganisms. Milk, however, is a fluid product with no barriers to the spreading of microorganisms throughout the product.

Antimicrobial Constituents: As part of the natural protection against microorganisms, many foods have antimicrobial factors. Milk has several nonimmunological proteins which inhibit the growth and metabolism of many microorganisms including the following most common:

1. lactoperoxidase
2. lactoferrin
3. lysozyme
4. xanthine

More information on these antimicrobials can be found in a chapter on dairy microbiology and safety written by Vasavada and Cousin.

Where the intrinsic factors are related to the food properties, the extrinsic factors are related to the storage environment. These would include temperature, relative humidity, and gases that surround the food.

Temperature: As a group, microorganisms are capable of growth over an extremely wide temperature range. However, in any particular environment, the types and numbers of microorganisms will depend greatly on the temperature. According to temperature, microorganisms can be placed into one of three broad groups:

- **Psychrotrophs:** optimum growth temperatures 20 to 30° capable of growth at temperatures less than 7° C. Psychrotrophic organisms are specifically important in the spoilage of refrigerated dairy products.
- **Mesophiles:** optimum growth temperatures 30 to 40° C; do not grow at refrigeration temperatures
- **Thermophiles:** optimum growth between 55 and 65° C

It is important to note that for each group, the growth rate increases as the temperature increases only up to an optimum, afterwhich it rapidly declines.

Detection and Enumeration of Microorganisms

There are several methods for detection and enumeration of microorganisms in food. The method that is used depends on the purpose of the testing.

Direct Enumeration:

Using direct microscopic counts (DMC), Coulter counter etc. allows a rapid estimation of all viable and nonviable cells. Identification through staining and observation of morphology also possible with DMC.

Viable Enumeration:

The use of standard plate counts, most probable number (MPN), membrane filtration, plate loop methos, spiral plating etc., allows the estimation of only viable cells. As with direct enumeration, these methods can be used in the food industry to enumerate fermentation, spoilage, pathogenic, and indicator organisms.

Metabolic Activity Measurement:

An estimation of metabolic activity of the total cell population is possible using resazurin, methylene blue dye reduction, acid production, electrical impedence etc. The level of bacterial activity can be used to assess the keeping quality and freshness of milk. Toxin levels can also be measured, indicating the presence of toxin producing pathogens.

Cellular Constituents Measurement:

Using the luciferase test to measure ATP is one example of the rapid and sensitive tests available that will indicate the presence of even one pathogenic bacterial cell.

Isolation of microorganisms is an important preliminary step in the identification of most food spoilage and pathogenic organisms. This can be done using a simple **streak plate method**.

Microorganisms in Milk

Milk is sterile at secretion in the udder but is contaminated by bacteria even before it leaves the udder. Except in the case of mastisis, the bacteria at this point are harmless and few in number. Further infection of the milk by microorganisms can take place during milking, handling, storage, and other pre-processing activities.

Lactic acid bacteria: this group of bacteria are able to ferment lactose to lactic acid. They are normally present in the milk and are also used as starter cultures in the production of cultured dairy products such as yogurt. Note: many lactic acid bacteria have recently been reclassified; the older names will appear in brackets as you will still find the older names used for convenience sake in a lot of literature. Some examples in milk are:

- lactococci
  - *L. delbrueckii* subsp. *lactis* (*Streptococcus lactis*)
  - *Lactococcus lactis* subsp. *cremoris* (*Streptococcus cremoris*)
- lactobacilli
  - *Lactobacillus casei*
  - *L.delbrueckii* subsp. *lactis* (*L. lactis*)
  - *L. delbrueckii* subsp. *bulgaricus* (*Lactobacillus bulgaricus*)
- *Leuconostoc*

Coliforms: coliforms are facultative anaerobes with an optimum growth at 37° C. Coliforms are indicator organisms; they are closely associated with the presence of pathogens but not necessarily pathogenic themselves. They also can cause rapid spoilage of milk because they are able to ferment lactose with the production of acid and gas, and are able to degrade milk proteins. They are killed by HTST treatment, therefore, their presence after treatment is indicative of contamination.*Escherichia coli* is an example belonging to this group.

Significance of microorganisms in milk:

- Information on the microbial content of milk can be used to judge its sanitary quality and the conditions of production
- If permitted to multiply, bacteria in milk can cause spoilage of the product
- Milk is potentially susceptible to contamination with pathogenic microorganisms. Precautions must be taken to minimize this possibility and to destroy pathogens that may gain entrance
- Certain microorganims produce chemical changes that are desirable in the production of dairy products such as cheese, yogurt.

Spoilage Microorganisms in Milk

The microbial quality of raw milk is crucial for the production of quality dairy foods. Spoilage is a term used to describe the deterioration of a foods' texture, colour, odour or flavour to the point where it is unappetizing or unsuitable for human consumption. Microbial spoilage of food often involves the degradation of protein, carbohydrates, and fats by the microorganisms or their enzymes.

In milk, the microorganisms that are principally involved in spoilage are psychrotrophic organisms. Most psychrotrophs are destroyed by pasteurization temperatures, however, some like *Pseudomonas fluorescens, Pseudomonas fragi* can produce proteolytic and lipolytic extracellular enzymes which are heat stable and capable of causing spoilage.

Some species and strains of *Bacillus, Clostridium, Cornebacterium, Arthrobacter, Lactobacillus, Microbacterium, Micrococcus* , and *Streptococcus* can survive pasteurization and grow at refrigeration temperatures which can cause spoilage problems.

Pathogenic Microorganisms in Milk

Hygienic milk production practices, proper handling and storage of milk, and mandatory pasteurization has decreased the threat of milkborne diseases such as tuberculosis, brucellosis, and typhoid fever. There have been a number of foodborne illnesses resulting from the ingestion of raw milk, or dairy products made with milk that was not properly pasteurized or was poorly handled causing post-processing contamination. The following bacterial pathogens are still of concern today in raw milk and other dairy products:

- *Bacillus cereus*
- *Listeria monocytogenes*
- *Yersinia enterocolitica*
- *Salmonella* spp.
- *Escherichia coli* O157:H7
- *Campylobacter jejuni*

It should also be noted that moulds, mainly of species of *Aspergillus* , *Fusarium* , and *Penicillium* can grow in milk and dairy products. If the conditions permit, these moulds may produce mycotoxins which can be a health hazard.

HACCP

Raw and end-products may be tested for the presence, level, or absence of microorganisms. Traditionally these practices were used to reduce manufacturing defects in dairy products and ensure compliance with specifications and regulations, however, they have many drawbacks:

1. destructive and time consuming
2. slow response
3. small sample size
4. delays in the release of the food

In the 1960's, the Pillsbury Company, the U.S. Army, and NASA introduced a system for assuring pathogen-free foods for the space program. This system, called **Hazard Analysis and Critical Control Points (HACCP)**, is a focus on critical food safety areas as part of total quality programs. It involves a critical examination of the entire food manufacturing process to determine every step where there is a possibility of physical, chemical, or microbiological contamination of the food which would render it unsafe or unacceptable for human consumption. These identified points are the critical control points (CCP). There are seven prinicples to HACCP:

1. analyze hazards
2. determine CCPs
3. establish critical limits
4. establish monitoring procedures
5. establish deviation procedures
6. establish verification procedures
7. establish record keeping procedures

Before these principles can be put into place, a prerequisite program and preliminary setup is necessary.
Prerequisite Program:

- premise control
- receiving and storage control
- equipment performance and maintenance control
- personnel training
- sanitation
- recall procedure

Preliminary Setup:

- asemble team
- describe the product
- identify intended use
- construct flow diagram and plant schematic
- verify the diagram on-site

Food Safety Enhancement Program-FSEP is Agriculture and Agri-Food Canada's HACCP initiative and is still undergoing development. There is some information at their Web site regarding the Federal Food Inspection System but not a whole lot on FSEP in particular.

Starter Cultures

Starter cultures are those microorganisms that are used in the production of cultured dairy products such as yogurt and cheese. The natural microflora of the milk is either inefficient, uncontrollable, and unpredictable, or is destroyed altogether by the heat treatments given to the milk. A starter culture can provide particular characteristics in a more controlled and predictable fermentation. The primary function of lactic starters is the production of lactic acid from lactose. Other functions of starter cultures may include the following:

- flavour, aroma, and alcohol production
- proteolytic and lipolytic activities
- inhibition of undesirable organisms

There are two groups of lactic starter cultures:

1. simple or defined: single strain, or more than one in which the number is known
2. mixed or compound: more than one strain each providing its own specific characteristics

Starter cultures may be categorized as mesophilic or thermophilic:

Mesophilic

- *Lactococcus lactis* subsp. *cremoris*
- *L. delbrueckii* subsp. *lactis*
- *L. lactis* subsp. *lactis* biovar *diacetylactis*
- *Leuconostoc mesenteroides* subsp. *cremoris*

Thermophilic

- *Streptococcus salivarius* subsp. *thermophilus* (*S.thermophilus*)
- *Lactobacillus delbrueckii* subsp. *bulgaricus*
- *L. delbrueckii* subsp. *lactis*
- *L. casei*
- *L. helveticus*
- *L. plantarum*

Mixtures of mesophilic and thermophilic microorganisms can also be used as in the production of some cheeses.

Bacteriophage

Bacteriophages are viruses that require bacteria host cells for growth and reproduction. Initially, the bacteriophage attaches itself to the bacteria cell wall and injects nuclear substance into the cell. Inside the cell, the nuclear substance produces shells, or phage coats, for the new bacteriophage which are quickly filled with nucleic acid. The bacterial cell ruptures and dies as the new bacteriophage are released. Bacteriophages are ubiquitous but generally enter the milk processing plant with the farm milk. They can be inactivated heat treatments of 30 min at 63 to 88° C, or by the use of chemical disinfectants. Bacteriophages are of most concern in cheese making. They attack and destroy most of the lactic acid bacteria which prevents normal ripening known as slow or dead vat.

Starter Culture Preparation

Commercial manufacturers provide starter cultures in lyophilized (freeze-dryed), frozen or spray-dried forms. The dairy product manufacturers need to inoculate the culture into milk or other suitable substrate. There are a number of steps necessary for the propagation of starter culture ready for production:

1. Commercial culture
2. Mother culture - first inoculation; all cultures will originate from this preparation
3. Intermediate culture - in preparation of larger volumes of prepared starter
4. Bulk starter culture - this stage is used in dairy product production

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Yogurt

Yogurt (also spelled yogourt or yoghurt) is a semi-solid fermented milk product which originated centuries ago in Bulgaria. It's popularity has grown and is now consumed in most parts of the world. Although the consistency, flavour and aroma may vary from one region to another, the basic ingredients and manufacturing are essentially consistent:

- Ingredients
- Starter Culture
- Manufacturing Methods
- Yogurt Products and Others

Ingredients

Although milk of various animals has been used for yogurt production in various parts of the world, most of the industrialized yogurt production uses cow's milk. Whole milk, partially skimmed milk, skim milk or cream may be used. In order to ensure the development of the yogurt culture the following criteria for the raw milk must be met:

- low bacteria count
- free from antibiotics, sanitizing chemicals, mastisis milk, colostrum, and rancid milk
- no contamination by bacteriophages

Other yogurt ingredients may include some or all of the following:
Other Dairy Products: concentrated skim milk, nonfat dry milk, whey, lactose. These products are often used to increase the nonfat solids content
Sweeteners: glucose or sucrose, high-intensity sweeteners (e.g. aspartame)
Stabilizers: gelatin, carboxymethyl cellulose, locust bean Guar, alginates, carrageenans, whey protein concentrate
Flavours
Fruit Preparations: including natural and artificial flavouring, colour

Starter Culture

The starter culture for most yogurt production in North America is a symbiotic blend of *Streptococcus salivarius* subsp. *thermophilus* (ST) and *Lactobacillus delbrueckii* subsp. *bulgaricus* (LB). Although they can grow independantly, the rate of acid production is much higher when used together than either of the two organisms grown individually. ST grows faster and produces both acid and carbon dioxide. The formate and carbon dioxide produced stimulates LB growth. On the other hand, the proteolytic activity of LB produces stimulatory peptides and amino acids for use by ST. These microorganisms are ultimately responsible for the formation of typical yogurt flavour and texture. The yogurt mixture coagulates during fermentation due to the drop in pH. The streptococci are responsible for the initial pH drop of the yogurt mix to approximately 5.0. The lactobacilli are responsible for a further decrease to pH 4.0. The following fermentation products contibute to flavour:

- lactic acid
- acetaldehyde
- acetic acid
- diacetyl

Manufacturing Method

The milk is **clarified** and **separated** into cream and skim milk, then **standardized** to acheive the desired fat content. The various ingredients are then blended together in a mix tank equipped with a powder funnel and an agitation system. The mixture is then **pasteurized** using a continuous plate heat exchanger for 30 min at 85° C or 10 min at 95° C. These heat treatments, which are much more severe than fluid milk pasteurization, are necessary to acheive the following:

- produce a relatively sterile and condusive environment for the starter culture
- denature and coagulate whey proteins to enhance the viscosity and texture

The mix is then **homogenized** using high pressures of 2000-2500 psi. Besides thoroughly mixing the stabilizers and other ingredients, homogenization also prevents creaming and wheying off during incubation and storage. Stability, consistency and body are enhanced by homogenization. Once the homogenized mix has cooled to an optimum growth temperature, the yogurt starter culture is added.

A ratio of 1:1, ST to LB, inoculation is added to the jacketed fermentation tank. A temperature of 43° C is maintained for 4-6 h under quiescent (no agitation) conditions. This temperature is a compromise between the optimums for the two micoorganisms (ST 39° C; LB 45° C). The titratable acidity is carefully monitored until the TA is 0.85 to 0.90%. At this time the jacket is replaced with cool water and agitation begins, both of which stop the fermentation. The coagulated product is cooled to 5-22° C, depending on the product. Fruit and flavour may be incorporated at this time, then packaged. The product is now cooled and stored at refrigeration temperatures (5° C) to slow down the physical, chemical and microbiological degradation.

Yogurt Products

There are two types of plain yogurt:

- Stirred style yogurt
- Set style yogurt

The above description is essentially the manufacturing proceedures for stirred style. In set style, the yogurt is packaged immediately after inoculation with the starter and is incubated in the packages. Other yogurt products include:

Fruit-on-the-bottom style:

> fruit mixture is layered at the bottom followed by inoculated yogurt, incubation occurs in the sealed cups

Soft-serve and Hard Pack frozen yogurt

Continental, French, and Swiss:

> stirred style yogurt with fruit preparation

Yogurt Beverages

Drinking yogurt is essentially stirred yogurt which has a total solids content not exceeding 11% and which has undergone homogenization to further reduce the viscosity, Flavouring and colouring are invariably added. Heat treatment may be applied to extend the storage life. HTST pasteurization with aseptic processing will give a shelf life of several weeks at 2-4°C, which UHT processes with aseptic packaging will give a shelf life of several weeks at room temperature.

Other Fermented Milk Beverages

Cultured Buttermilk

This product was originally the fermented byproduct of butter manufacture, but today it is more common to produce cultured buttermilks from skim or whole milk. The culture most frequently used in S. lactis, , perhaps also spp. cremoris. Milk is usually heated to 95°C and cooled to 20-25°C before the addition of the starter culture. Starter is added at 1-2% and the fermentation is allowed to proceed for 16-20 hours, to an acidity of 0.9% lactic acid. This product is frequently used as an ingredient in the baking industry, in addition to being packaged for sale in the retail trade.

Acidophilus milk

Acidophilus milk is a traditional milk fermented with Lactobacillus acidophilus (LA), which has been thought to have therapeutic benefits in the gastrointestinal tract. Skim or whole milk may be used. The milk is heated to high temperature, e.g., 95°C for 1 hour, to reduce the microbial load and favour the slow growing LA culture. Milk is inoculated at a level of 2-5% and incubated at 37°C until coagulated. Some acidophilus milk has an acidity as high as 1% lactic acid, but for therapeutic purposes 0.6-0.7% is more common.

Another variation has been the introduction of a sweet acidophilus milk, one in which the LA culture has been added but there has been no incubation. It is thought that the culture will reach the GI tract where its therapeutic effects will be realized, but the milk has no fermented qualities, thus delivering the benefits without the high acidity and flavour, considered undesirable by some people.

Sour Cream

Cultured cream usually has a fat content between 12-30%, depending on the required properties. The starter is similar to that used for cultured buttermilk. The cream after standardization is usually heated to 75-80°C and is homogenized at >13 MPa to improve the texture. Inoculation and fermentation conditions are also similar to those for cultured buttermilk, but the fermentation is stopped at an acidity of 0.6%.

Others

There are a great many other fermented dairy products, including kefir, koumiss, beverages based on bulgaricus or bifidus strains, labneh, and a host of others. Many of these have developed in regional areas and, depending on the starter organisms used, have various flavours, textures, and components from the fermentation process, such as gas or ethanol.

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Clarification and Cream Separation

The following topics will be covered in this section:

- Centrifugation
- Separation
- Clarification
- Standardization

Centrifugation

Centrifugal separation is a process used quite often in the dairy industry. Some uses include:

- clarification (removal of solid impurities from milk prior to pasteurization)
- skimming (separation of cream from skim milk)
- standardizing
- whey separation (separation of whey cream (fat) from whey)
- bactofuge treatment (separation of bacteria from milk)
- quark separation (separation of quarg curd from whey)
- butter oil purification (separation of serum phase from anhydrous milk fat)

Principles of Centrifugation

Centrifugation is based on ***Stoke's Law***. The particle sedimentation velocity increases with:

- increasing diameter
- increasing difference in density between the two phases
- decreasing viscosity of the continuous phase

If raw milk were allowed to stand, the fat globules would begin to rise to the surface in a phenomena called **creaming**. Raw milk in a rotating container also has centrifugal forces acting on it. This allows rapid separation of milk fat from the skim milk portion and removal of solid impurities from the milk.

Separation

Centrifuges can be used to separate the cream from the skim milk. The centrifuge consists of up to 120 discs stacked together at a 45 to 60 degree angle and separated by a 0.4 to 2.0 mm gap or separation channel. Milk is introduced at the outer edge of the disc stack. The stack of discs has vertically aligned distribution holes into which the milk is introduced.

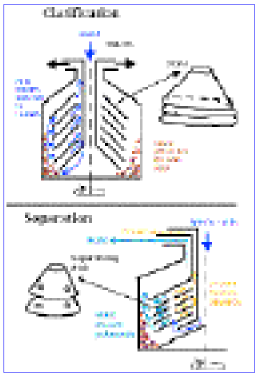
Under the influence of centrifugal force the fat globules (cream), which are less dense than the skim milk, move inwards through the separation channels toward the axis of rotation. The skim milk will move outwards and leaves through a separate outlet.

Clarification

Separation and clarification can be done at the same time in one centrifuge. Particles, which are more dense than the continuous milk phase, are thrown back to the perimeter. The solids that collect in the centrifuge consist of dirt, epithelial cells, leucocytes, corpuscles, bacteria sediment and sludge. The amount of solids that collect will vary, however, it must be removed from the centrifuge.

More modern centrifuges are self-cleaning allowing a continuous separation/clarification process. This type of centrifuge consists of a specially constructed bowl with peripheral discharge slots. These slots are kept closed under pressure. With a momentary release of pressure, for about 0.15 s, the contents of sediment space are evacuated. This can mean anywhere from 8 to 25 L are ejected at intervals of 60 min. For one dairy, self-cleaning translated to a loss of 50 L/hr of milk.

The following image is a schematic of both a clarifier and a separator.



Clarification and Separation: 26 KB

Standardization

The streams of skim and cream after separation must be recombined to a specified fat content. This can be done by adjusting the throttling valve of the cream outlet; if the valve is completely closed, all milk will be discharged through the skim milk outlet. As the valve is progressively opened, larger amounts of cream with diminishing fat contents are discharged from the cream outlet. With direct standardization the cream and skim are automatically remixed at the separator to provide the desired fat content. Some basic standardization problems including mass balance and Pearson square approach can be viewed here.

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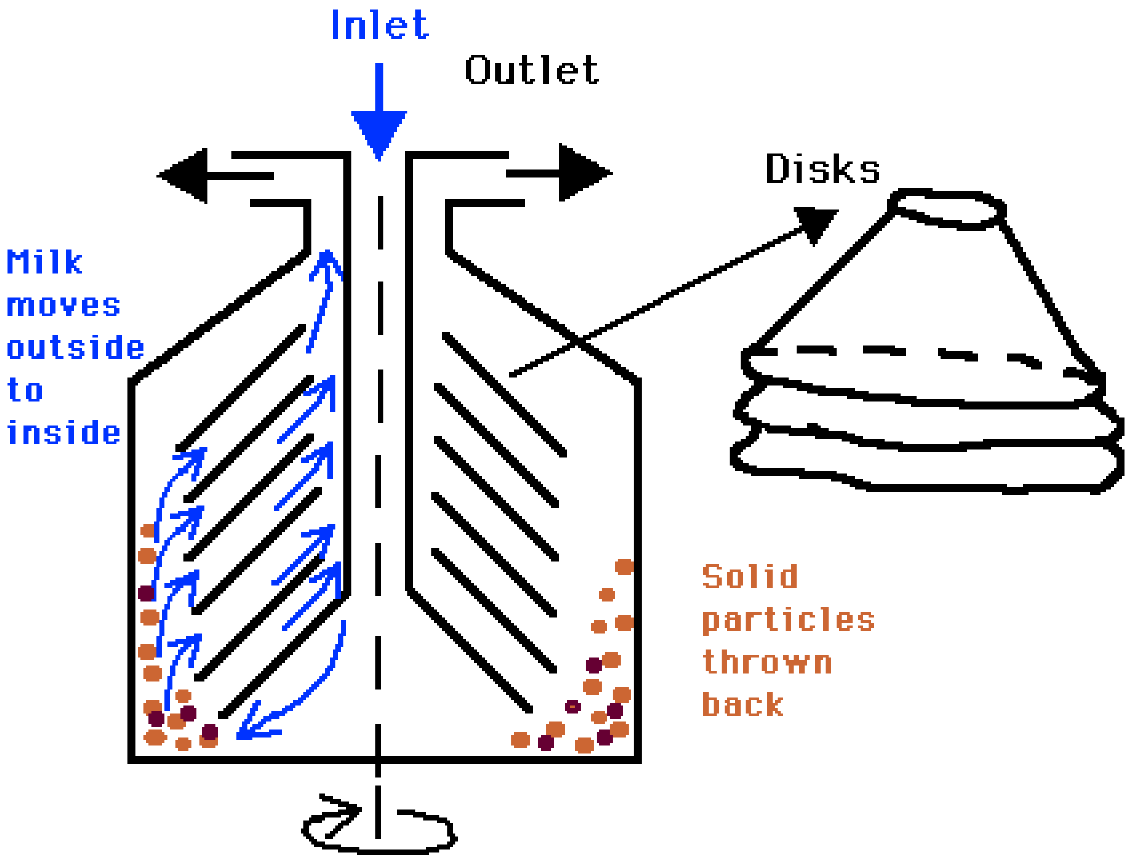
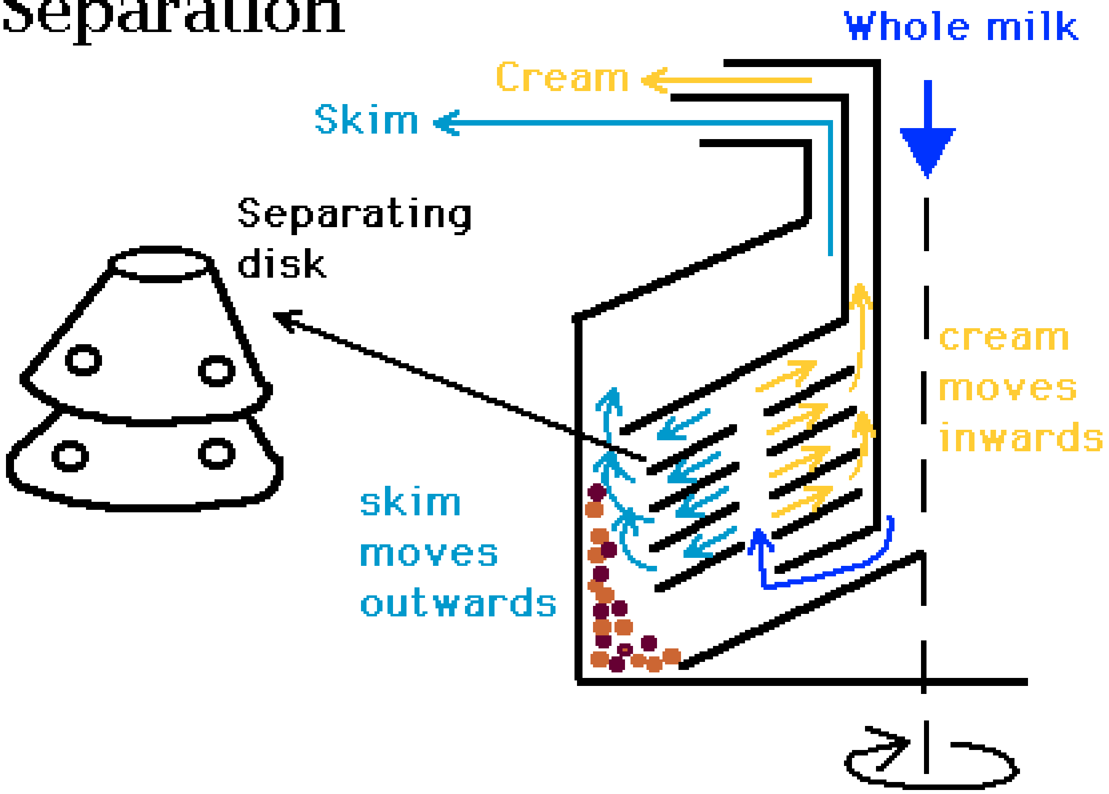
Clarification



Separation



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Pasteurization

Introduction

Thermal lethality determinations

Methods

- Batch
- Continuous: HTST
  - Milk Flow Overview
  - Holding Time
  - Pressure Differential
  - Equipment
  - Automated Public Health Controller

Introduction

The process of pasteurization was named after **Louis Pasteur** who discovered that spoilage organisms could be inactivated in wine by applying heat at temperatures below its boiling point. The process was later applied to milk and remains the most important operation in the processing of milk.

Definition:

> The heating of every particle of milk or milk product to a specific temperature for a specified period of time without allowing recontamination of that milk or milk product during the heat treatment process.

Purpose There are two distinct purposes for the process of milk pasteurization:

1. **Public Health Aspect** - to make milk and milk products safe for human consumption by destroying all bacteria that may be harmful to health (pathogens)
2. **Keeping Quality Aspect** - to improve the keeping quality of milk and milk products. Pasteurization can destroy some undesirable enzymes and many spoilage bacteria. Shelf life can be 7, 10, 14 or up to 16 days.

The extent of microorganism inactivation depends on the combination of temperature and holding time.

Minimum temperature and time requirements for milk pasteurization are based on thermal death time studies for the most heat resistant pathogen found in milk, *Coxelliae burnettii*. **Thermal lethality determinations** require the applications of microbiology to appropriate processing determinations. An overview can be found here.

To ensure destruction of all pathogenic microorganisms, time and temperature combinations of the pasteurization process are highly regulated:

Ontario Pasteurization Regulations

Milk:
63° C for not less than 30 min.,
72° C for not less than 16 sec.,
or equivalent destruction of pathogens and the enzyme phosphatase as permitted by Ontario Provincial Government authorities. Milk is deemed pasteurized if it tests negative for alkaline phosphatase.

Frozen dairy dessert mix (ice cream or ice milk, egg nog):
at least 69° C for not less than 30 min;
at least 80° C for not less than 25 sec;
other time temperature combinations must be approved (e.g. 83° C/16 sec).

Milk based products- with 10% mf or higher, or added sugar (cream, chocolate milk, etc)
66° C/30 min, 75° C/16 sec

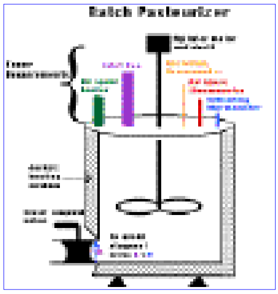
There has also been some progress with low temperature pasteurization methods using membrane processing technology..

Methods of Pasteurization

There are two basic methods, batch or continuous.

Batch method

The batch method uses a vat pasteurizer which consists of a jacketed vat surrounded by either circulating water, steam or heating coils of water or steam.



Batch Pasteurizer (26 KB)

In the vat the milk is heated and held throughout the holding period while being agitated. The milk may be cooled in the vat or removed hot after the holding time is completed for every particle. As a modification, the milk may be partially heated in tubular or plate heater before entering the vat. This method has very little use for milk but some use for milk by-products (e.g. creams, chocolate) and special batches. The vat is used extensivly in the ice cream industry for mix quality reasons other than microbial reasons.

Continuous Method

Continuous process method has several advantages over the vat method, the most important being time and energy saving. For most continuous processing, a high temperature short time (HTST) pasteurizer is used. The heat treatment is accomplished using a **plate heat exchanger**. This piece of equipment consists of a stack of corrugated stainless steel plates clamped together in a frame. There are several flow patterns that can be used. Gaskets are used to define the boundaries of the channels and to prevent leakage. The heating medium can be vacuum steam or hot water.

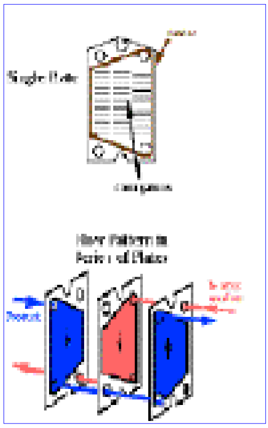


Plate Heat Exchanger 26 KB

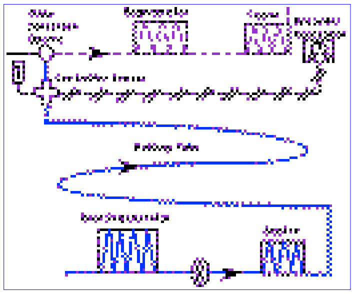
HTST Milk Flow Overview

This overview is meant as an introduction and a summary. Each piece of HTST equipment will be discussed in further detail later.

Cold raw milk at 4° C in a constant level tank is drawn into the **regenerator** section of pasteurizer. Here it is warmed to approximately 57° C - 68° C by heat given up by hot pasteurized milk flowing in a counter current direction on the opposite side of thin, stainless steel plates. The raw milk, still under suction, passes through a positive displacement **timing pump** which delivers it under positive pressure through the rest of the HTST system.

The raw milk is forced through the heater section where hot water on opposite sides of the plates heat milk to a temperature of at least 72° C. The milk, at pasteurization temperature and under pressure, flows through the **holding tube** where it is held for at least 16 sec. The maximum velocity is governed by the speed of the timing pump, diameter and length of the holding tube, and surface friction. After passing temperature sensors of an **indicating thermometer** and a **recorder-controller** at the end of the holding tube, milk passes into the **flow diversion device (FDD)**. The FDD assumes a forward-flow position if the milk passes the recorder-controller at the preset cut-in temperature (>72° C). The FDD remains in normal position which is in diverted-flow if milk has not achieved preset cut-in temperature. The improperly heated milk flows through the diverted flow line of the FDD back to the raw milk **constant level tank.** Properly heated milk flows through the forward flow part of the FDD to the pasteurized milk regenerator section where it gives up heat to the raw product and in turn is cooled to approximately 32° C - 9° C.

The warm milk passes through the cooling section where it is cooled to 4° C or below by coolant on the opposite sides of the thin, stainless steel plates. The cold, pasteurized milk passes through a **vacuum breaker** at least 12 inches above the highest raw milk in the HTST system then on to a storage tank filler for packaging.



Basic Flow - HTST Pasteurization 17 KB

Holding Time

When fluids move through a pipe, either of two distinct types of flow can be observed. The first is known as **turbulent flow** which occurs at high velocity and in which eddies are present moving in all directions and at all angles to the normal line of flow. The second type is streamline, or **laminar flow** which occurs at low velocities and shows no eddy currents. The ***Reynolds number***, is used to predict whether laminar or turbulent flow will exist in a pipe:
Re < 2100 laminar
Re > 4000 fully developed turbulent flow

There is an impact of these flow patterns on holding time calculations and the assessment of proper holding tube lengths.

The holding time is determined by timing the interval for an added trace substance (salt) to pass through the holder. The time interval of the fastest particle of milk is desired. Thus the results found with water are converted to the milk flow time by formulation since a pump may not deliver the same amount of milk as it does water.

Note: the formulation assumes flow patterns are the same for milk and water. If they are not, how would this affect the efficiency of the pasteurization process?

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Pressure Differential

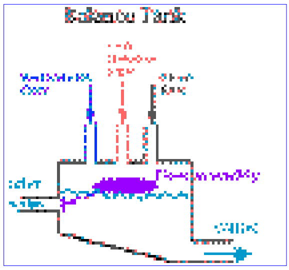
For contiunuous pasteurizing, it is important to maintain a higher pressure on the pasteurized side of the heat exchanger. By keeping the pasteurized milk at least 1 psi higher than raw milk in regenerator, it prevents contamination of pasteurized milk with raw milk in event that a pin-hole leak develops in thin stainless steel plates. This **pressure differential** is maintained using a timing pump in simple systems, and differential pressure controllers and back pressure flow regulators at the chilled pasteurization outlet in more complex systems. The position of the timing pump is crucial so that there is suction on the raw regenerator side and pushes milk under pressure through pasteurized regenerator. There are several other factors involved in maintaining the pressure differential:

- The balance tank overflow level must be less than the level of lowest milk passage in the regenerator
- Properly installed booster pump is all that is permitted between balance tank and raw regenerator
- No pump after pasteurized milk outlet to vacuum breaker
- There must be greater than a 12 inch vertical rise to the vacuum breaker
- The raw regenerator drains freely to balance tank at shut-down

Basic Component Equipment of HTST Pasteurizer

Balance Tank

The balance, or constant level tank provides a constant supply of milk. It is equipped with a **float valve assembly** which controls the liquid level nearly constant ensuring uniform head pressure on the product leaving the tank. The overflow level must always be below the level of lowest milk passage in regenerator. It, therefore, helps to maintain a higher pressure on the pasteurized side of the heat exchanger. The balance tank also prevents air from entering the pasteurizer by placing the top of the outlet pipe lower than the lowest point in the tank and creating downward slopes of at least 2%. The balance tank provides a means for recirculation of diverted or pasteurized milk.



Balance Tank 17 KB

Regenerator

Heating and cooling energy can be saved by using a regenerator which utilizes the heat content of the pasteurized milk to warm the incoming cold milk. Its efficiency may be calculated as follows:

% regeneration = temp. increase due to regenerator/total temp. increase

For example: Cold milk entering system at 4° C, after regeneration at 65° C, and final temperature of 72° C would have an 89.7% regeneration:

$$\frac{65 - 4}{72 - 4} = 89.7$$

Timing pump

The timing pump draws product through the raw regenerator and pushes milk under pressure through pasteurized regenerator. It governs the rate of flow through the holding tube. It must be a **positive displacement** pump equipped with variable speed drive that can be legally sealed at the maximum rate to give minimum holding time in holding tubes. It also must be interwired so it only operates when FDD is fully forward or fully diverted, and must be "fail-safe". A centrifigal pump with magnetic flow meter and controller may also be used.

Holding tube

Must slope upwards 1/4"/ft. in direction of flow to eliminate air entrapment so nothing flows faster at air pocket restrictions.

Indicating thermometer

The indicating thermometer is considered the most accurate temperature measurement. It is the official temperature to which the **safety thermal limit recorder (STLR)** is adjusted. The probe should sit as close as possible to STLR probe and be located not greater than 18 inches upstream of the flow diversion device.

Recorder-controller (STLR)

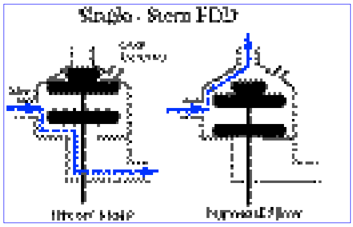
The STLR records the temperature of the milk and the time of day. It monitors, controls and records the position of the flow diversion device (FDD) and supplies power to the FDD during forward flow. There are both **pneumatic** and **electronic** types of controllers. The operator is responsible for recording the date, shift, equipment, ID, product and amount, indicating thermometer temperature, cleansing cycles, cut in and cut out temperatures, any connects for unusual circumstances, and his/her signature.

Flow Diversion Device (FDD)

Also called the flow diversion valve (FDV), it is located at the downstream end of the upward sloping holding tube. It is essentially a 3-way valve, which, at temperatures greater than 72° C,opens to **forward flow**. This step requires power. At temperatures less than 72° C, the valve recloses to the normal position and diverts the milk back to the balance tank. It is important to note that the FDD operates on the measured temperature, not time, at the end of the holding period. There are two types of FDD:

single stem - an older valve system that has the disadvantage that it can't be cleaned in place.

dual stem - consists of 2 valves in series for additional fail safe systems. This FDD can be cleaned in place and is more suited for automation.



Flow Diversion Devices 17 KB

Vacuum Breaker

At the pasteurized product discharge is a vacuum breaker which breaks to atmospheric pressure. It must be located greater than 12 inches above the highest point of raw product in system. It ensures that nothing downstream is creating suction on the pasteurized side.

Auxiliary Equipment

Booster Pump

It is centrifugal "stuffing" pump which supplies raw milk to the raw regenerator for the balance tank. It must be used in conjunction with pressure differential controlling device and shall operate only when timing pump is operating, proper pressures are achieved in regenerator, and system is in forward flow.

Homogenizer

The homogenizer may be used as timing pump. It is a positive pressure pump; if not, then it cannot supplement flow. Free circulation from outlet to inlet is required and the speed of the homogenizer must be greater than the rate of flow of the timing pump.

Automated Public Health Controllers These systems are used for time and temperature control of HTST systems. There are concerns that with sequential control, the critical control points (CCP's) are not monitored all the time; if during the sequence it got held up, the CCP's would not be monitored. With operator control, changes can be made to the program which might affect CCP's; the system is not easily sealed. No computer program can be written completely error free in large systems; as complexity increases, so too do errors.

This gives rise to a need for specific regulations or computer controlled CCP's of public health significance:

1. dedicated computer - no other assignments, monitor all CCP's at least once/sec
2. not under control of any other computer system or override system, i.e., network
3. separate computer on each pasteurizer
4. I/O bus for outputs only, to other computers no inputs from other computers

5. on loss of power - public health computers should revert to fail safe position (e.g. divert)
6. last state switches during power up must be fail safe position
7. programs in ROM - tapes/disks not acceptable
8. inputs must be sealed, modem must be sealed, program sealed
9. no operator override switches
10. proper calibration procedure during that printing - Public health computer must not leave public health control for > 1 sec and upon return must complete 1 full cycle before returning to printing
11. FDV position must be monitored and temperature in holding tube recorded during change in FDV position
12. download from ROM to RAM upon startup
13. integrated with CIP computer which can be programmed e.g., FDV, booster pump controllable by CIP computer when in CIP made only

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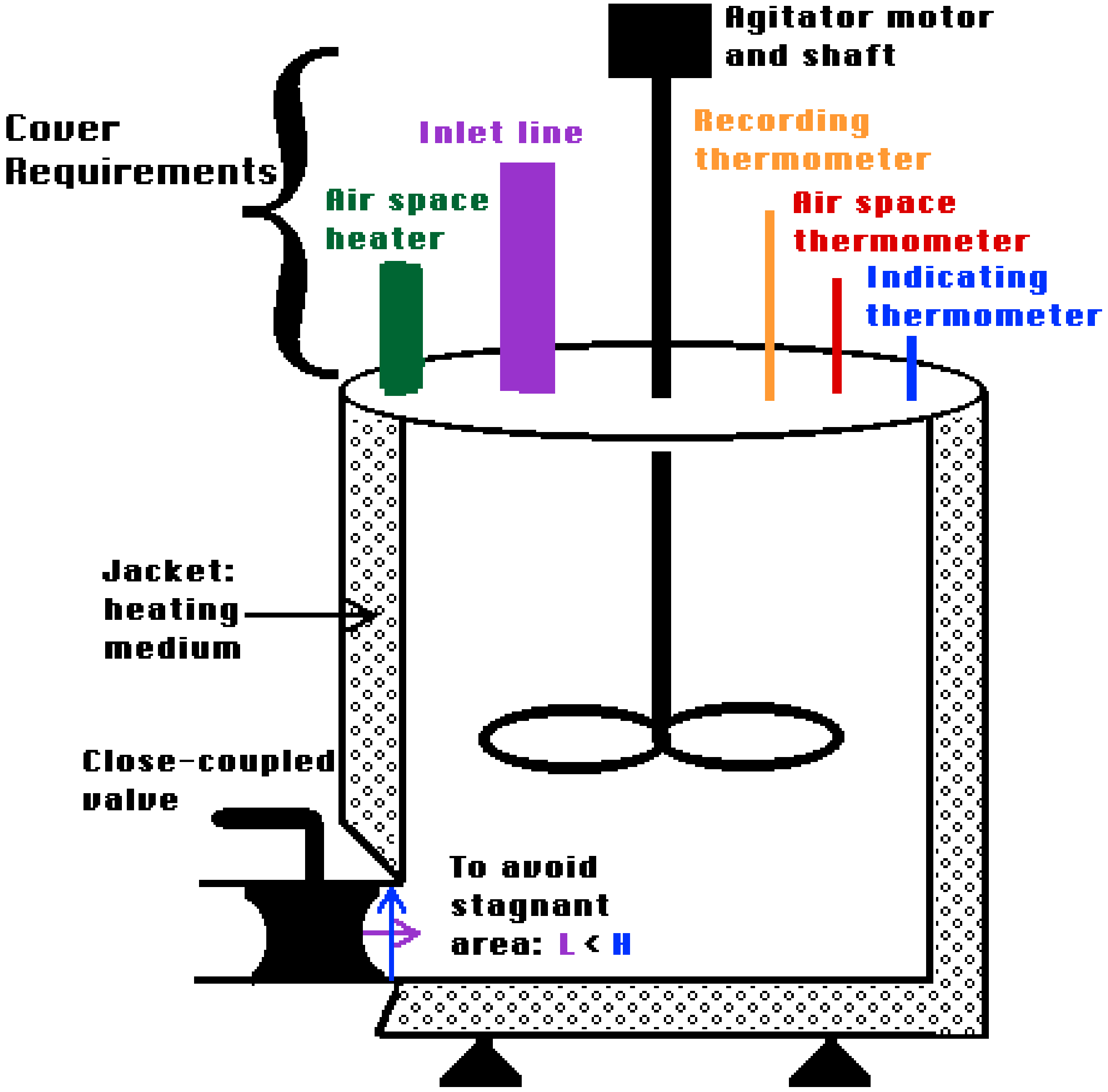
Batch Pasteurizer



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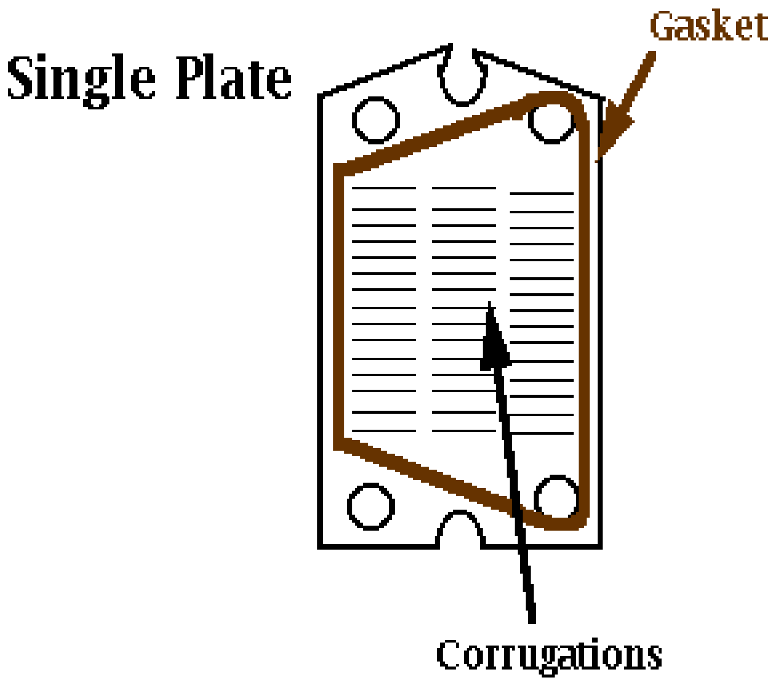

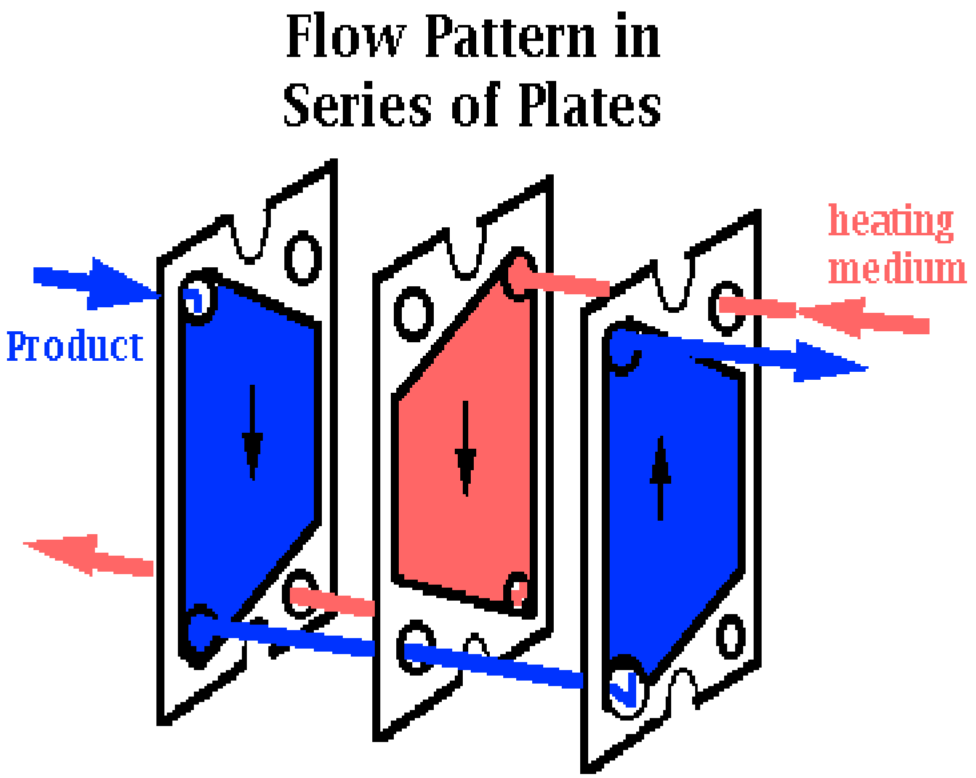

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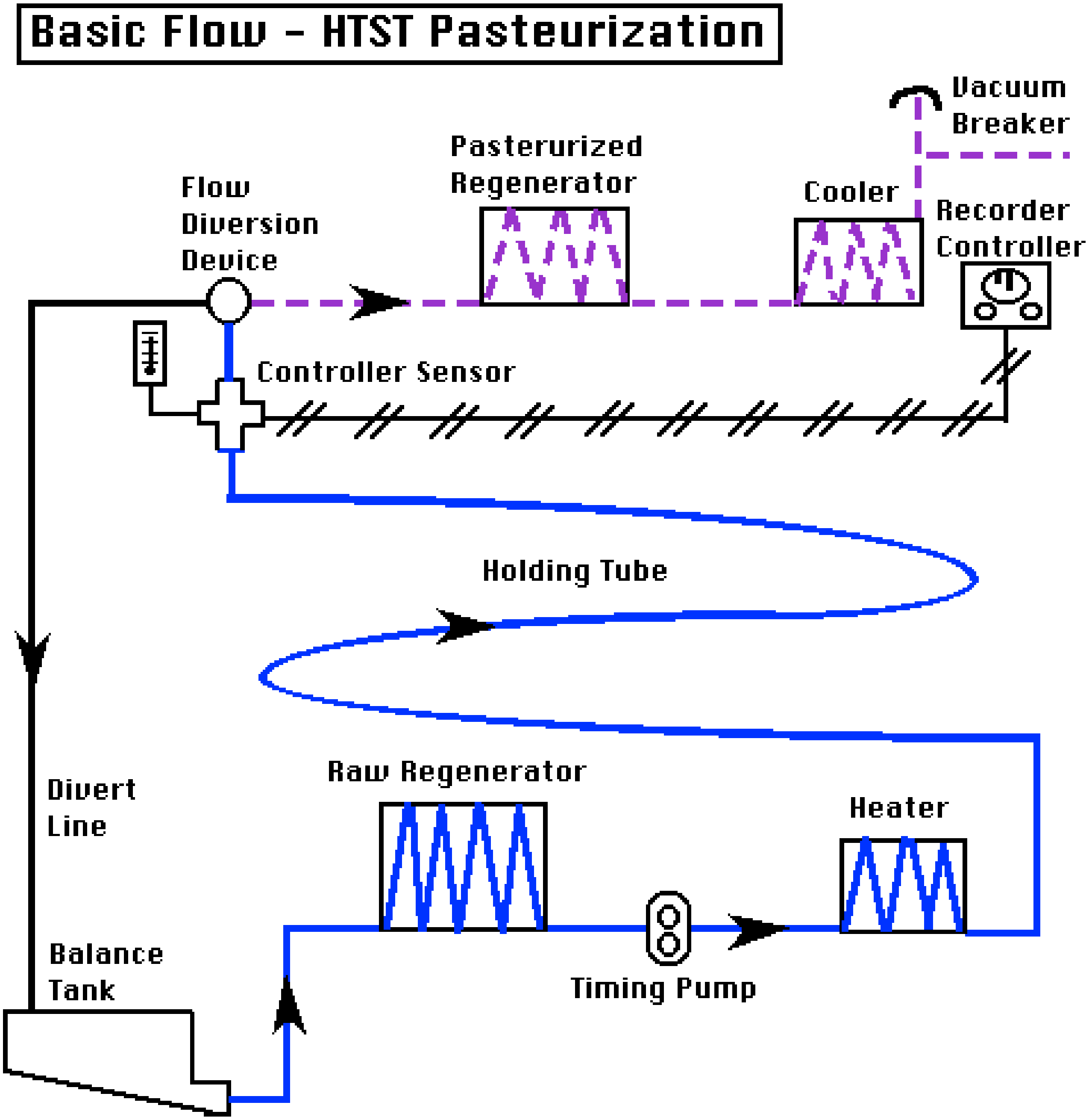
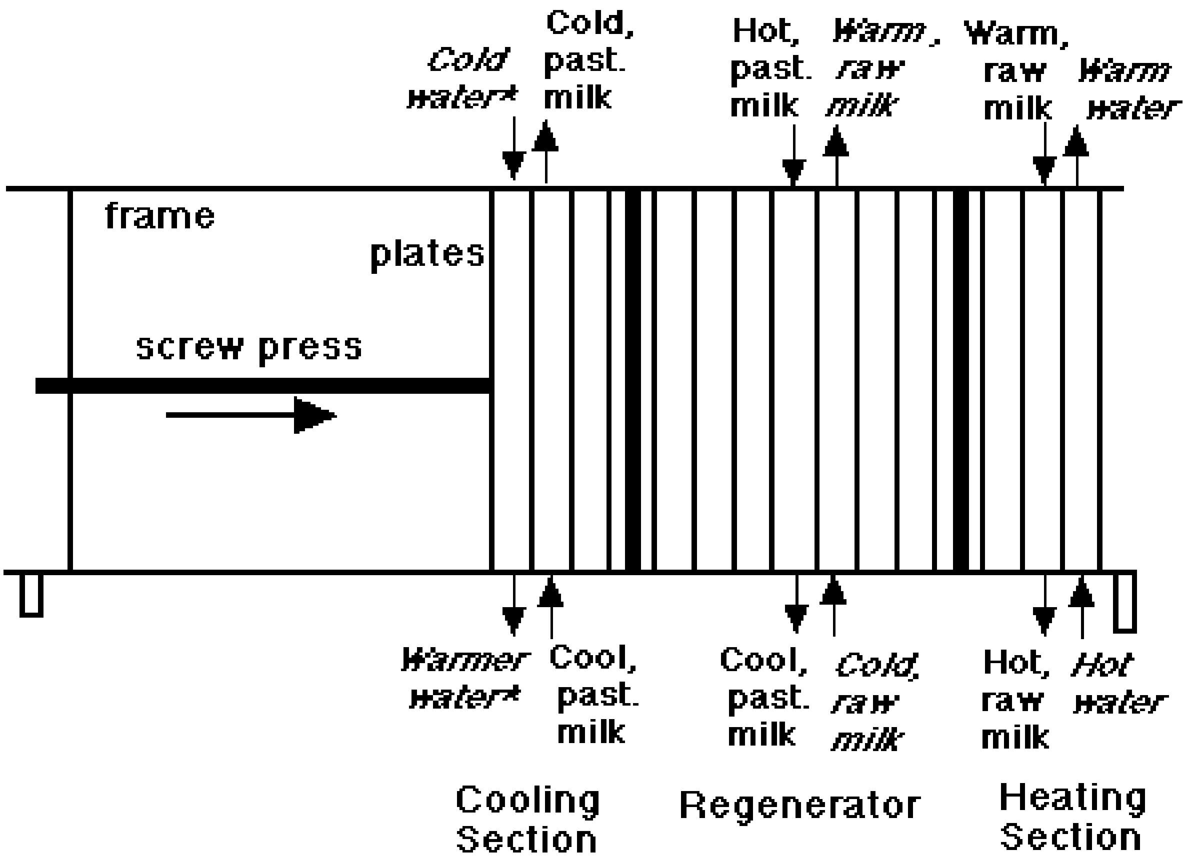
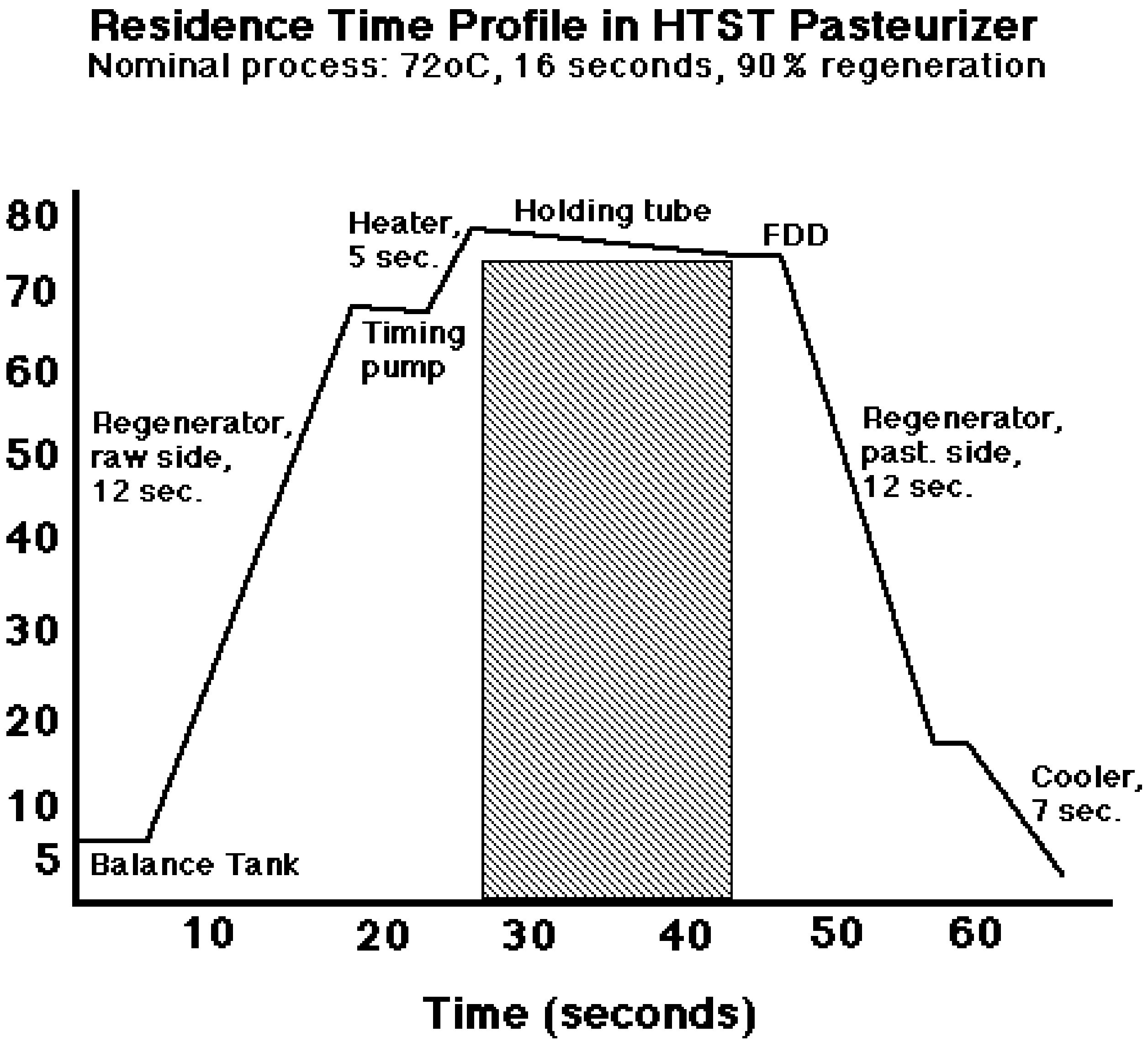
HTST milk pasteurization equipment and the flow of milk through it.



HTST Continuous Plate Pasteurizer



* or brine, or glycol



The hatched area in the graph above represents the area under the time temperature curve that is taken into consideration for thermal lethality calculations.

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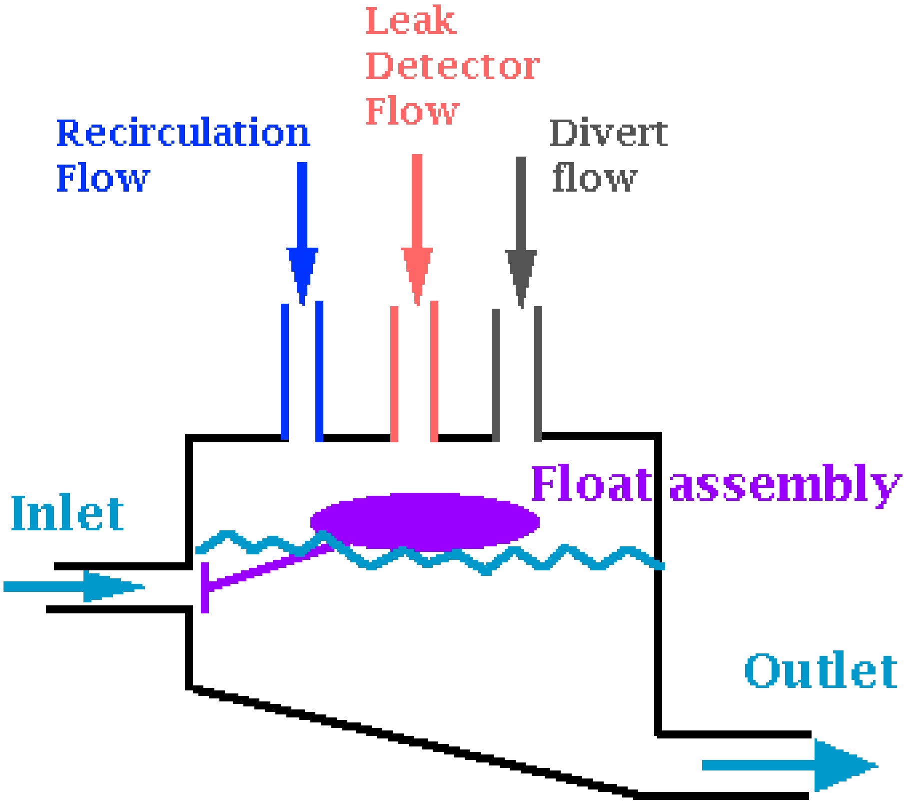
Balance Tank



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UHT Processing

- Introduction
- Advantages
- Difficulties
- **UHT Methods**
    - Direct Heating
    - Indirect Heating
- Packaging

Introduction

While pasteurization conditions effectively eliminate potential pathogenic microorganisms, it is not sufficient to inactivate the thermoresistant spores in milk. The term **sterilization** refers to the complete elimination of all microorganisms. The food industry uses the more realistic term **"commercial sterilization"**; a product is not necessarily free of all microorganisms, but those that survive the sterilization process are unlikely to grow during storage and cause product spoilage.

In canning we need to ensure the "cold spot" has reached the desired temperature for the desired time. With most canned products, there is a low rate of heat penetration to the thermal centre. This leads to overprocessing of some portions, and damage to nutritional and sensory characteristics, especially near the walls of the container. This implies long processing times at lower temperatures.

Milk can be made commercially sterile by subjecting it to temperatures in excess of 100° C, and packaging it in air-tight containers. The milk may be packaged either before or after sterilization. The basis of **UHT**, or ultra-high temperature, is the sterilization of food **before** packaging, then filling into pre-sterilized containers in a sterile atmosphere. Milk that is processed in this way using temperatures exceeding 135° C, permits a decrease in the necessary holding time (to 2-5 s) enabling a **continuous flow** operation.

Some examples of food products processed with UHT are:

- liquid products - milk, juices, cream, yoghurt, wine, salad dressings
- foods with discrete particles - baby foods; tomato products; fruits and vegetables juices; soups
- larger particles - stews

Advantages of UHT

High quality:

The D and Z valves are higher for quality factors than microorganisms. The reduction in process time due to higher temperature (UHTST) and the minimal come-up and cool-down time leads to a higher quality product.

Long shelf life:

Greater than 6 months, without refrigeration, can be expected.

Packaging size:

Processing conditions are independent of container size, thus allowing for the filling of large containers for food-service or sale to food manufacturers (aseptic fruit purees in stainless steel totes).

Cheaper packaging:

Both cost of package and storage and transportation costs; laminated packaging allows for use of extensive graphics

Difficulties with UHT

Sterility:

Complexity of equipment and plant are needed to maintain sterile atmosphere between processing and packaging (packaging materials, pipework, tanks, pumps); higher skilled operators; sterility must be maintained through aseptic packaging

Particle Size:

With larger particulates there is a danger of overcooking of surfaces and need to transport material - both limits particle size

Equipment:

There is a lack of equipment for particulate sterilization, due especially to settling of solids and thus overprocessing

Keeping Quality:

Heat stable lipases or proteases can lead to flavour deterioration, age gelation of the milk over time - nothing lasts forever! There is also a more pronounced cooked flavour to UHT milk.

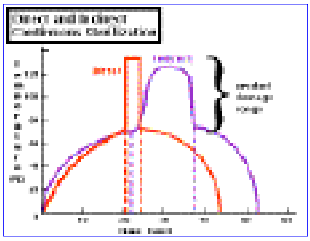
UHT Methods

There are two principal methods of UHT treatment:

1. Direct Heating
2. Indirect Heating

Direct heating systems

The product is heated by direct contact with steam of potable or culinary quality. The main advantage of direct heating is that the product is held at the elevated temperature for a shorter period of time. For a heat-sensitive product such as milk, this means less damage.



Indirect vs Direct Heating (17 KB)

There are two methods of direct heating;

1. injection
2. infusion

Injection: High pressure steam is injected into pre-heated liquid by a steam injector leading to a rapid rise in temperature. After holding, the product is flash-cooled in a vacuum to remove water equivalent to amount of condensed steam used. This method allows fast heating and cooling, and volatile removal, but is only suitable for some products. It is energy intensive and because the product comes in contact with hot equipment, there is potential for flavour damage.

Infusion: Food in a free falling film is pumped into a chamber of high pressure steam. The time of the fall matches the desired holding time. The product, therefore, falls onto a cooled surface, followed by flash cooling in vacuum chamber. This method has several advantages:

- instantaneous heating and rapid cooling
- no localized overheating or burn-on
- suitable for low and higher viscosity products

Indirect heating systems

The heating medium and product are not in direct contact, but separated by equipment contact surfaces. Several types of heat exchangers are applicable:

- plate
- tubular
- scraped surface

- double-cone

Plate Heat Exchangers: Similar to that used in HTST but operating pressures are limited by gaskets. Liquid velocities are low which could lead to uneven heating and burn-on. This method is economical in floor space, easily inspected, and allows for potential regeneration.

Tubular Heat Exchangers: There are several types:

- shell and tube
- shell and coil
- double tube
- triple tube

All of these tubular heat exchangers have fewer seals involved than with plates. This allows for higher pressures, thus higher flow rates and higher temperatures. The heating is more uniform but difficult to inspect.

Scraped Surface Heat Exchangers: The product flows through a jacketed tube, which contains the heating medium, and is scraped from the sides with a rotating knife. This method is suitable for viscous products and particulates (< 1 cm) such as fruit sauces, and can be adjusted for different products by changing configuration of rotor. There is a problem with larger particulates; the long process time for particulates would mean long holding sections which are impractical. This may lead to damaged solids and overprocessing of sauce.

Double-cone Heat Exchangers eg APV Jupiter: Suitable for large particulates because it involves separation of solids/liquids and combines indirect heating in double cone (batch) with direct heating of liquid portion (maybe also scraped surface if too viscous). The solid pieces are fed into a double-cone, rotated slowly on horizontal axis with steam injection and heated surfaces. There is no burn-on because they are the same temperature. The liquid is directly heated with steam separately, then added after pre-cooling. The double cone acts as a blender and coats solids. The product is then discharged to an aseptic filler by overpressure with sterile air. Used for soups, stews, carrots, and vegetables.

Packaging for Aseptic Processing

The most important point to remember is that it must be **sterile**! All handling of product post-process must be within the sterile environment.

There are 5 basic types of aseptic packaging lines:

1. **Fill and seal:** preformed containers made of thermoformed plastic, glass or metal are sterilized, filled in aseptic environment, and sealed
2. **Form, fill and seal:** roll of material is sterilized, formed in sterile environment, filled, sealed e.g. tetrapak
3. **Erect, fill and seal:** using knocked-down blanks, erected, sterilized, filled, sealed. e.g. gable-top cartons, cambri-bloc

4. **Thermoform, fill, sealed** roll stock sterilized, thermoformed, filled, sealed aseptically. e.g. creamers, plastic soup cans
5. **Blow mold, fill, seal:**

There are several different **package forms** that are used in aseptic UHT processing:

- cans
- paperboard/plastic/foil/plastic laminates
- flexible pouches
- thermoformed plastic containers
- flow molded containers
- bag-in-box
- bulk totes

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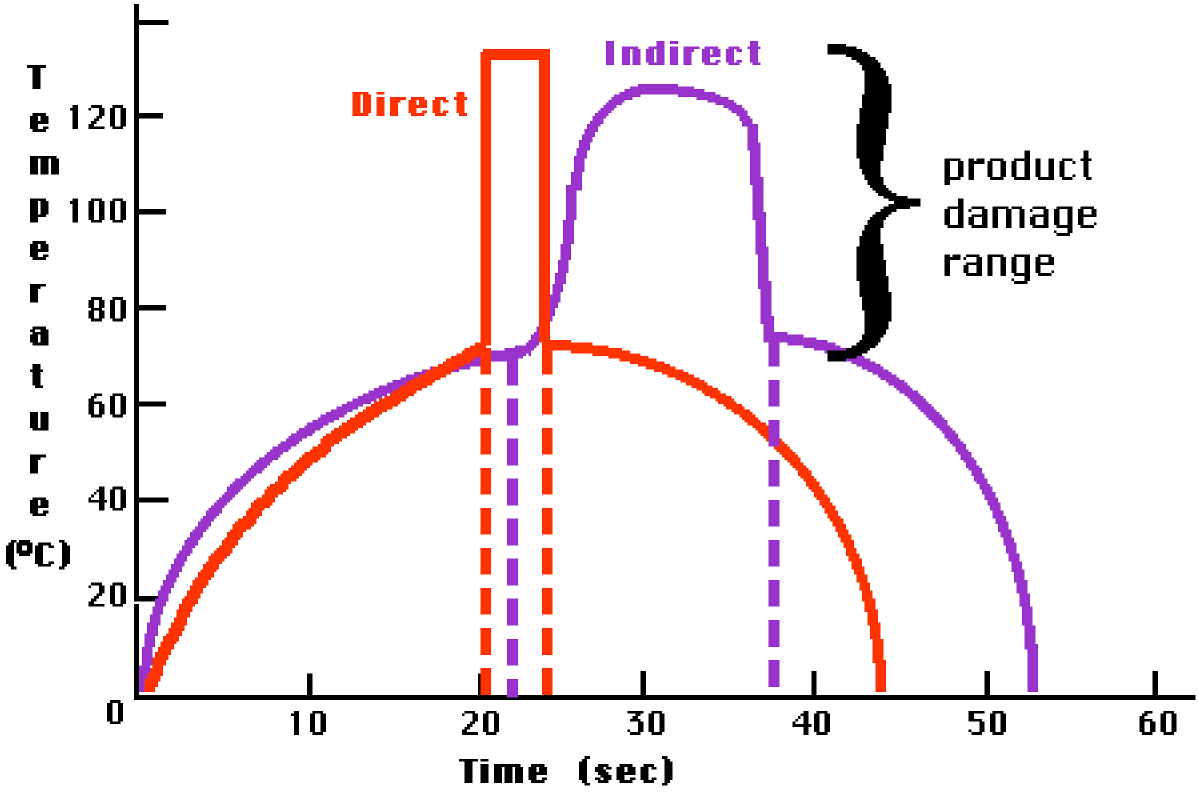
Direct and Indirect Continuous Sterilization



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Membrane Processing

Membrane processing is a technique that permits concentration and separation without the use of heat. Particles are separated on the basis of their molecular size and shape with the use of pressure and specially designed semi-permeable membranes. There are some fairly new developments in terms of commercial reality and is gaining readily in its applications:

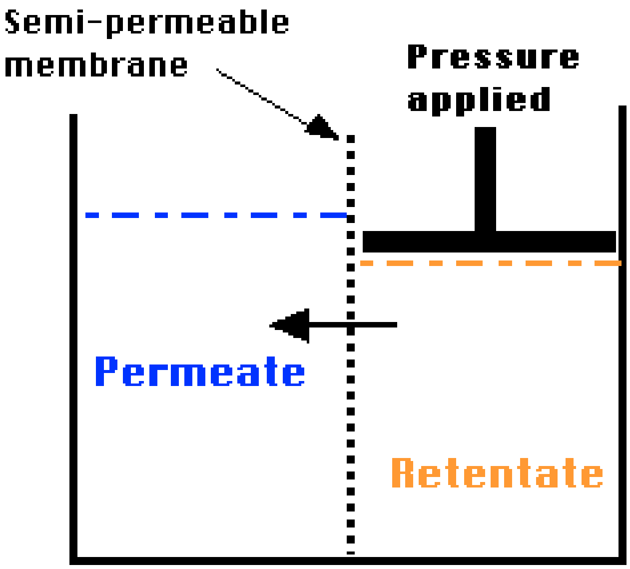
- proteins can be separated in whey for the production of whey protein concentrate (WPC)
- milk can be concentrated prior to cheesemaking at the farm level
- apple juice and wine can be clarified
- waste treatment and product recovery is possible in edible oil, fat, potato, and fish processing
- fermentation broths can be clarified and separated
- whole egg and egg white ultrafiltration as a preconcentration prior to spray drying

The following topics will be covered in this section:

Principle of Operation

When a solution and water are separated by a semi-permeable membrane, the water will move into the solution to equilibrate the system. This is known as ***osmotic pressure*** If a mechanical force is applied to exceed the osmotic pressure (up to 700 psi), the water is forced to move down the concentration gradient i.e. from low to high concentration. **Permeate** designates the liquid passing through the membrane, and **retentate** (concentrate) designates the fraction not passing through the membrane.

Membrane Processing



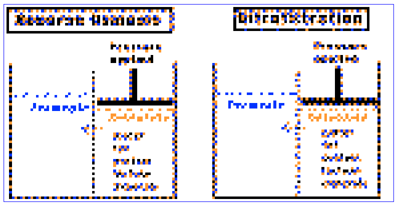
Membrane Processing

Reverse Osmosis

Reverse osmosis (RO) designates a membrane separation process, driven by a pressure gradient, in which the membrane separates the solvent (generally water) from other components of a solution. With reverse osmosis, the membrane pore size is very small allowing only small amounts of very low molecular weight solutes to pass through the membranes. It is a **concentration process** using a 100 MW cutoff, 700 psig, temperatures less than 40°C with cellulose acetate membranes and 70-80°C with composite membranes. **Hyperfiltration** is the same as RO.

Ultrafiltration

Ultrafiltration (UF) designates a membrane separation process, driven by a pressure gradient, in which the membrane fractionates components of a liquid as a function of their solvated size and structure. In UF, the membrane pore size is larger allowing some components to pass through the pores with the water. It is a **separation/ fractionation process** using a 10,000 MW cutoff, 40 psig, and temperatures of 50-60°C with polysulfone membranes. In UF milk, lactose and minerals pass in a 50% separation ratio; for example, in the retentate would be 100% of fat, 100% of protein, 50% of lactose, and 50% of free minerals.



RO and UF (17 KB)

Microfiltration

Microfiltration (MF) designates a membrane separation process similar to UF but with even larger membrane pore size allowing particles in the range of 0.2 to 2 micrometers to pass through. The pressure used is generally lower than that of UF process. MF is used in the dairy industry for making low-heat sterile milk as proteins may pass through but bacteria do not.

Hardware Design

Open Tubular:

Tubes of membrane with a diameter of 1/2 to 1 inch and length to 12 ft. are encased in reinforced fibreglass or enclosed inside a rigid PVC or stainless steel shell. As the feed solution flows through the membrane core, the permeate passes through the membrane and is collected in the tubular housing.Imagine 12 ft long straws!

Hollow Fibre:

Similar to open tubular, but the cartridges contain several hundred very small (1 mm diam) hollow membrane tubes or fibres. As the feed solution flows through the open cores of the fibres, the permeate is collected in the cartridge area surrounding the fibres.

Plate and Frame:

This system is set up like a plate heat exchanger with the retentate on one side and the permeate on the other. The permeate is collected through a central collection tube.

Spiral Wound:

This design tries to maximize surface area in a minimum amount of space. It consists of consecutive layers of large membrane and support material in an envelope type design rolled up around a perforated steel tube.

Ion Exchange

Fractionation may also be accomplished using ion exchange processing. It relies on inert resins (cellulose or silica based) that can adsorb charged particles at either end of the pH scale. The design can be a batch type, stirred tank or continuous column. The column is more suitable for selective fractionation. **Whey protein isolate (WPI)**, with a 95% protein content, can be produced by this method. Following adsorption and draining of the deproteined whey, the pH or charge properties are altered and proteins are eluted. Protein is recovered from the dilute stream through UF and drying. Selective resins may be used for fractionated protein products or enriched in fraction allow tailoring of ingredients.

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Dairy Science and Technology

Concentrated and Dried Dairy Products

Fluid milk contains approximately 88% water. Concentrated milk products are obtained through partial water removal. Dried dairy products have even greater amounts of water removed to usually less than 4%. The benefits of both these processes include an increased shelf-life, convenience, product flexibility, decreased transportation costs, and storage.

The following products will be discussed here:

Concentrated Dairy Products

- Evaporated Skim or Whole Milk
- Sweetened Condensed Milk
- Condensed Buttermilk
- Condensed Whey

Dried Dairy Products

- Milk Powder
- Whey Powder
- Whey Protein Concentrates

The principles of evaporation and dehydration can be found in the Dairy Processing section.

Concentrated Dairy Products

Evaporated Skim or Whole Milk

After the raw milk is clarified and standardized, it is given a pre-heating treatment of 93-100° C for 10 to 25 min or 115-128° C for 1 to 6 min.. There are several benefits to this treatment:

- increases the concentrated milk stability during sterilization; decreases the chance of coagulation taking place during storage
- decreases the initial microbial load
- modifies the viscosity of the final product
- milk enters the evaporator already hot

Milk is then concentrated at low temperatures by **vacuum evaporation**. This process is based on the physical law that the boiling point of a liquid is lowered when the liquid is exposed to a pressure below atmospheric pressure. In this case, the boiling point is lowered to approximately 40-45° C. This results in little to no cooked flavour. The milk is concentrated to 30-40% total solids.

The evaporated milk is then **homogenized** to improve the milkfat emulsion stability. There are other benefits particular to this type of product:

- increased white colour
- increased viscosity
- decreased coagulation ability

A **second standardization** is done at this time to ensure the proper salt balance is present. The ability of milk to withstand intensive heat treatment depends to a great degree on its salt balance.

The product at this point is quite perishable. The fat is easily oxidized and the microbial load, although decreased, is still a threat. The evaporated milk at this stage is often shipped by the tanker for use in other products.

In order to extend the shelf life, evaporated milk can be packaged in cans and then **sterilized** in an autoclave. Continuous flow sterilization followed by packaging under aseptic conditions is also done. While the sterilization process produces a light brown colouration, the product can be successfully stored for up to a year.

Sweetened Condensed Milk

Where evaporated milk uses sterilization to extend its shelf-life, sweetened condensed milk has an extended shelf-life due to the addition of sugar. Sucrose, in the form of crystals or solution, increases the ***osmotic pressure*** of the liquid. This in turn, prevents the growth of microorganisms.

The only real **heat treatment** (85-90° C for several seconds) this product recieves is after the raw milk has been clarified and standardized. The benefits of this treatment include totally destroying osmophilic and thermophilic microorganisms, inactivating lipases and proteases, decreases fat separation and inhibits oxidative changes. Unfortunately it also affects the final product viscosity and may promote the defect age gelation.

The milk is **evaporated** in a manner similar to the evaporated milk. Although sugar may be added before evaporation, post evaporation addition is recommended to avoid undesirable viscosity changes during storage. Enough sugar is added so that the final concentration of sugar is approximately 45%.

The sweetened evaporated milk is then cooled and **lactose crystallization** is induced. The milk is inoculated, or seeded, with powdered lactose crystals, then rapidly cooled while being agitated. The lactose can crystalize without the seeding but there is the danger of forming crystals that are too large. This would result in a texture defect similar in ice cream called **sandiness**, which affects the mouthfeel. By seeding, the number of crystals increases and the size of those crystals decreases.

The product is packaged in smaller containers, such as cans, for retail sales and bulk containers for industrial sales.

Condensed Buttermilk

Buttermilk is a by-product of the butter industry. It can be evaporated on its own or it can be blended with skimmilk and dried to produce skimmilk powder. This blended product may oxidise readily due to the higher fat content. Condensed buttermilk is perishable and, therefore, the supply must be fresh and it must be stored cool.

Condensed Whey

In the process of cheesemaking, there is alot of whey that needs to be disposed of. One of the ways of utilizing cheesewhey is to condense it. The whey contains fat, lactose, ß -lactoglobulin, alpha-lactalbumin, and water. The fat is generally removed by centrifugation and churned as whey cream or used in ice cream. Evaporation is the first step in producing whey powder.

Dried Dairy Products

Milk Powder

Milk used in the production of milk powders is first clarified, standardized and then given a heat treatment. This heat treatment is usually more severe than that required for pasteurization. Besides destroying all the pathogenic and most of the spoilage microorganisms, it also inactivates the enzyme lipase which could cause lipolysis during storage.

The milk is then evaporated prior to drying for the following reasons:

- less occluded air and longer shelf life for the powder
- viscosity increase leads to larger powder particles
- less energy required to remove part of water by evaporation; more economical

Homogenization may be applied to decrease the free fat content. Spray drying is the most used method for producing milk powders. After drying, the powder must be packaged in containers able to provide protection from moisture, air, light, etc. Whole milk powder can then be stored for long periods (up to about 6 months) of time at ambient temperatures.

Skim milk powder (SMP) processing is similar to that described above except for the following points:

1. contains less milkfat (0.05-0.10%)
2. heat treatment prior to evaporation can be more or less severe
3. homogenization not required
4. maximum shelf life extended to approximately 3 years

Low-heat SMP is given a pasteurization heat treatment and is used in the production of cheese, baby foods etc. **High-heat SMP** requires a more intense heat treatment in addition to pasteurization. This product is used in the bakery industry, chocolate industry, and other foods where a high degree of protein denaturation is required.

Instant milk powder is produced by partially rehydrating the dried milk powder particles causing them to become sticky and agglomerate. The water is then removed by drying resulting in an increased amount of air incorporated between the powder particles.

Whey Powder

Whey is the by-product in the manufacturing of cheese and casein. Disposing of this whey has long been a problem. For environmental reasons it is no longer discharged into lakes and rivers; for economical reasons it is not feasible to use it as animal feed or fertilizer. Converting whey into powder has led to a number products that it can be incorporated into.

Whey powder is essentially produced by the same method as other milk powders. Reverse osmosis can be used to partially concentrate the whey prior to vacuum evaporation. Before the whey concentrate is spray dried, lactose crystallization is induced to decrease the hygroscopicity. This is accomplished by quick cooling in flash coolers after evaporation. Crystallization continues in agitated tanks for 4 to 24 h.

A fluidized bed may be used to produce large agglomerated particles with free-flowing, non-hygroscopic, no caking characteristics.

Whey Protein Concentrates

Both whey disposal problems and high-quality animal protein shortages have increased world-wide interest in whey protein concentrates. After clarification and pasteurization, the whey is cooled and held to stabilize the calcium phosphate complex, which later decreases membrane fouling. The whey is commonly processed using ultrafiltration, although reverse osmosis, microfiltration, and demineralization methods can be used. During ultrafiltration, the low molecular weight compounds such as lactose, minerals, vitamins and nonprotein nitrogen are removed in the permeate while the proteins become concentrated in the retentate. After ultrafiltration, the retentate is pasteurized, may be evaporated, then dried. Drying, usually spray drying, is done at lower temperatures than for milk in order that large amounts of protein denaturation may be avoided.

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Evaporation and Dehydration

The removal of water from foods provides microbiological stability, reduces deteriorative chemical reactions, and reduces transportation and storage costs. Both evaporation and dehydration are methods used in the dairy industry for this purpose. The following topics will be addressed here:

Evaporation

- Principle of Operation
- Evaporator designs
    - Batch Pan
    - Rising Film
    - Falling Film
    - Multiple Effect Evaporators
    - Thermo compression
    - Mechanical Vapour Recompression

Dehydration

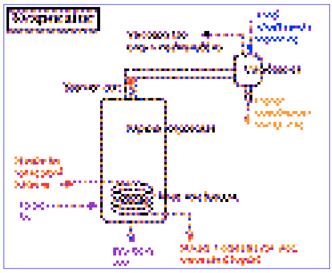
- Spray Drying Process
- Powder Recovery
    - Bag filters
    - Cyclone collector
    - Wet scrubber
- Two and Three Stage Spray Driers
    - Principles of Fluid Beds
    - Process
- Agglomeration and Instantizing

Evaporation

Evaporation refers to the process of heating liquid to the boiling point to remove water as vapour. Because milk is heat sensitive, heat damage can be minimized by evaporation under vacuum to reduce the boiling point. The basic components of this process consist of:

- heat-exchanger
- vacuum
- vapour separator
- condenser

The **heat exchanger** is enclosed in a large chamber and transfers heat from the heating medium, usually low pressure steam, to the product usually via indirect contact surfaces. The **vacuum** keeps the product temperature low and the difference in temperatures high. The **vapour separator** removes entrained solids from the vapours, channelling solids back to the heat exchanger and the vapours out to the **condenser**. It is sometimes a part of the actual heat exchanger, especially in older vacuum pans, but more likely a separate unit in newer installations. The condenser condenses the vapours from inside the heat exchanger and may act as the vacuum source.


Evaporator 17 KB

Principle of Operation

The driving force for heat transfer is the difference in temperature between the steam in the coils and the product in the pan. The steam is produced in large boilers, generally tube and chest heat exchangers. The steam temperature is a function of the steam pressure. Water boils at 100° C at 1 atm., but at other pressures the boiling point changes. At its boiling point, the steam condenses in the coils and gives up its latent heat. If the steam temperature is too high, burn-on/fouling increases so there are limits to how high steam temperatures can go. The product is also at its boiling point. The boiling point can be elevated with an increase in solute concentration. This ***boiling point elevation*** works on the same principles as freezing point depression.

Evaporator Designs

Types of single effect evaporators:

- Batch Pan
- Rising film
- Falling film
- Plate evaporators
- Scraped surface

Batch pan evaporators are the simplest and oldest. They consist of spherical shaped, steam jacketed vessels. The heat transfer per unit volume is small requiring long residence times. The heating is due only to natural convection, therefore, the heat transfer characteristics are poor. Batch plants are of historical significance; modern evaporation plants are far-removed from this basic idea. The vapours are a tremendous source of low pressure steam and must be reused.

Rising film evaporators consist of a heat exchanger isolated from the vapour separator. The heat exchanger, or calandria, consists of 10 to 15 meter long tubes in a tube chest which is heated with steam. The liquid rises by percolation from the vapours formed near the bottom of the heating tubes. The thin liquid film moves rapidly upwards. The product may be recycled if necessary to arrive at the desired final concentration. This development of this type of modern evaporator has given way to the falling film evaporator.

The **falling film** evaporators are the most widely used in the food industry. They are similar in components to the rising film type except that the thin liquid film moves downward under gravity in the tubes. A uniform film distribution at the feed inlet is much more difficult to obtain. This is the reason why this development came slowly and it is only within the last decade that falling film has superceded all other designs. Specially designed nozzels or spray distributors at the feed inlet permit it to handle more viscous products. The residence time is 20-30 sec. as opposed to 3-4 min. in the rising film type. The vapour separator is at the bottom which decreases the product hold-up during shut down. The tubes are 8-12 meters long and 30-50 mm in diameter.

Multiple Effect Evaporators

Two or more evaporator units can be run in sequence to produce a multiple effect evaporator. Each effect would consist a heat transfer surface, a vapour separator, as well as a vacuum source and a condenser. The vapours from the preceding effect are used as the heat source in the next effect. There are two advantages to multiple effect evaporators:

- economy - they evaporate more water per kg steam by re-using vapours as heat sources in subsequent effects
- improve heat transfer - due to the viscous effects of the products as they become more

concentrated

Each effect operates at a lower pressure and temperature than the effect preceding it so as to maintain a temperature difference and continue the evaporation procedure. The vapours are removed from the preceding effect at the boiling temperature of the product at that effect so that no temperature difference would exist if the vacuum were not increased. The operating costs of evaporation are relative to the number of effects and the temperature at which they operate. The boiling milk creates vapours which can be recompressed for high steam econonmy. This can be done by adding energy to the vapour in the form of a steam jet, **thermo compression** or by a mechanical compressor, **mechanical vapour recompression**.

Thermo Compression (TC)

Involves the use of a steam-jet booster to recompress part of the exit vapours from the first effect. Through recompression, the pressure and temperature of the vapours are increased. As the vapours exit from the first effect, they are mixed with very high pressure steam. The steam entering the first effect calandria is at slightly less pressure than the supply steam. There is usually more vapours from the first effect than the second effect can use; usually only the first effect is coupled with multiple effect evaporators.

Mechanical Vapour Recompression (MVR)

Whereas only part of the vapour is recompressed using TC, all the vapour is recompressed in an MVR evaporator. Vapours are mechanically compressed by radial compressors or simple fans using electrical energy.

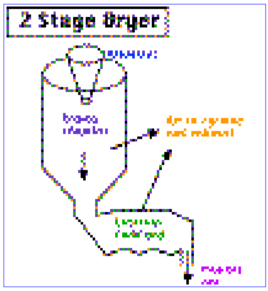
There are several variations; in single effect, all the vapours are recompressed therefore no condensing water is needed; in multiple effect, can have MVR on first effect, followed by two or more traditional effects; or can recompress vapours from all effects.

Dehydration

Dehydration refers to the nearly complete removal of water from foods to a level of less than 5%. Although there are many types of driers, **spray driers** are the most widely used type of air convection drier. It turns out more tonnage of dehydrated products than all other types of driers combined. It is limited to food that can be atomized, i.e. liquids, low viscosity pastes, and purees. Drying takes place within a matter of seconds at temperatures approximately 200° C. Evaporative cooling maintains low product temperatures, however, prompt removal of the product is still necessary.

Spray Drying - Process Summary

The liquid food is generally preconcentrated by evaporation to economically reduce the water content. The concentrate is then introduced as a fine spray or mist into a tower or chamber with heated air. As the small droplets make intimate contact with the heated air, they flash off their moisture, become small particles, and drop to the bottom of the tower and are removed. The advantages of spray drying include a low heat and short time combination which leads to a better quality product.



Spray Dryer 17 KB

Principal components include:

- a high pressure pump for introducing liquid into the tower
- a device for atomizing the feed stream
- a heated air source with blower
- a secondary collection vessel for removing the dried food from the airstream
- means for exhausting the moist air
- usually includes a preconcentration step i.e. MVR evaporation

Atomizing devices are the distinguishing characteristic of spray drying. They provide a large surface area for exposure to drying forces:

1 litre = 12 billion particles = >300 ft^2 (30m^2)

The exit air temperature is an important parameter to monitor because it responds readily to changes in the process and reflects the quality of the product. Generally, we want it high enough to yield desired moisture without heat damage. There are two controls that may be used to adjust the exit air temperature:

- altering feed flow rate
- altering inlet temperature

If heat damage occurs before the product is dried, the particle size must be reduced; smaller particle dries faster, therefore, less heat damage. This can be accomplished in three ways:

- smaller orifice
- increase atomizing pressure
- reduce viscosity - by increasing feed temperature or reducing solids

Powder Recovery

It is essential for both economic and environmental reasons that as much powder as possible be recovered from the air stream. Three systems are available, however wet scrubbers usually act as a secondary collection system following a cyclone.

Bag filters

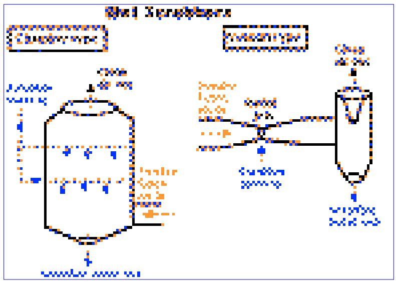
Bag filters are very efficient (99.9%), but not as popular due to labor costs, sanitation, and possible heat damage because of the long residence time. They are not recommended in the case of handling high moisture loads or hygroscopic particles.

Cyclone collector

Cyclones are not as efficient (99.5%) as bag filters but several can be placed in series. Air enters at tangent at high velocity into a cylinder or cone which has a much larger cross section. Air velocity is decreased in the cone permitting settling of solids by gravity. Centrifugal force is important in removing particles from the air stream. High air velocity is needed to separate small diameter and light materials from air; velocities may approach 100 ft/sec (70 MPH). Higher centrifugal force can be obtained by using small diameter cyclones, several of which may be placed in parallel; losses may range from 0.5-2%. A rotary airlock is used to remove powder from the cyclone. (An example of a rotary airlock is a revolving door at a hotel lobby which is intended to break the outside and inside environments).

Wet scrubber

Wet scrubbers are the most economical outlet air cleaner. The principle of a wet scrubber is to dissolve any dust powder left in the airstream into either water or the feed stream by spraying the wash stream through the air. This also recovers heat from the exiting air and evaporates some of the water in the feed stream (if used as the wash water).



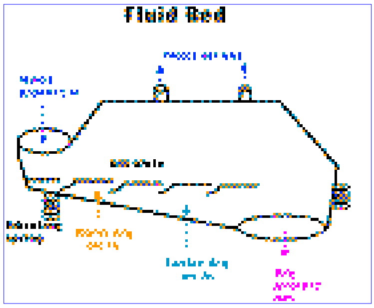
Wet scrubbers 17 KB

Wet scrubbers not only recover most of what would be lost product, but also recover approximately 90% of the potential drying energy normally lost in exit air. The exit air picks up moisture which increases evaporative capacity by 8% (concentration of feed). Cyclone separators are probably the best primary powder separator system because they are hygienic, easy to operate, and versatile, however, high losses may occur. Wet scrubbers are designed for a secondary air cleaning system in conjunction with the cyclone. Either feed stream or water can be used as scrubbing liquor. Also, there are heat recovery systems available.

Two and Three Stage Spray Drying With a Fluidized Bed

Principles of Fluid Beds

Air is blown up through a wire mesh belt on porous plate that supports and conveys the product. A slight vibration motion is imparted to the food particles. When the air velocity is increased to the point where it just exceeds the velocity of free fall (gravity) of the particles, fluidization occurs. The dancing/boiling motion subdivides the product and provides intimate contact of each particle with the air, but keeps clusters from forming.



Fluidized Bed 17 KB

With products that are particularly difficult to fluidize, a vibrating motion of the drier itself is used to aid fluidization; it is called vibro-fluidizer which is on springs. The fluidized solid particles then behave in an analogous manner to a liquid., i.e. they can be conveyed. Air velocities will vary with particle size and density, but are in the range of 0.3 - 0.75 m/s. They can be used not only for drying but also for cooling. If the velocity is too high, the particles will be carried away in the gas stream, therefore, gravitational forces need to be only slightly exceeded.

Two and Three Stage Drying Processes

In standard, single stage spray drying, the rate of evaporation is particularly high in the first part of the process, and it gradually decreases because of the falling moisture content of the particle surfaces. In order to complete the drying in one stage, a relatively high outlet temperature is required during the final drying phase. Of course the outlet temperature is reflective of the particle temperature and thus heat damage .

Consequently the **two stage** drying process was introduced which proved to be superior to the traditional single stage drying in terms of product quality and cost of production.

The two stage drier consists of a spray drier with an external vibrating fluid bed placed below the drying chamber. The product can be removed from the drying chamber with a higher moisture content, and the final drying takes place in the external fluid bed where the residence time of the product is longer and the temperature of the drying air lower than in the spray dryer.

This principle forms the basis of the development of the **three stage** drier. The second stage is a fluid bed built into the cone of the spray drying chamber. Thus it is possible to achieve an even higher moisture content in the first drying stage and a lower outlet air temperature from the spray drier. This fluid bed is called the integrated fluid bed. The inlet air temperature can be raised resulting in a larger temperature difference and improved efficiency in the drying process. The exhaust heat from the chamber is used to preheat the feed stream. The third stage is again the external fluid bed, which can be static or vibrating, for final drying and/or cooling the powder. The results are as follows:

- higher quality powders with much better rehydrating properties directly from the drier
- lower energy consumption
- increased range of products which can be spray dried i.e., non density, non hygroscopic
- smaller space requirements

Agglomerating and Instantizing

These processes have allowed the manufacturing of milk powders with better reconstitution properties, such as instantized skim milk powder.

Agglomeration Mechanism: Powder is wetted with water or steam. The surface must be uniformly wetted but not excessively. The powder is held wet over a selected period of time to give moisture stability to the clusters which have formed. The clusters are dried to the desired moisture content and then cooled (e.g., fluid bed). Dried clusters are screened and sized to reduce excessively large particles and remove excessively small ones. The aggomeration process causes an increase in the amount of air incorporated between powder particles. More incorporated air is replaced with more water when the powder is reconstituted, which immediately wet the powder particles.

Agglomerating Techniques

Rewet Methods:

This method uses powder as feed stock. An example is the ARCS Instantizer. Humidified air moistens powder which causes it to cluster. It is re-dried and wetted. The clustered powder is then exposed to heated, filtered, high-velocity air. The dried clusters are then exposed to cooled air on a vibrating belt. It is then sized (pelleted to uniform size) and the fines are removed.

Straight Thru Process:

A multi-stage drying process produces powders with much better solubility characteristics similar to instantized powder. This method uses a low outlet temperature which allows higher moisture in powder as it is taken from spray drier with excess moisture removed in the fluid bed. The powder fines are reintroduced to the atomizing cloud in the drying chamber.

More information on specific evaporated and dehydrated products is located in the Dairy Commodoties section.

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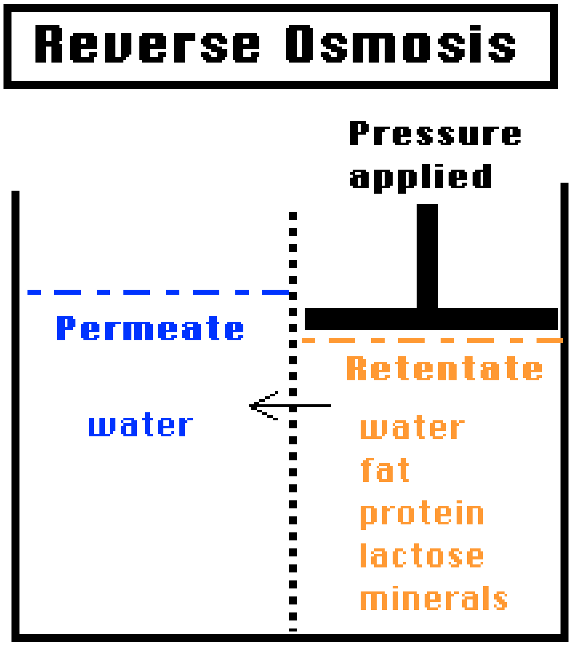
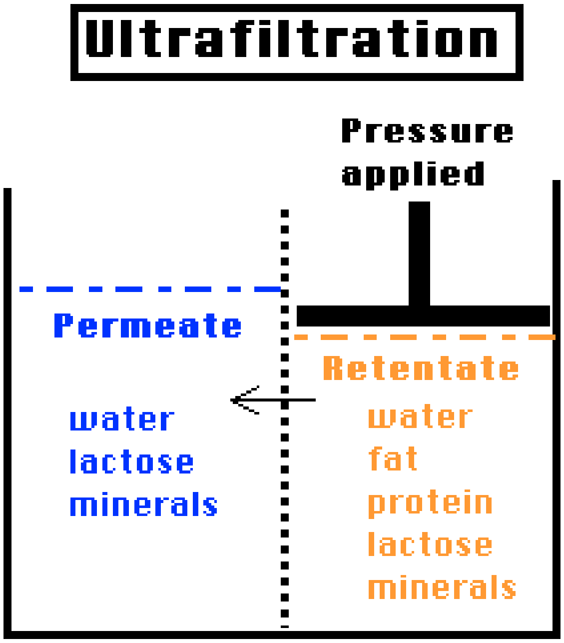
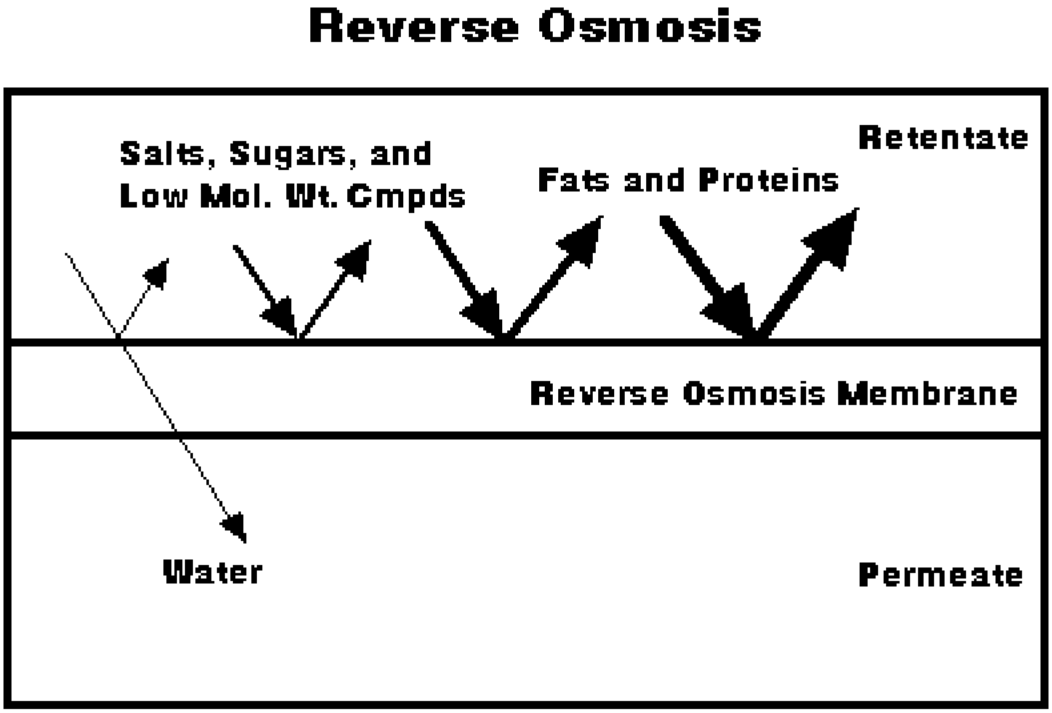
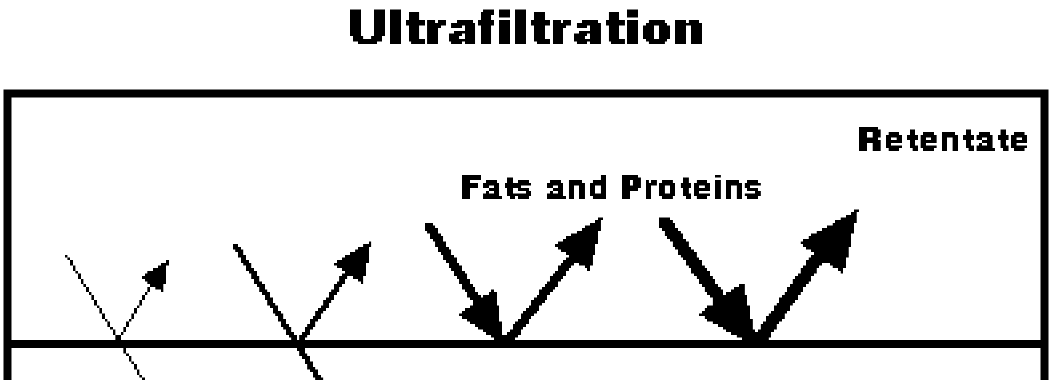
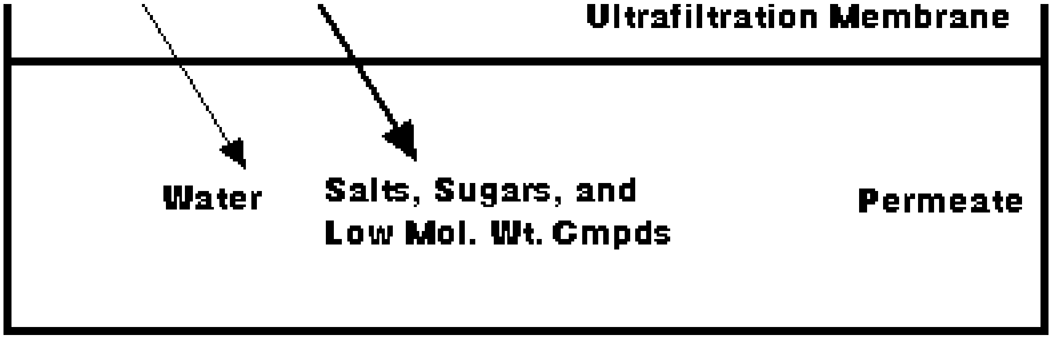




This can be visualized with another schematic, as follows, which may be more informative:







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Cheese

Traditionally, cheese was made as a way of preserving the nutrients of milk. In a simple definition, cheese is the fresh or ripened product obtained after coagulation and whey separation of milk, cream or partly skimmed milk, buttermilk or a mixture of these products. It is essentially the product of selective concentration of milk. Thousands of varieties of cheeses have evolved that are characteristic of various regions of the world.

Some common cheesemaking steps will be outlined here.

- Treatment of Milk
- Additives
- Inoculation and Milk Ripening
- Coagulation
    - enzyme
    - acid
    - heat-acid
- Curd Treatment
- Cheese Ripening

Treatment of Milk for Cheesemaking

Like most dairy products, cheesemilk must first be **clarified**, **separated** and **standardized**. The milk may then be subjected to a sub-pasteurization treatment of 63-65° C for 15 to 16 sec. This **thermization** treatment results in a reduction of high initial bacteria counts before storage. It must be followed by proper pasteurization. While HTST pasteurization (72° C for 16 sec) is often used, an alternative heat treatment of 60° C for 16 sec may also be used. This less severe heat treatment is thought to result in a better final flavour cheese by preserving some of the natural flora. If used, the cheese must be stored for 60 days prior to sale, which is similar to the regulations for raw milk cheese.

Homogenization is not usually done for most cheesemilk. It disrupts the fat globules and increases the fat surface area where casein particles adsorb. This reults in a soft, weak curd at renneting and increased hydrolytic rancidity.

Additives

The following may all be added to the cheese milk:

- Calcium choride
- nitrates
- colour
- hydrogen peroxide
- lipases

Calcium choride is added to replace calcium lost during pasteurization. The calcium assists in coagulation and reduces the amount of rennet required.

Sodium or potassium nitrate is added to the milk to control the undesirable effects of *Clostridium tyrobutyricum* in cheeses such as Edam, Gouda, and Swiss.

Because milk colour varies from season to season, colour may added to standardize the colour of the cheese throughout the year. **Annato, Beta-carotene, and paprika** are used.

The addition of **hydrogen peroxide** is sometimes used as an alternative treatment for full pateurization.

Lipases, normally present in raw milk, are inactivated during pasteurization. The addition of kid goat lipases are common to ensure proper flavour development through fat hydrolysis.

Inoculation and Milk Ripening

The basis of cheesemaking relies on the fermentation of lactose by **lactic acid bacteria** (LAB). LAB produce lactic acid which lowers the pH and in turn assists coagulation, promotes syneresis, helps prevent spoilage and pathogenic bacteria from growing, contributes to cheese texture, flavour and keeping quality. LAB also produce growth factors which encourages the growth of non-starter organisms, and provides lipases and proteases necessary for flavour development during curing. Further information on LAB and starter cultures can be found in the microbiology section.

After innoculation with the starter culture, the milk is held for 45 to 60 min at 25 to 30° C to ensure the bacteria are active, growing and have developed acidity. This stage is called **ripening the milk** and is done prior to renneting.

Milk Coagulation

Coagulation is essentially the formation of a gel by destabilizing the casein micelles causing them to aggregate and form a network which partially immobilizes the water and traps the fat globules in the newly formed matrix. This may be accomplished with:

- enzymes
- acid treatment
- heat-acid treatment

Enzymes
Chymosin, or rennet, is most often used for enzyme coagulation.

Acid Treatment
Lowering the pH of the milk results in casein micelle destabilization or aggregation. Acid curd is more fragile than rennet curd due to the loss of calcium. Acid coagulation can be achieved naturally with the starter culture, or artificially with the addition of gluconodeltalactone. Acid coagulated fresh cheeses may include Cottage cheese, Quark, and Cream cheese.

Heat-Acid Treatment
Heat causes denaturation of the whey proteins. The denatured proteins then interact with the caseins. With the addition of acid, the caseins precipitate with the whey proteins. In rennet coagulation, only 76-78% of the protein is recovered, while in heat-acid coagulation, 90% of protein can be recovered. Examples of cheeses made by this method include Paneer, Ricotta and Queso Blanco.

Curd Treatment

After the milk has gel has been allowed to reach the desired firmness, it is carefully **cut** into small pieces with knife blades or wires. This shortens the distance and increases the available area for whey to be released. The curd pieces immediately begin to shrink and expel the greenish liquid called whey. This **syneresis** process is further driven by a cooking stage. The increase in temperature causes the protein matrix to shrink due to increased hydrophobic interactions, and also increases the rate of fermentation of lactose to lactic acid. The increased acidity also contributes to shrinkage of the curd particles. The final moisture content is dependant on the time and temperature of the cook stage. This is important to monitor carefully because the final moisture content of the curd determines the residual amount of fermentable lactose and thus the final pH of the cheese after curing.

When the curds have reached the desired moisture and acidity they are **separated from the whey**. The whey may be removed from the top or drained by gravity. The curd-whey mixture may also be placed in moulds for draining. Some cheese varieties, such as Colby, Gouda, and Brine Brick include a curd washing which increases the moisture content, reduces the lactose content and final acidity, decreases firmness, and increases openness of texture.

Curd handling from this point on is very specific for each cheese variety. Salting may be achieved through brine as with Gouda, surface salt as with Feta, or vat salt as with Cheddar. To acheive the characteritics of Cheddar, a cheddaring stage (curd manipulation), milling (cut into shreds), and pressing at high pressure are crucial.

Cheese Ripening

Except for fresh cheese, the curd is ripened, or matured, at various temperatures and times until the characteristic flavour, body and texture profile is achieved. During ripening, degradation of lactose, proteins and fat are carried out by ripening agents. The ripening agents in cheese are:

- bacteria and enzymes of the milk
- lactic culture
- rennet
- lipases
- added moulds or yeasts
- environmental contaminants

Thus the microbiological content of the curd, the biochemical composition of the curd, as well as temperature and humidity affect the final product. This final stage varies from weeks to years according to the cheese variety.

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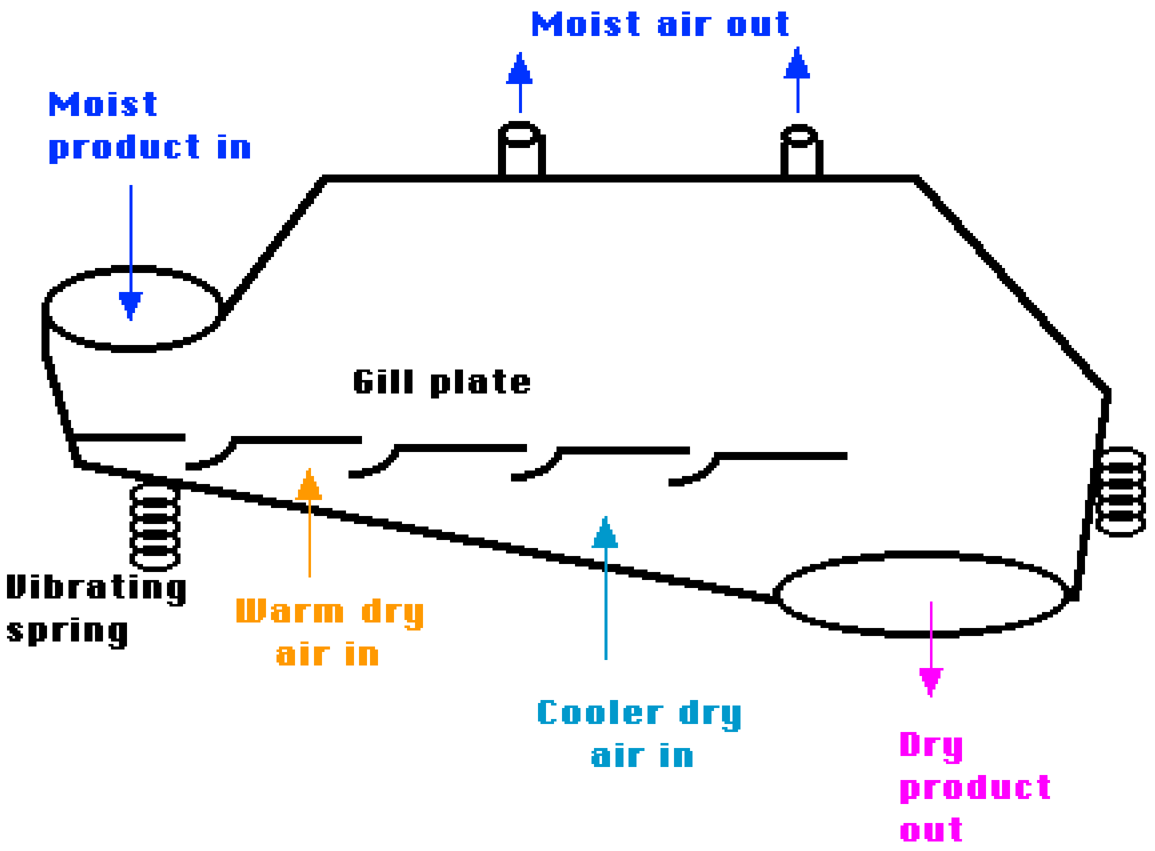
Fluid Bed



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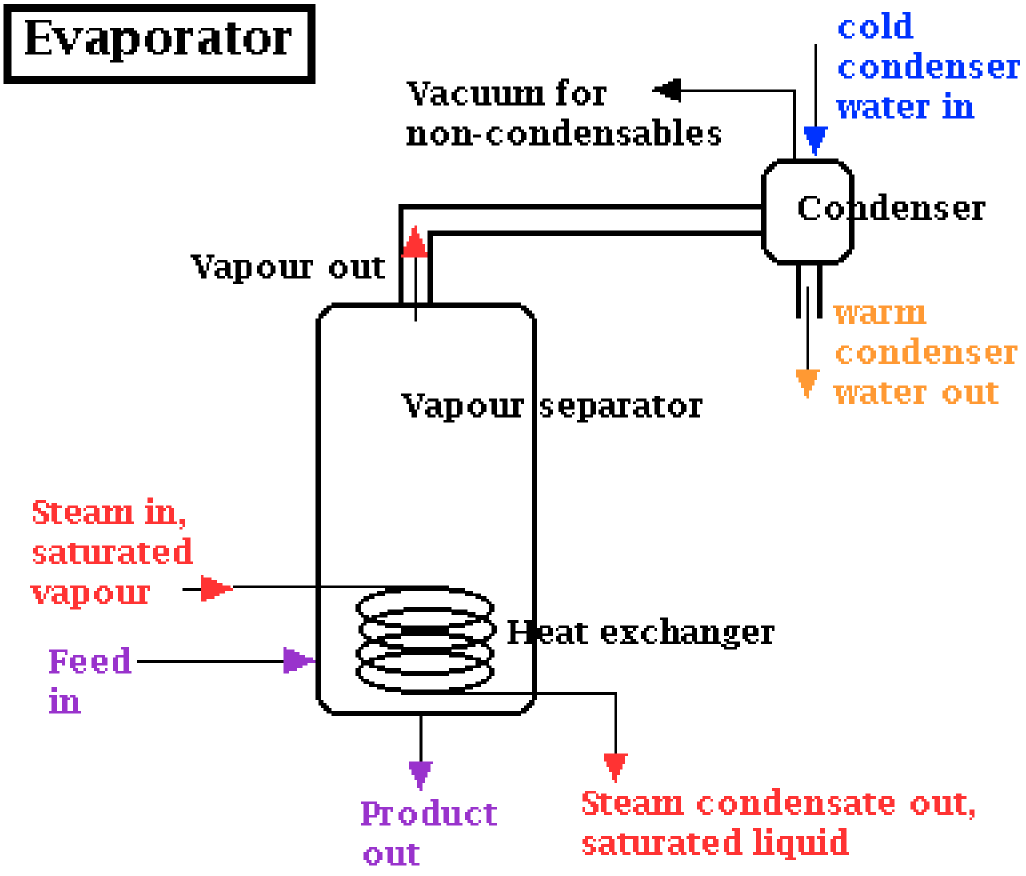
Evaporator



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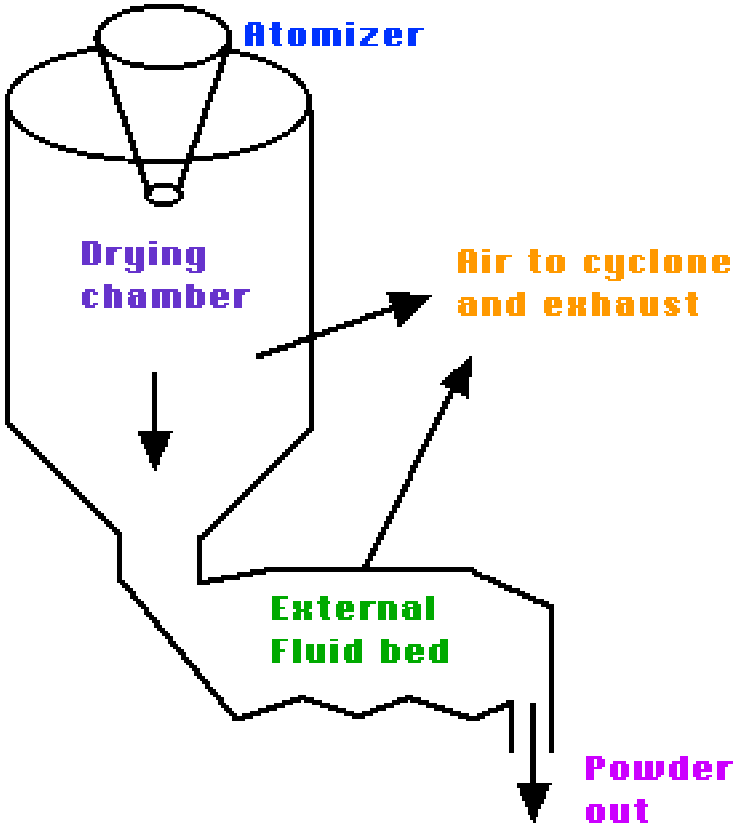
2 Stage Dryer



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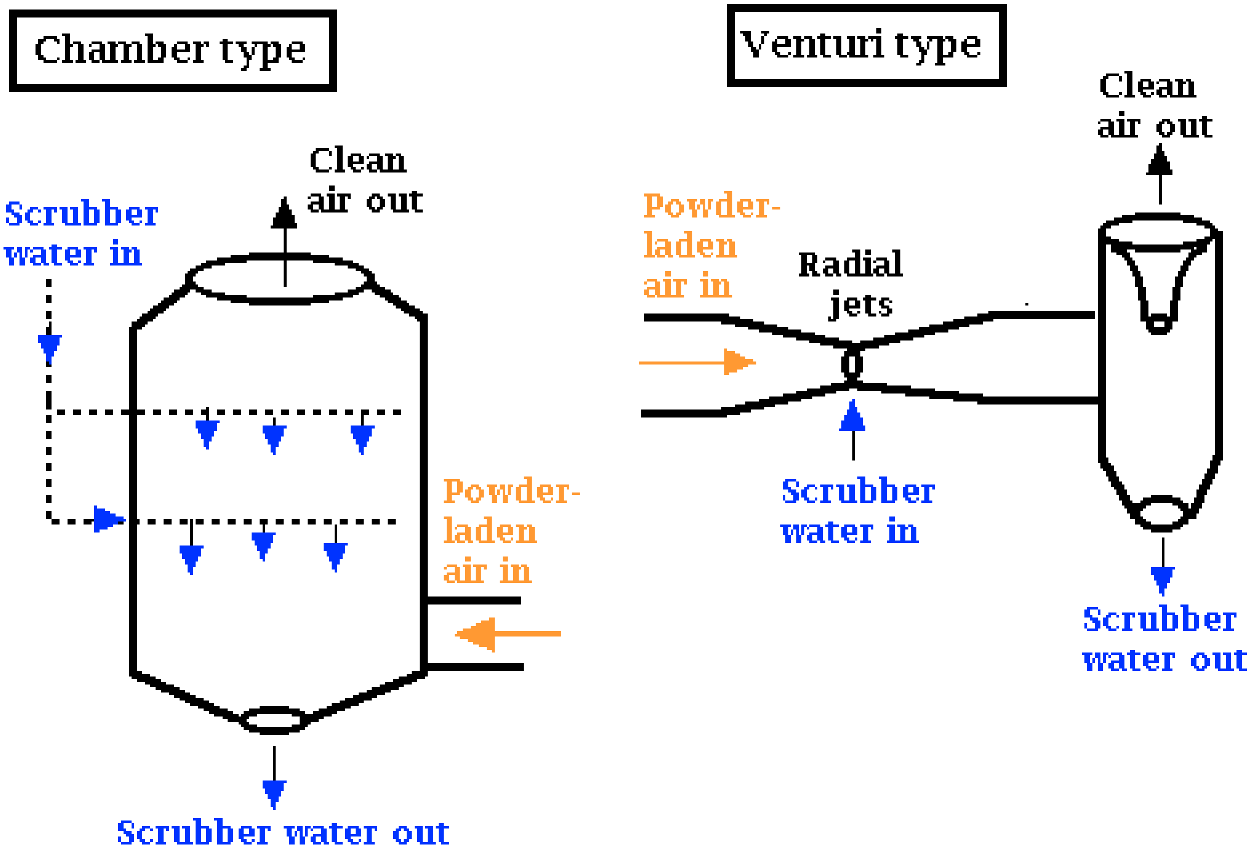
Wet Scrubbers



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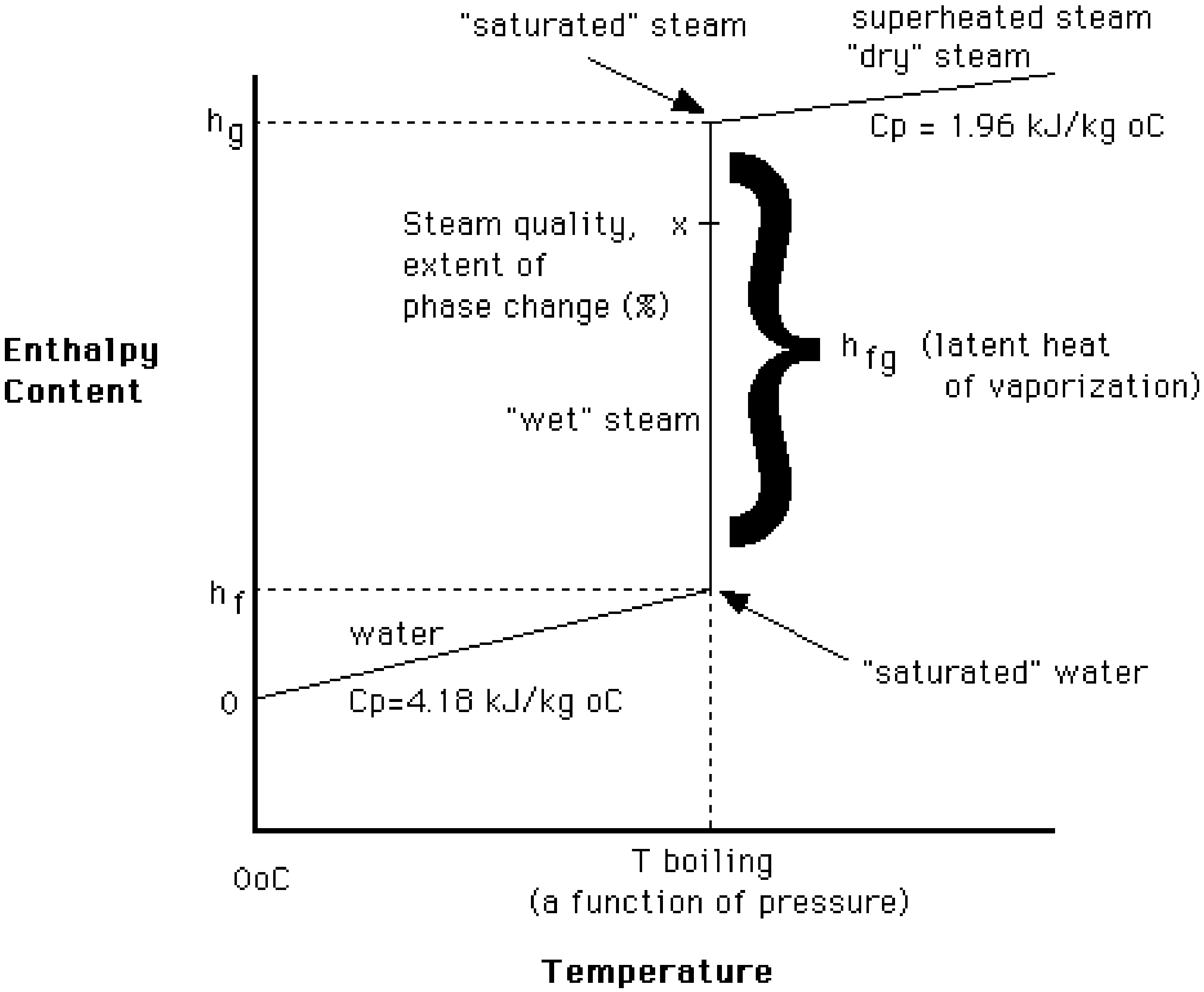
Production and Utilization of Steam and Refrigeration

This section will describe the production and utilization of both steamand refrigeration, two utilities absolutely essential to the operation of a dairy processing plant.

Steam Production and Utilization

Understanding steam

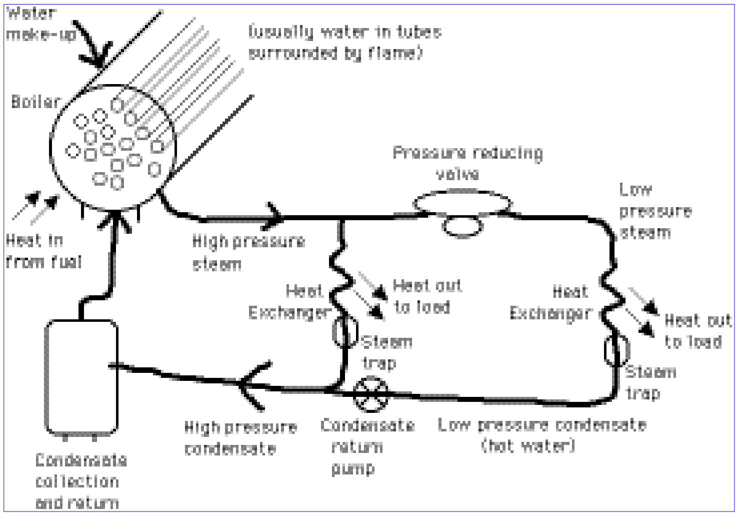
The diagram below helps to explain the various principles involved in the thermodynamics of steam. It shows the relationship between temperature and enthalpy (energy or heat content) of water as it passes through its phase change.



The reference point for enthalpy of water and steam is 0oC, at which point an enthalpy value of 0 kJ/kg is given to it (but of course water at 0o has alot of energy in it, which is given up as it freezes - it's not until 0K, absolute zero, when it truely has no enthalpy!). As we increase the temperature of water, its enthalpy increases by 4.18 kJ/kg oC until we hit its boiling point (which is a function of its pressure - the boiling point of water is 100oC ONLY at 1 atm. pressure). At this point, a large input of enthalpy causes no temperature change but a phase change, latent heat is added and steam is produced. Once all the water has vaporized, the temperature again increases with the addition of heat (sensible heat of the vapour).

Steam Production and Distribution

Steam is produced in large tube and chest heat exchangers, called water tube boilers if the water is in the tubes, surrounded by the flame, or fire tube boilers if the opposite is true. The pressure inside a boiler is usually high, 300-800 kPa. The steam temperature is a function of this pressure. The steam, usually saturated or of very high quality, is then distributed to the heat exchanger where it is to be used, and it provides heat by condensing back to water (called condensate) and giving up its latent heat. The temperature desired at the heat exchanger can be adjusted by a pressure reducing valve, which lowers the pressure to that corresponding to the desired temperature. After the steam condenses in the heat exchanger, it passes through a steam trap (which only allows water to pass through and hence holds the steam in the heat exchanger) and then the condensate (hot water) is returned to the boiler so it can be reused. The following image is a schematic of a steam production and distribution cycle.



Steam Production and Utilization

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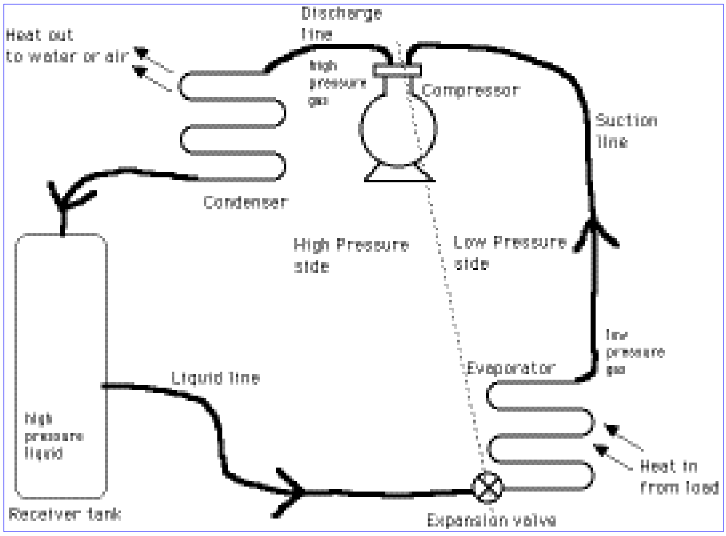
Refrigeration

The following image is a schematic of a refrigeration cycle. It is described in detail below, so you may want to go back and forth between the diagram and the description.



Refrigeration Cycle

Mechanical refrigerators have four basic elements: an evaporator, a compressor, a condenser, and a refrigerant flow control (expansion valve). A refrigerant circulates among the four elements changing from liquid to gas and back to liquid.

In the evaporator, the liquid refrigerant evaporates (boils) under reduced pressure and in doing so absorbs latent heat of vaporization and cools the surroundings. The evaporator is at the lowest temperature in the system and heat flows to it. This heat is used to vaporize the refrigerant. The temperature at which this occurs is a function of the pressure on the refrigerant: for example if ammonia is the refrigerant, at -18oC the ammonia pressure required is 1.1 kg/sq. cm. The part of the process described thus far is the useful part of the refrigeration cycle; the remainder of the process is necessary only so that the refrigerant may be returned to the evaporator to continue the cycle.

The refrigerant vapour is sucked into a compressor, a pump that increases the pressure and then exhausts it at a higher pressure to the condenser. For ammonia, this is approx. 10 kg/sq. cm. To complete the cycle, the refrigerant must be condensed back to liquid and in doing this it gives up its latent heat of vaporization to some cooling medium such as water or air. The condensing temperature of ammonia is 29oC, so that cooling water at about 21oC could be used. In home refrigerators, the compressed gas (not ammonia) is sent through the pipes at the back, which are cooled by circulating air around them. Often fins are added to these tubes to increase the cooling area. The gas had to be compressed so that it could be condensed at these higher temperatures, using free cooling from water or air.

The refrigerant is now ready to enter the evaporator to be used again. It passes through an expansion valve to enter into the region of lower pressure, which causes it to boil and absorb more heat from the load. By adjusting the high and low pressures, the condensing and evaporating temperatures can be adjusted as required.

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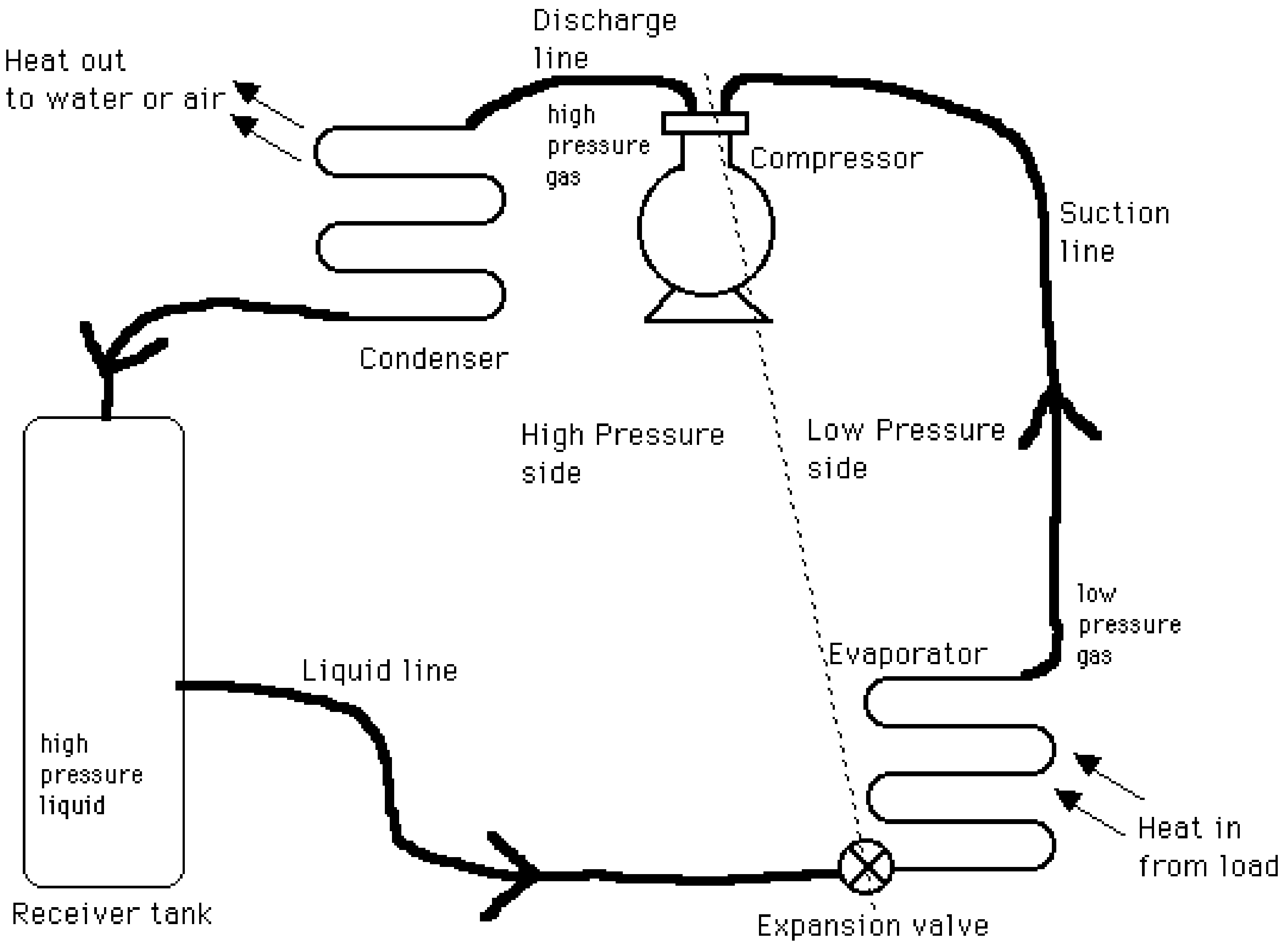

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Dairy Products: Overview and Fluid Milk Products

Dairy Science and Technology

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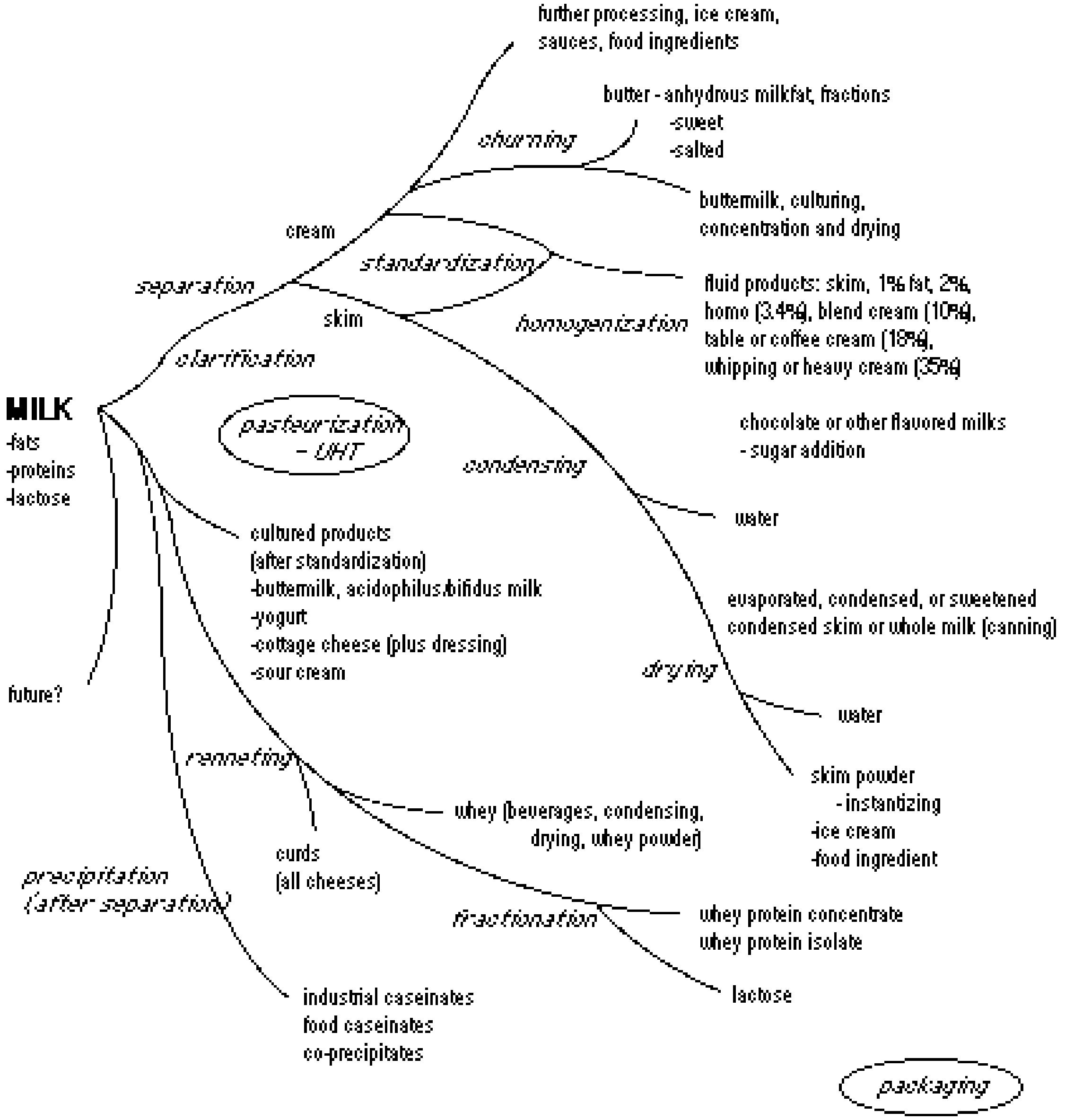
Overview of the Range of Dairy Products from Milk



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Fluid Milk Processing

Beverage Milks

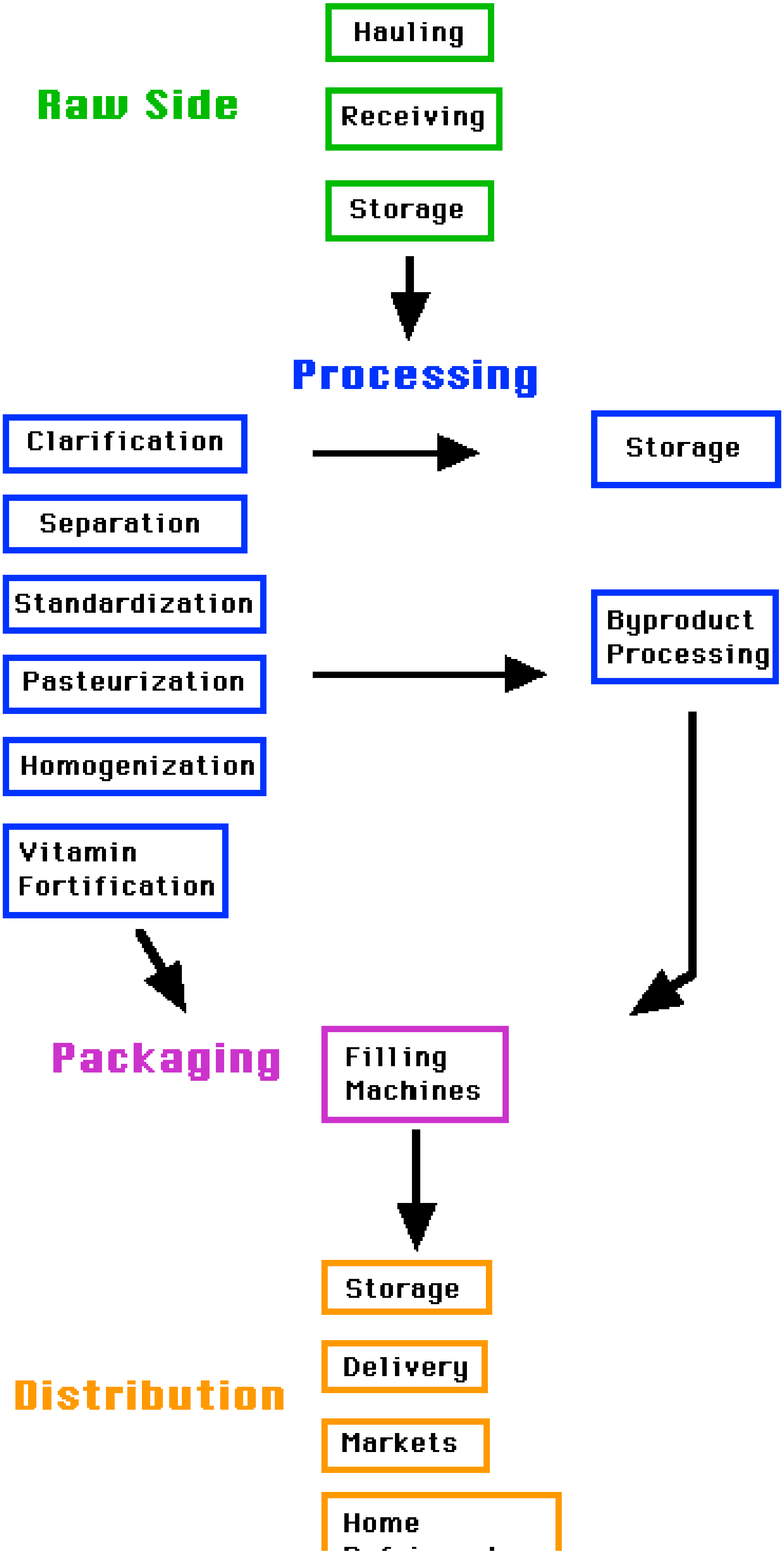
The production of beverage milks combines the unit operations of clarification, separation (for the production of lower fat milks), pasteurization, and homogenization. The process is simple, as indicated in the flow chart. While the fat content of most raw milk is 4% or higher, the fat content in most beverage milks has been reduced to 3.4%. Lower fat alternatives, such as 2% fat, 1% fat, or skim milk (<0.1% fat) or also available in most markets. These products are either produced by partially skimming the whole milk, or by completely skimming it and then adding an appropriate amount of cream back to achieve the desired final fat content.

Vitamins may be added to both full fat and reduced fat milks. Vitamins A and D (the fat soluble ones) are often supplemented in the form of a water soluble emulsion to offset that quantity lost in the fat separation process.

Creams

During the separation of whole milk, two streams are produced: the fat-depleted stream, which produces the beverage milks as described above or skim milk for evaporation and possibly for subsequent drying, and the fat-rich stream, the cream. This usually comes off the separator with fat contents in the 35-45% range. Cream is used for further processing in the dairy industry for the production of ice cream or butter, or can be sold to other food processing industries. These industrial products normally have higher fat contents than creams for retail sale, normally in the range of 45-50% fat. A product known as "plastic" cream can be produced from certain types of milk separators. This product has a fat content approaching 80% fat, but it remains as an oil-in-water emulsion (the fat is still in the form of globules and the skim milk is the continuous phase of the emulsion), unlike butter which also has a fat content of 80% but which has been churned so that the fat occupies the continuous phase and the skim milk is dispersed throughout in the form of tiny droplets (a water-in-oil emulsion).

For retail cream products, the fat is normally standardized to 35% (heavy cream for whipping), 18% or 10% (cream for coffee or cereal). Higher fat creams have also been produced for retail sale, a product known as double cream has a fat content of 55% and is quite thick. Creams for packaging and sale in the retail market must be pasteurized to ensure freedom from pathogenic bacteria. Whipping cream is not normally homogenized, as the high fat content will lead to extensive fat globule aggregation and clustering, which leads to excessive viscosity and a loss of whipping ability. This phenomena has been used, however, to produce a spoonable cream product to be used as a dessert topping. Lower fat creams (10% or 18%) can be homogenized, usually at lower pressure than whole milk.


Raw Side
Hauling
Receiving
Storage
Processing
Clarification
Separation
Standardization
Pasteurization
Homogenization
Vitamin Fortification
Storage
Byproduct Processing
Packaging
Filling Machines
Distribution
Storage
Delivery
Markets
Home

Refrigerators

Recombined Milk

Beverage milks can also be prepared by recombining skim milk powder and butter with water. This is often done in countries where there is not enough milk production to meet the demand for beverage milk consumption. The concept is simple. Skim milk powder is dispersed in water and allowed to hydrate. Butter is then emulsified into this mixture by either blending melted butter into the liquid mixture while hot, or by dispersing solid butter into the liquid through a high shear blender device. In some cases, a non-dairy fat source may also be used. The recombined milk product is then pasteurized, homogenized and packaged as in regular milk production. The final composition is similar to that of whole milk, approximately 9% milk solids-not-fat, and either 2% or 3.4% fat. The water source must be of excellent quality. The milk powder used for recombining must be of high quality and good flavour. Care must be taken to ensure adequate blending of the ingredients to prevent aggregation or lumping of the powder. Its dispersal in water is the key to success.

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Ice Cream

Ice cream has a long history as a popular dairy food item. It has evolved from a manually manufactured household product to a fairly automated industrial product. This will be the ice cream homepage, a subset of the Dairy Technology Education Series, as this section is fairly extensive, covering all the following topics:

- History and Folklore
- Suggested Formulations
- Ingredients
- Mix Calculations
- Commercial Manufacturing Process
- Overrun Calculations
- Ice Cream Structure
- Theoretical Aspects of the Freezing Process
- Flavours
- Ice Cream Defects
- Homemade Ice Cream
- "Finding Science in Ice Cream" - An Experiment for the Secondary School Classroom

- **About the Author**

- **Ice Cream Technology Course at the University of Guelph, December 6-10, 1999**

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Ice Cream History and Folklore

Most of the following material has been extracted from "The History of Ice Cream", written by the International Association of Ice Cream Manufacturers (IAICM), Washington DC, 1978. As you will note below, however, much of the early history of ice cream remains unproven folklore.

Once upon a time, hundreds of years ago, Charles I of England hosted a sumptous state banquet for many of his friends and family. The meal, consisting of many delicacies of the day, had been simply superb but the "coup de grace" was yet to come. After much preparation, the King's french chef had concocted an apparently new dish. It was cold and resembled fresh- fallen snow but was much creamier and sweeter than any other after- dinner dessert. The guests were delighted, as was Charles, who summoned the cook and asked him not to divulge the recipe for his frozen cream. The King wanted the delicacy to be served only at the Royal table and offered the cook 500 pounds a year to keep it that way. Sometime later, however, poor Charles fell into disfavour with his people and was beheaded in 1649. But by that time, the secret of the frozen cream remained a secret no more. The cook, named DeMirco, had not kept his promise.

This story is just one of many of the fascinating tales which surround the evolution of our country's most popular dessert, ice cream. It is likely that ice cream was not invented, but rather came to be over years of similar efforts. Indeed, the Roman Emperor Nero Claudius Caesar is said to have sent slaves to the mountains to bring snow and ice to cool and freeze the fruit drinks he was so fond of. Centuries later, the Italian Marco Polo returned from his famous journey to the Far East with a recipe for making water ices resembling modern day sherbets.

A newly published book, by Caroline Liddell and Robin Weir, Ices: The Definitive Guide, publ. by Hodder and Stoughton, 1993, ISBN 0-340-58335-5, suggests that the historical basis of these tales is skeptical.

What follows is from the opening of the first chapter of their book:

Most books are full of myths about the history of ice cream. According to popular accounts, Marco Polo (1254-1324) saw ice creams being made during his trip to China, and on his return, introduced them to Italy. The myth continues with the Italian chefs of the you Catherine de'Medici taking this magical dish to France when she went there in 1533 to marry the Duc d'Orleans, with Charles I rewarding his own ice-cream maker with a lifetime pension on condition that he did not divulge his secret recipe to anyone, thereby keeping ice cream as a royal perogative.

Unfortunately, there is no historical evidence to support any of these stories. They would appear to be purely the creation of imaginative nineteenth-century ice-cream makers and vendors. Indeed, we have found no mention of any of these stories before the nineteenth century.

They go on to refute the claims about Marco Polo, Catherine de'Medici, and Charles I (in particular, while the IAICM reference credits DeMirco as the Charles I chef, apparently while other various sources credit 10 different men, there are no records of such a pension being paid to any of Charles I's cooks).

They do go on in their book to discuss history for which there is a record, with (I think) the earliest written record being something made in China.

In 1774, a caterer named Phillip Lenzi announced in a New York newspaper that he had just arrived from London and would be offering for sale various confections, including ice cream. Dolly Madison, wife of U.S. President James Madison, served ice cream at her husband's Inaugural Ball in 1813.

The first improvement in the manufacture of ice cream (from the handmade way in a large bowl) was given to us by a New Jersey woman, Nancy johnson, who in 1846 invented the hand-cranked freezer. This device is still familiar to many. By turning the freezer handle, they agitated a container of ice cream mix in a bed of salt and ice until the mix was frozen. Because Nancy Johnson lacked the foresight to have her invention patented, her name does not appear on the patent records. A similar type of freezer was, however, patented on May 30, 1848, by a Mr. Young who at least had the courtesy to call it the "Johnson Patent Ice Cream Freezer".

Commercial production was begun in North America in Baltimore, Maryland, 1851, by Mr. Jacob Fussell, now known as the father of the American ice cream industry.

About 1926 the first commercially-successful continuous process freezer was perfected. The continuous freezer, developed by Clarence Vogt, and later ones produced by other manufacturers, has allowed the ice cream industry to become a mass producer of its product.

The first Canadian to start selling ice cream was Thomas Webb of Toronto, a confectioner, around 1850. William Neilson produced his first commercial batch of ice cream on Gladstone Ave. in Toronto in 1893, and his company produced ice cream at that location for close to 100 years.

After writing this page, I received the following email message:

Date: Thu, 06 Jun 1996
From: Anne Funderburg
To: dgoff@uoguelph.ca
Subject: Ice Cream History --- New Scholarly Book -- Based On Primary Sources

For a documented history of ice cream in the United States, read the just published "Chocolate, Strawberry, and Vanilla: A History of American Ice Cream" by Anne Funderburg. This book sheds new light on errors created by previous historians. For example, Nancy Johnson lived in Philadelphia and she did have a patent! To order, call Bowling Green State University Popular Press at (419) 372-7865 or fax (419) 372-8095.

The Funderburg book is soley concerned with ice cream history in the United States, and does not discuss any of these earlier myths, although it does give an excellent history of ice cream development in the United States. Another excellent source of reading on the history and folklore of ice cream is by Paul

Dickson, The Great American Ice Cream Book.

Here's a link to a web page devoted to the history of the ice cream cone.

Subject: Award from "Surfing the Net with Kids"
Received: 8/13/98 4:31 PM
From: Barbara J. Feldman, feldman@surfnetkids.com
To: dgoff@uoguelph.ca

Congratulations! Your site (Ice Cream History and Folklore) has been rated "Great!" and awarded3 stars in my 8/19/98 syndicated newspaper column "Surfing the Net with Kids". My column appears in many papers nationally including San Diego Union-Tribune, Atlanta Journal-Constitution, Indianapolis Star News, Contra Costa Times and Winston Salem Journal. For a complete list of papers and Web sites that carry my column, visit http://www.surfnetkids.com/newspap.htm.

If you would like to read the review, you'll find it at the "Summer Snacks" link on: http://www.surfnetkids.com.

.

Sincerely,
Barbara J. Feldman
"Surfing the Net with Kids"
http://www.surfnetkids.com

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Ice Cream Formulations

Dairy Science and Technology

University of Guelph

Ice Cream Mix General Composition:

(See details under mix ingredients.)

- Milkfat: >10% - 16%
- Milk solids-not-fat: 9% - 12%
- Sucrose: 10% - 14%
- Corn syrup solids: 4% - 5%
- Stabilizers: 0% - 0.4%
- Emulsifiers: 0% - 0.25%
- Water: 55% - 64%

Formulation Considerations

Desired Fat and Total solids (%): - Quality considerations

Fat: MSNF Ratio's usually determined next based on fat content.

Sugar: Glucose solids Ratio's determined based on fat and total solids requirements, sweetness, freezing point depression, body and shelf life desired, and cost considerations.

Stabilizer/Emulsifier considerations come last, based on the ice cream formulation, and processing and distribution factors involved in each application.

SUGGESTED MIXES

HARD ICE CREAM

	Percent (%)						
Fat	10.20	11.00	12.00	13.00	14.00	15.00	16.00
Serum Solids	11.50	11.00	10.50	10.25	10.00	9.75	9.50
Sucrose	13.00	13.00	13.00	13.50	13.75	14.00	15.00
Corn Syrup Solids	4.00	4.00	4.00	3.50	3.25	2.75	2.00
Stabilizer	0.35	0.35	0.30	0.30	0.27	0.26	0.25
Emulsifier	0.15	0.15	0.15	0.14	0.13	0.12	0.10
Total Solids	39.20	39.50	39.95	40.69	41.40	41.88	42.85

SOFT ICE CREAM

	Percent (%)			
Fat	10.20	10.20		
Serum Solids		12.50	12.00	
Sucrose	13.00	11.00		
Corn Syrup Solids		-------		4.00
Stabilizer		0.35	0.15	
Emulsifier		0.15	0.15	
Total Solids		36.20	37.70	

LIGHT ICE CREAM

				Percent (%)
Fat		6.00		8.00
Serum Solids		12.00		11.50
Sucrose	13.00		12.00	
Corn Syrup Solids		4.00		4.00
Stabilizer		0.35		0.35
Emulsifier		0.15		0.15
Total Solids		35.50		36.00

ICE MILK

		Percent (%)		
Fat	3.20	4.00	5.00	
Serum Solids		13.00	12.50	12.50
Sucrose	11.00	11.00	11.00	
Corn Syrup Solids		6.00	5.50	5.50
Stabilizer		0.35	0.35	0.35
Emulsifier		0.10	0.10	0.10
Total Solids		33.65	33.45	34.45

MILK SHAKE

				Percent (%)			
Fat	3.50	4.00	4.50	5.00	5.50	6.00	
Serum Solids		12.00	12.00	11.50	11.50	11.25	11.00
Sucrose	8.00	8.00	8.00	8.00	8.00	8.00	
Stabilizer		0.40	0.40	0.40	0.35	0.35	0.30
Total Solids		23.95	24.40	24.40	24.85	25.10	25.30

SHERBET

			Percent (%)
Sucrose	23.00		
Corn Syrup Solids		8.50	
Stabilizer		0.40	
Citric acid (50% sol.)			0.70
Ice cream mix		10.00	

Water	57.40
Total	100.00

Sorbets or water ices are similar to sherbets but usually no milk solids. Usually combinations of fruit (juices), sugar, stabilizer, and water. Overrun is very low; difficult to achieve without protein or emulsifier. Can also be quiescently frozen, as in "popsicle" type novelties, with or without real fruit (juice).

FROZEN YOGURT

	Percent (%)
Fat	2.0
MSNF	14.0
Sugar	15.0
Stabilizer	0.35
Water	68.65
Total	100.0

Example Processing Instructions: 20% of this mix, consisting of skimmilk and skimmilk powder blended to give 12.5% solids, is to be incubated as the yogurt portion. To make the "incubated" portion, combine the appropriate amount of skimmilk and skimmilk powder, pasteurize at a high temperature, cool to 104 to 110oF, and inoculate with a yogurt culture (typical of yogurt processing). When the fermentation is complete (to the desired acidity), cool the "yogurt".

To make the "sweet" mix, combine the cream, sugar and stabilizer, and the balance of the skimmilk powder and skimmilk, pasteurize, homogenize, cool (typical for ice cream processing), and blend with the "yogurt". The completed frozen yogurt mix is then aged and prepared for flavouring and freezing.

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Ice Cream Ingredients

Ice cream has the following composition:

- greater than 10% **milkfat** by legal definition, and usually between 10% and as high as 16% fat in some premium ice creams
- 9 to 12% **milk solids-not-fat:** this component, also known as the serum solids, contains the proteins (caseins and whey proteins) and carbohydrates (lactose) found in milk
- 12 to 16% **sweeteners**: usually a combination of sucrose and glucose-based corn syrup sweeteners
- 0.2 to 0.5% **stabilizers** and **emulsifiers**
- 55% to 64% water which comes from the milk or other ingredients

These percentages are by weight, either in the mix or in the frozen ice cream. Please remember, however, that when frozen, about one half of the volume of ice cream is air (**overrun**, for definition, see ice cream processing, for calculation, see overrun), so by volume in ice cream, these numbers can be reduced by one-half. However, since air does not contribute weight, we usually talk about the composition of ice cream on a weight basis, bearing in mind this important distinction. All ice cream, with the possible exception of chocolate, is made from a basic white mix.

Formulations can be derived from a number of different starting points. Details and suggested formulas are detailed on the formulations page, but turning the formulation into a recipe depends on the ingredients used to supply the components, and it is then necessary to do a **mix calculation** to determine the required ingredients based on the formula. **Ice milk** is very similar to the composition of ice cream but must contain between 3% and 5% milkfat by legal definition.

The ingredients to supply the desired components are chosen on the basis of availability, cost, and desired quality. These ingredients will now be examined in more detail.

Butterfat

Butterfat is important to ice cream for the following reasons:

- increases the richness of flavour in ice cream
- produces a characteristic smooth texture by lubricating the palate
- helps to give body to the ice cream

- aids in good melting properties
- aids in lubricating the freezer barrel during manufacturing (Non-fat mixes are extremely hard on the freezing equipment)

The **limitations** of excessive use of butterfat in a mix include:

- cost
- hindered whipping ability
- decreased consumption due to excessive richness
- high caloric value

The best source of butterfat in ice cream for high quality flavour is fresh sweet cream from fresh sweet milk. The **triglycerides** in milkfat have a wide melting range, +40° C to -40° C, and thus there is always a combination of liquid and crystalline fat. Alteration of this solid: liquid ratio can affect the amount of fat destabilization which occurs. Duplicating this structure with other sources of fat is difficult.

During freezing of ice cream, the fat emulsion which exists in the mix will partially destabilize or churn as a result of the air incorporation, ice crystallization and high shear forces of the blades. This partial churning is necessary to set up the structure and texture in ice cream, which is very similar to the structure in whipped cream. Emulsifiers help to promote this destabilization process which will be discussed below.

Milk Solids-not-fat

The serum solids or milk solids-not-fat (MSNF) contain the lactose, caseins, whey proteins, minerals, and ash content of the product from which they were derived. They are an important ingredient for the following reasons:

- improve the texture of ice cream
- help to give body and chew resistance to the finished product
- are capable of allowing a higher overrun without the characteristic snowy or flaky textures associated with high overrun
- may be a cheap source of total solids

The best sources of serum solids for high quality products are:

- concentrated skimmed milk
- sweetened condensed whole or skimmed milk
- superheated condensed skimmed milk
- frozen condensed skimmed milk
- spray process low heat skimmilk powder

Other sources of serum solids include buttermilk powder or condensed buttermilk, condensed whole milk, or dried or condensed whey.

The **limitations** on their use include off flavours which may arise from some of the products, and an excess of lactose which can lead to the defect of sandiness prevelant when the lactose crystallizes out of solution. Excessive concentrations of lactose in the serum phase may also lower the freezing point of the finished product to an unacceptable level.

Lactose Crystallization

1. A decrease in temperature favours rapid crystallization insofar as it increases the supersaturation.
2. A decrease in temperature favours slow crystallization insofar as it increases the viscosity, reduces the kinetic energy of the particles, and decreases the rate of transformation from beta to alpha lactose.

Supersaturated state can exist, however, due to extreme viscosity, and it is likely that much of the lactose in ice cream is non-crystalline. Stabilizers help to hold lactose in supersaturated state due to viscosity enhancement. Fruits, nuts, candy - add crystal centers and may enhance lactose crystallization. Nuts pull out moisture from ice cream immediately surrounding the nut thus concentrating the mix.

The **proteins** ,which make up approximately 4% of the mix, contribute much to the development of structure in ice cream including:

- emulsification properties in the mix
- whipping properties in the ice cream
- water holding capacity leading to enhanced viscosity and reduced iciness

Citrate and **phosphate** ions decrease tendency for fat coalescence (Sodium citrate, Disodium Phosphate). They prevent churning in soft ice cream for example, producing a wetter product. These salts decrease the degree of protein aggregation. Calcium and magnesium ions have the opposite effect, promote partial coalescence. Calcium sulfate, for example, results in a drier ice cream. Calcium and Magnesium increase the degree of protein aggregation.
Salts may also influence electrostatic interactions. Fat globules carry a small net negative charge, these ions could increase or decrease that charge as they were attracted to or repelled from surface.

Sweeteners

A sweet ice cream is usually desired by the consumer. As a result, sweetening agents are added to ice cream mix at a rate of usually 12 - 16% by weight. Sweeteners improve the texture and palatability of the ice cream, enhance flavors, and are usually the cheapest source of total solids. In addition, the sugars, including the lactose from the milk components, contribute to a ***depressed freezing point*** so that the ice cream has some unfrozen water associated with it at very low temperatures typical of their serving temperatures, -15° to -18° C. Without this unfrozen water, the ice cream would be too hard to scoop.

Sucrose is the main sweetener used because it imparts excellent flavour. Sucrose is a disaccharide made up of glucose (dextrose, cerelose), and fructose (levulose). Sucrose is dextrorotatory - meaning it rotates a plane of polarized light to the right, + 66.5° . With hydrolyzed sucrose the plane of polarization is to the left, "inverted" -20° . An acid, plus water, plus heat treatment, at concentrations above 10%, yields **invert sugar** and increases the sweetness.

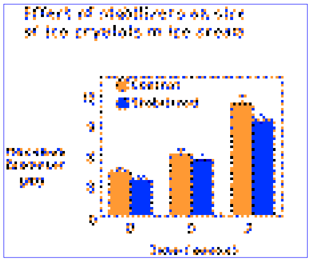
It has become common in the industry to substitute all or a portion of the sucrose content with sweeteners derived from **corn syrup**. This sweetener is reported to contribute a firmer and more chewy body to the ice cream, is an economical source of solids, and improves the shelf life of the finished product. Corn syrup in either its liquid or dry form is available in varying **dextrose equivalents (DE)**. The DE is a measure of the reducing sugar content of the syrup calculated as dextrose and expressed as a percentage of the total dry weight. As the DE is increased by hydrolysis of the corn starch, the sweetness of the solids is increased and the average molecular weight is decreased. This results in an increase in the freezing point depression, in such foods as ice cream, by the sweetener. The lower DE corn syrup contains more dextrins which tie up more water in the mix thus supplying greater stabilizing effect against coarse texture.

An enzymatic hydrolysis and isomerization procedure can convert glucose to fructose, a sweeter carbohydrate, in corn syrups thus producing a blend (**high fructose corn syrup, HFCS**) which can be used to a much greater extent in sucrose replacement. However, these HFCS blends further reduce the freezing point producing a very soft ice cream at usual conditions of storage and dipping in the home.

A balance is involved between **sweetness**, **total solids**, and **freezing point**.

Stabilizers

The stabilizers are a group of compounds, usually polysaccharides, that are responsible for adding viscosity to the unfrozen portion of the water and thus holding this water so that it cannot migrate within the product. This results in an ice cream that is firmer to the chew. Without the stabilizers, the ice cream would become coarse and icy very quickly due to the migration of this free water and the growth of existing ice crystals.



Effect of stabilizer on ice crystal size in ice cream 17 KB

The smaller the ice crystals in the ice cream, the less detectable they are to the tongue. Especially in the distribution channels of today's marketplace, the supermarkets, the trunks of cars, and so on, ice cream has many opportunities to warm up, partially melt some of the ice, and then refreeze as the temperature is once again lowered. This process is known as **heat shock** and every time it happens, the ice cream becomes more icy tasting. Stabilizers help to prevent this.

The functions of stabilizers in ice cream are:

- Produce smoothness in body and texture
- Retard or reduce ice crystal growth during storage
- Provide uniformity of product and resistance to melting
- Aid in suspension of flavouring particles

- Produce a stable foam in the ice cream
- Produce an easy cutoff and stiffness for packaging
- Prevent shrinkage in the frozen product
- Slow down moisture migration out of the frozen product

Limitations on their use include:

- production of undesirable melting characteristics
- excessive mix viscosity
- contribution to a heavy, soggy body

Gelatin, a protein of animal origin, was used almost exclusively in the ice cream industry as a stabilizer but has gradually been replaced with polysaccharides of plant origin due to their increased effectiveness and reduced cost. The stabilizers in use today include:

Carboxymethyl cellulose (CMC):

derived from the bulky components, or pulp cellulose, of plant material

Locust Bean Gum:

soluble fibre of plant material derived from the beans of exotic trees grown mostly in Africa (Note: locust bean gum is a synonym for **carob bean gum**, the beans of which were used centuries ago for weighing precious metals, a system still in use today, the word carob and Karat having similar derivation)

Guar Gum:

from the guar bush, a member of the legume family grown in India for centuries and now grown to a limited extent in Texas

Carrageenan:

an extract of Irish Moss or red algae, originally harvested from the coast of Ireland, near the village of Carragheen sodium alginate, an extract of another seaweed, brown kelp

Each of the stabilizers has its own characteristics and often, two or more of these stabilizers are used in combination to lend synergistic properties to each other and improve their overall effectiveness. Guar, for example, is more soluble than locust bean gum at cold temperatures, thus it finds more application in HTST pasteurization systems. Carrageenan is a secondary colloid used to prevent the wheying off of mix which is usually promoted by one of the other stabilizers.

Emulsifiers

The emulsifiers are a group of compounds in ice cream which aid in developing the appropriate fat structure and air distribution necessary for the smooth eating and good meltdown characteristics desired in ice cream. Since each molecule of an emulsifier contains a hydrophilic portion and a lypophilic portion, they reside at the interface between fat and water. As a result they act to reduce the interfacial tension or the force which exists between the two phases of the ***emulsion***. The emulsifiers actually promote a **destabilization** of the fat emulsion which leads to a smooth, dry product with good meltdown properties. Their action will be more fully explained in the structure of ice cream section.

The original ice cream emulsifier was **egg yolk**, which was used in most of the original recipes. Today, two emulsifiers predominate most ice cream formulations:

mono- and **di-glycerides:**

derived from the partial hydrolysis of fats or oils of animal or vegetable origin

Polysorbate 80:

a sorbitan ester consisting of a glucose molecule bound to a fatty acid, oleic acid

Other possible sources of emulsifiers include buttermilk, and glycerol esters. All of these compounds are either fats or carbohydrates, important components in most of the foods we eat and need. Together, the stabilizers and emulsifiers make up less than one half percent by weight of our ice cream. They are all compounds which have been exhaustively tested for safety and have received the **"generally recognized as safe"** or **GRAS** status.

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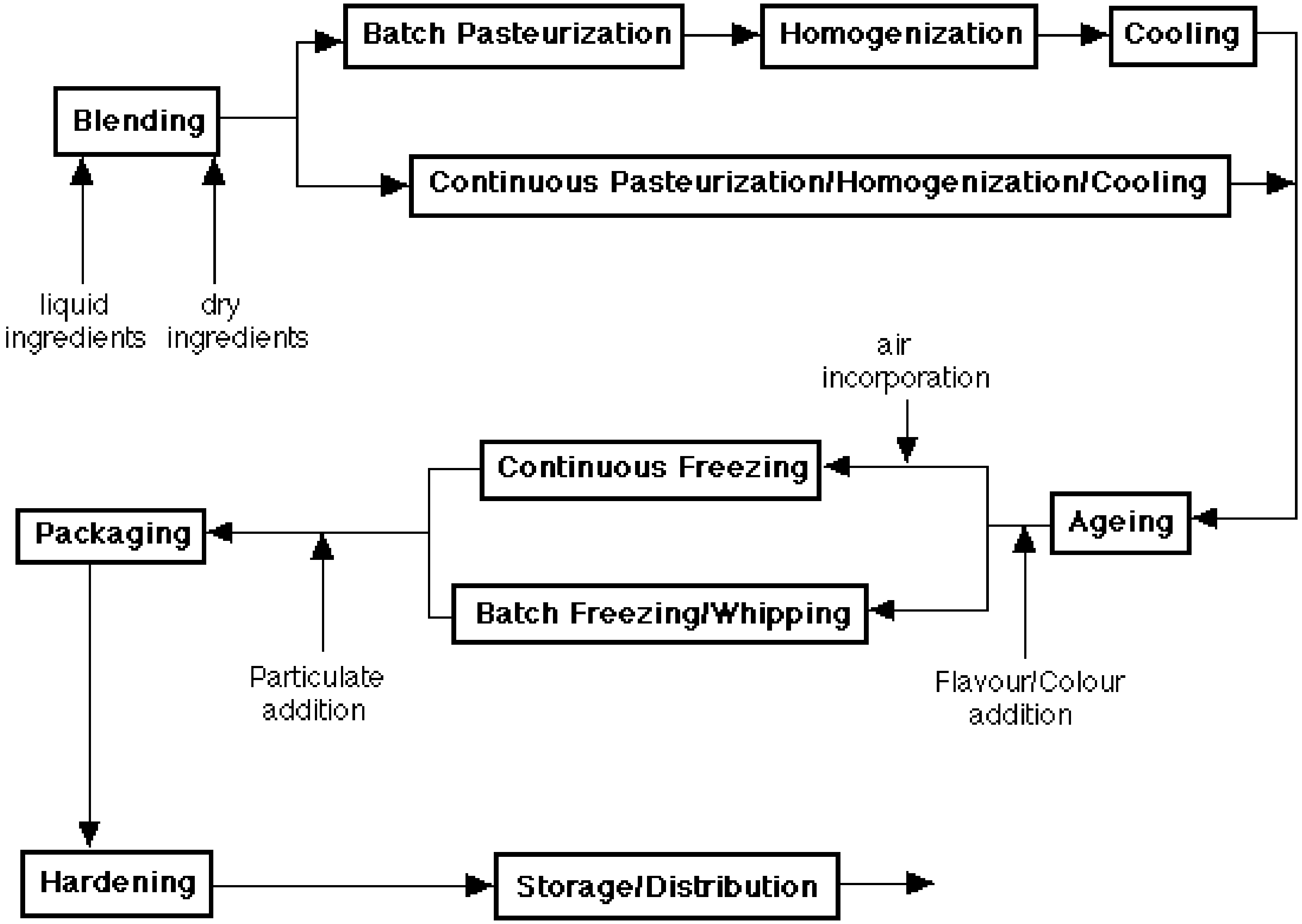
Ice Cream Manufacture

The basic steps in the manufacturing of ice cream are generally as follows:

- blending of the mix ingredients
- pasteurization
- homogenization
- aging the mix
- freezing
- packaging
- hardening



Blending

First the ingredients are selected based on the desired formulation and the calculation of the recipe from the formulation and the ingredients chosen, then the ingredients are weighed and blended together to produce what is known as the "ice cream mix". Blending requires rapid agitation to incorporate powders, and often high speed blenders are used.

Pasteurization

The mix is then **pasteurized**. Pasteurization is the biological control point in the system, designed for the destruction of pathogenic bacteria. In addition to this very important function, pasteurization also reduces the number of spoilage organisms such as psychrotrophs, and helps to hydrate some of the components (proteins, stabilizers).

Pasteurization (Ontario regulations): 69° C/30 min. 80° C/25s

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Both batch pasteurizers and continuous (HTST) methods are used.

Batch pasteurizers lead to more whey protein denaturation which some people feel gives a better body to the ice cream. In a batch pasteurization system, blending of the proper ingredient amounts is done in large jacketed vats equipped with some means of heating, usually steam or hot water. The product is then heated in the vat to at least 69 C (155 F) and held for 30 minutes to satisfy legal requirements for pasteurization, necessary for the destruction of pathogenic bacteria. Various time temperature combinations can be used. The heat treatment must be severe enough to ensure destruction of pathogens and to reduce the bacterial count to a maximum of 100,000 per gram. Following pasteurization, the mix is homogenized by means of high pressures and then is passed across some type of heat exchanger (plate or double or triple tube) for the purpose of cooling the mix to refrigerated temperatures (4 C). Batch tanks are usually operated in tandem so that one is holding while the other is being prepared. Automatic timers and valves ensure the proper holding time has been met.

Continuous pasteurization is usually performed in a high temperature short time (HTST) heat exchanger following blending of ingredients in a large, insulated feed tank. Some preheating, to 30 to 40 C, is necessary for solubilization of the components. The HTST system is equipped with a heating section, a cooling section, and a regeneration section. Cooling sections of ice cream mix HTST presses are usually larger than milk HTST presses. Due to the preheating of the mix, regeneration is lost and mix entering the cooling section is still quite warm.

Homogenization

The mix is also **homogenized** which forms the fat emulsion by breaking down or reducing the size of the fat globules found in milk or cream to less than 1 μ m. Two stage homogenization is usually preferred for ice cream mix. Clumping or clustering of the fat is reduced thereby producing a thinner, more rapidly whipped mix. Melt-down is also improved. Homogenization provides the following functions in ice cream manufacture:

- Reduces size of fat globules
- Increases surface area
- Forms membrane
- makes a smoother ice cream
- gives a greater apparent richness and palatability
- better whipping ability
- decreases danger of churning the fat
- makes possible the use of butter, frozen cream, etc.
- increases resistance to melting

Homogenization of the mix should take place at the pasteurizing temperature. The high temperature produces more efficient breaking up of the fat globules at any given pressure and also reduces fat clumping and the tendency to thick, heavy bodied mixes. No one pressure can be recommended that will give satisfactory results under all conditions. The higher the fat and total solids in the mix, the lower the pressure should be. If a two stage homogenizer is used, a pressure of 2000 - 2500 lbs. on the first stage and 500 - 1000 lbs. on the second stage should be satisfactory under most conditions. Two stage homogenization is usually preferred for ice cream mix. Clumping or clustering of the fat is reduced thereby producing a thinner, more rapidly whipped mix. Melt-down is also improved.

Ageing

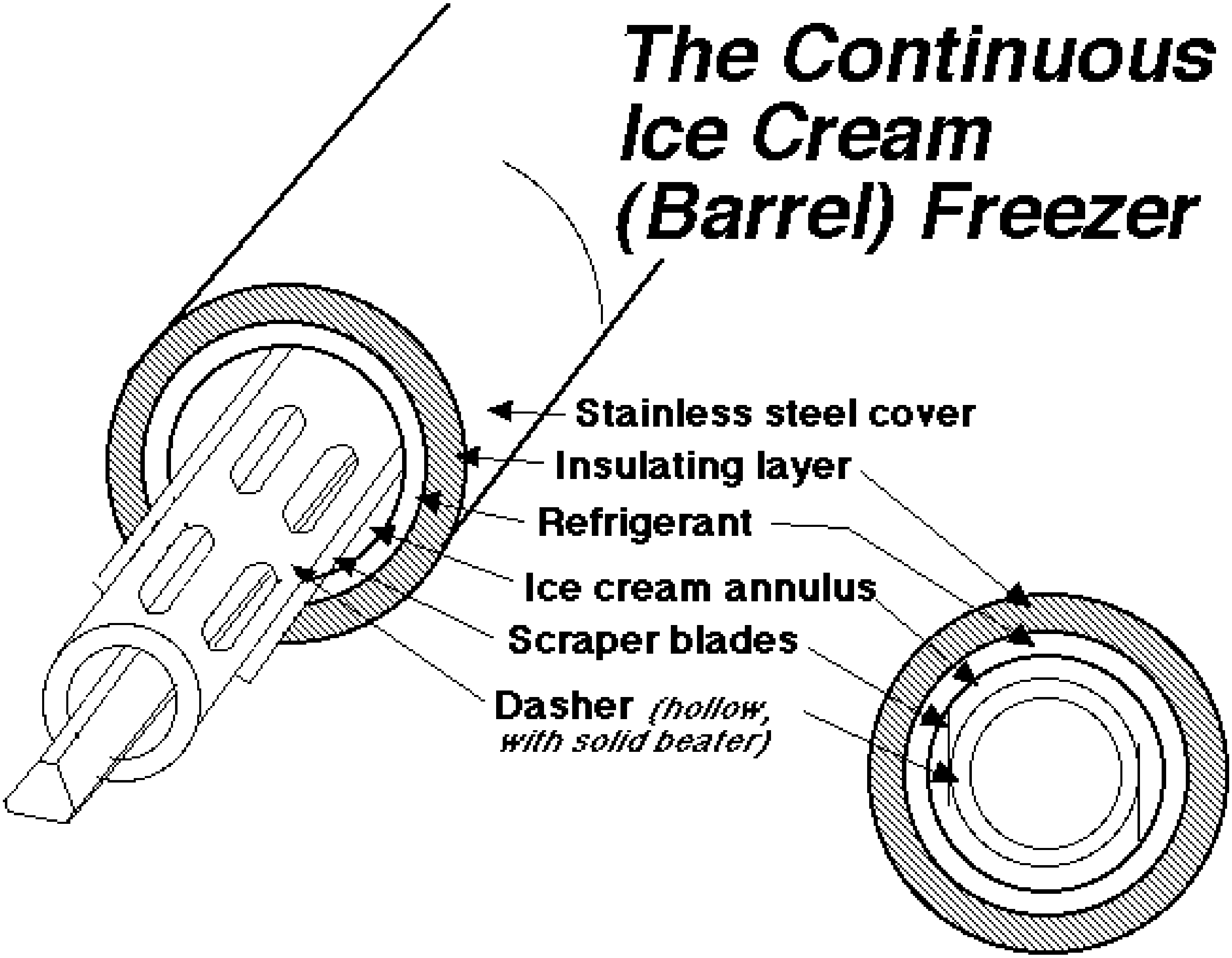
The mix is then **aged** for at least four hours and usually overnight. This allows time for the fat to cool down and crystallize, and for the proteins and polysaccharides to fully hydrate. Aging provides the following functions:

- Improves whipping qualities of mix and body and texture of ice cream
- Fat crystallization
- Protein and stabilizer hydration viscosity increase
- Membrane rearrangement protein/emulsifier interaction

Aging is performed in insulated or refrigerated storage tanks, silos, etc. Mix temperature should be maintained as low as possible without freezing, at or below 5 C. An aging time of overnight is likely to give best results under average plant conditions. A "green" or unaged mix is usually quickly detected at the freezer.

Freezing and Hardening

Following mix processing, the mix is drawn into a flavour tank where any liquid flavours, fruit purees, or colours are added. The mix then enters the **dynamic freezing process** which both freezes a portion of the water and whips air into the frozen mix. The "barrel" freezer is a scraped-surface, tubular heat exchanger, which is jacketed with a boiling refrigerant such as ammonia or freon. Mix is pumped through this freezer and is drawn off the other end in a matter of 30 seconds, (or 10 to 15 minutes in the case of batch freezers) with about 50% of its water frozen. There are rotating blades inside the barrel that keep the ice scraped off the surface of the freezer and also dashers inside the machine which help to whip the mix and incorporate air.



Ice cream contains a considerable quantity of air, up to half of its volume. This gives the product its characteristic lightness. Without air, ice cream would be similar to a frozen ice cube. The air content is termed its overrun, which can be calculated mathematically.

As the ice cream is drawn with about half of its water frozen, particulate matter such as fruits, nuts, candy, cookies, or whatever you like, is added to the semi-frozen slurry which has a consistency similar to **soft-serve ice cream**. In fact, almost the only thing which differentiates hard frozen ice cream from soft-serve, is the fact that soft serve is drawn into cones at this point in the process rather than into packages for subsequent hardening. After the particulates have been added, the ice cream is packaged and is placed into a blast freezer at -30° to -40° C where most of the remainder of the water is frozen. Below about -25° C, ice cream is stable for indefinite periods without danger of ice crystal growth; however, above this temperature, ice crystal growth is possible and the rate of crystal growth is dependant upon the temperature of storage. This limits the shelf life of the ice cream.

A primer on the theoretical aspects of freezing will help you to fully understand the freezing process.

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Mix Calculations for Ice Cream and Frozen Dairy Desserts

The general object in calculating ice cream mixes is to turn our formula into a recipe based on the ingredients we intend to use and the amount of mix we desire. The formula is given as percentages of fat, milk solids-not-fat, sugar, corn syrup solids (glucose solids), stabilizers and emulsifiers. The ingredients we choose to supply these components are chosen on the basis of availability, quality and cost. The following table illustrates the relationship between the major components, the main ingredients that supply the major components, and the minor components that are supplied with the major ones for each ingredient.

Component:	Ingredients to supply: (but also supplies:)
Milkfat	Cream (SNF, water) Butter (SNF, water)
Milk solids-not-fat	Skim powder (water) Condensed skim (water) Condensed milk (water, fat) Sweetened condensed (water, sugar) Whey powder (water)
Water	Skim milk (msnf) Milk (fat, msnf) Water
Sweetener	Sucrose Corn syrup solids Liquid sugars (water)
Stabilizers/ emulsifiers	

The first step in a mix calculation is to identify for each ingredient we intend to use its components. If there is only one source of the component we need for the formula, for example the stabilizer or the sugar, we determine it directly by multiplying the percentage we need by the amount we need, e.g., 100 kg of mix @ 10% sugar would require 10 kg sugar. If there are two or more sources, for example we need 10 % fat and it is coming from both cream and milk, then we need to utilize an algebraic method. Computer programs developed for mix calculations generally solve a simultaneous equation based on mass and component balances. To solve simultaneous equations, you need as many independent equations as you have unknowns. For manual calculations, a method known as the "Serum Point" method has been derived. This method has solved the simultaneous equations in a general way so that only the equations need to be known and not resolved each time.

In standardizing mixes, the composition of the various ingredients used must be known. In some cases the percentage of solids contained in a product is taken as constant, while in others the composition must be obtained by analysis. Information on the various ingredients is given below:

(a) Skim milk - can be determined by analysis or assumed at 9 percent serum solids. Fat (0.01% - 0.10%) should be taken into account if significant.

(b) Dried products, e.g. skim milk powder, whey powder, WPC, milk powder blends, usually taken to be 97 percent solids.

(c) Cream - Percent fat obtained by Babcock test or other acceptable method.

Percent serum solids found by formula as follows: (100 - percent fat) x .09 = % serum solids (assuming that the "skim milk" contains 9% total solids). Example: In cream testing 30% fat, the percent serum solids would be (100 - 30) x .09 = 6.3% S.S.

(d) Milk - Percent fat by Babcock test or other acceptable method.

Percent serum solids may be found same as for cream or by making a total solids test and deducting the percent fat.

(e) Condensed Milk Products - Composition of these products should be furnished by the condensery but should be checked at ice cream plant.

(f) Sweeteners - Sucrose - Dry 100% solids
Sucrose - Liquid 66% solids
Dextrose - Dry 100% solids
Corn Syrup Solids 100% solids
Corn Syrup Liquid 80% solids
Glucose 80% solids
Honey 80% solids

(g) Stabilizers and Emulsifiers (if solid) - Because of the small percentage used may be figured as 100 percent solids.

(h) Egg Products - Fresh whole eggs: 10% fat, 25% solids
Fresh egg yolk: 33% fat, 50% solids
Frozen egg yolk: 33% fat, 50% solids
Dried egg yolk: 60% fat, 100% solids

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Ice Cream Flavours

Introduction

Most ice cream is purchased by the consumer on basis of flavour and ingredients. There are several different flavours of ice cream manufactured. In Canada the favourites are vanilla, chocolate, strawberry, maplenut and others depending upon geographical preferences. **Vanilla accounts for over half of the ice cream consumed**. It is the ice cream manufacturers responsibility to prepare an excellent mix but often they put the responsibility of the flavours and ingredients on the supplier.

Ice Cream Flavours, 1995 Annual, Canada and the US

		percentage of production volume
1.	Vanilla	29.1
2.	Chocolate	10.4
3.	Neapolitan	8.6
4.	Nut Flavours	6.8
5.	Cookies	6.0
6.	Candy Flavours	5.9
7.	Fruit flavours - except strawberry	4.8
8.	Fudge/Marble	4.3
9.	Butter pecan	3.7
10.	Chocolate Chip	3.6
Top ten		83.2
11.	Strawberry	3.4
12.	Mint	2.5
13.	Coffee/Mocha	1.8
14.	Cake/Bakery	1.3

Liquor	0.1
All other	7.7
Total	100.0

Source: International Dairy Foods Association

Ingredients are added to ice cream in three ways during the manufacturing process:

1. **Mix Tank:** for liquid flavours, colours, fruit purees, flavored syrup bases
2. **Variegating Pump:** for ribbons, swirls, ripples, revels
3. **Fruit Feeder:** for particulates - fruits, nuts, candy pieces, cookies, etc., some complex flavours may utilize 2 feeders

Generally, the delicate, mild flavours are easily blended and tend not to become objectionable at high concentrations, while harsh flavours are usually objectionable even in low concentrations. Therefore, delicate flavours are preferable to harsh flavours, but in any case a flavour should only be intense enough to be easily recognized. Flavouring materials may be:

1. Natural or true
2. Artificial or imitation
3. Fortified or compound

According to the **Canada Food and Drug Regulations**:
(Refer to Act for complete description)
(Naming the flavour) Extract, or (naming the flavour) Essence must be the true extract or essence from the plant after which the flavouring extract or essence is named, dissolved in the prescribed solvent. These are natural or true flavours.

Artificial (naming the flavour) Extract, Artificial (naming the flavour) Essence, Imitation (etc.) Extract, Imitation (etc.), Essence may be derived in whole or in part from sources but the flavouring strength cannot be less than the true materials.

Artificial or Imitation flavours may be chemically the same as true flavours but are prepared synthetically. For example, one of the best sources of vanilla now is from a by-product of the pulp and paper industry; it is called **Vanillin**.

Fortified flavours extracts and essences are derived from the named fruit but other natural extractives have been added.

Vanilla

Vanilla is without exception the most popular flavour for Ice Cream in North America. The dairy industry uses 48% of the total imported vanilla. Very important ice cream ingredient, not only in vanilla ice cream, but in many other flavours where it is used as a flavour enhancer, e.g. chocolate much improved by presence of vanilla.

Vanilla comes from a plant belonging to the orchid family called **Vanilla planifolia**. There are several varieties of vanilla beans among which are Mexican (Mexico), Bourbon (islands off the east coast of Africa), Tahiti (Tahiti and Society Islands), South American (Guadeloupe, Dominica, Martinique), Java (Java). Mexican and Bourbon beans are used to produce best vanilla extracts. Bourbons from Madagescar are the finest and account for over 75% of World production, Mexicans, 5%. Tahiti and other beans are combined with Mexican and Bourbon to make cheaper flavours and usually result in an ice cream being criticized for "lacks fine flavour". Same criticism will apply if flavours too highly fortified with vanillin are used.

From each blossom of the vine which is successfully fertilized comes a pod which reaches 6-10 inches in length, picked at 6-9 months. It requires 75-85° F day and night throughout the season, and frequent rains with dry season near end for development of flavour.

Pods are immersed in hot water to "kill them" (also increases enzyme activity), then fermented for 3-6 months by repeated wrapping in straw to "sweat" and then uncovered to sun dry. 5-6 kg green pods produce 1 kg. cured pods. Beans then aged 1-2 yrs. Enzymatic reactions produced many compounds - vanillin is the principal flavour compound. However, there is no free vanillin in the beans when they are harvested, it develops gradually during the curing period from glucosides, which break down during the fermentation and "sweating" of the beans. Extraction takes place as the beans are chopped (not ground) and placed in stainless steel percolator and cold alcohol (no heat involved) and water are pumped over and through the beans until all flavouring matter is extracted.

Concentrated Extract

Vacuum distillation takes place for a large part of the solvent. The desired concentration is specified as two fold, four fold, etc. Each multiple must be derived from an original 13.35 oz. beans.
Vanilla can be and is produced synthetically to a large extent. By-product of pulp and paper industry. Compound flavours are produced from combination of vanilla extract and vanillin. Vanillin maybe added at one ounce to the fold and labelled Vanilla-Vanillin Flavour. Number of folds plus number oz. of vanillin equal total strength, eg. 2 fold + 2 oz. = 4 fold vanilla-vanillin. However,more than 1 oz to the fold is deamed imitation.

Vanilla flavouring is available in liquid or powder form as:

- Pure Vanilla
- Reinforced Vanilla with Vanillin
- Imitation Vanilla

Usage level in the mix is a function of purity and concentration:

- Single fold vanilla - 5-8 oz./10 gal. mix
- Two fold vanilla-vanillin - 3 oz/10 gal.

Some vanillin may improve flavour over pure vanilla extract but too much vanillin results in harsh flavours.

Food and Drug Act Vanilla Extract, Vanilla Essence, Vanilla Flavour, shall:
(a) be prepared from the vanilla bean, the dried, cured fruit of Vanilla planifolia, Andrews, or Vanilla tahitensis, J.W. Moore,
(b) contain in 100 millilitres, regardless of the method of extraction, at least the quantity of soluble substances in their natural proportions which are extractable by the official method from:
(i) not less than 10 grams of vanilla beans, when such beans contain 25 percent or less of moisture,
(ii) not less than 7.5 grams of vanilla beans on the moisture free basis, when such beans contain more than 25

percent moisture, and notwithstanding sections B.10.003 and B.10.005 shall contain no added colour.

As with dairy products, the choicest of ice creams can be made only with the best of flavouring materials. A good vanilla enhances the flavour of good dairy products in ice cream. It does not mask it.

Chocolate and Cocoa

The cacao bean is the fruit of the tree **Theobroma cacao**, (Cacao, food of the gods) which grows in tropical regions such as Mexico, Central America, South America, West Indies, African West Coast. The word cocoa is a corruption of the native word cacao. The beans are embedded in pods on the tree, 20-30 beans per pod. When ripe, the pods are cut from the trees, and after drying, the beans are removed from the pods and allowed to ferment, 10 days (microbiological and enzymatic fermentation). Beans then are washed, dried, sorted, graded and shipped.

At the processing plant, beans are roasted, seed coat removed - called the **nib**. The nib is ground, friction melts the fat and the nibs flow from the grinding as a liquid, known as **chocolate liquor.**

Liquor:

55% fat, 17% carbohydrate, 11% protein, 6% tannins and many other compounds (bitter chocolate - baking).

Cocoa butter:

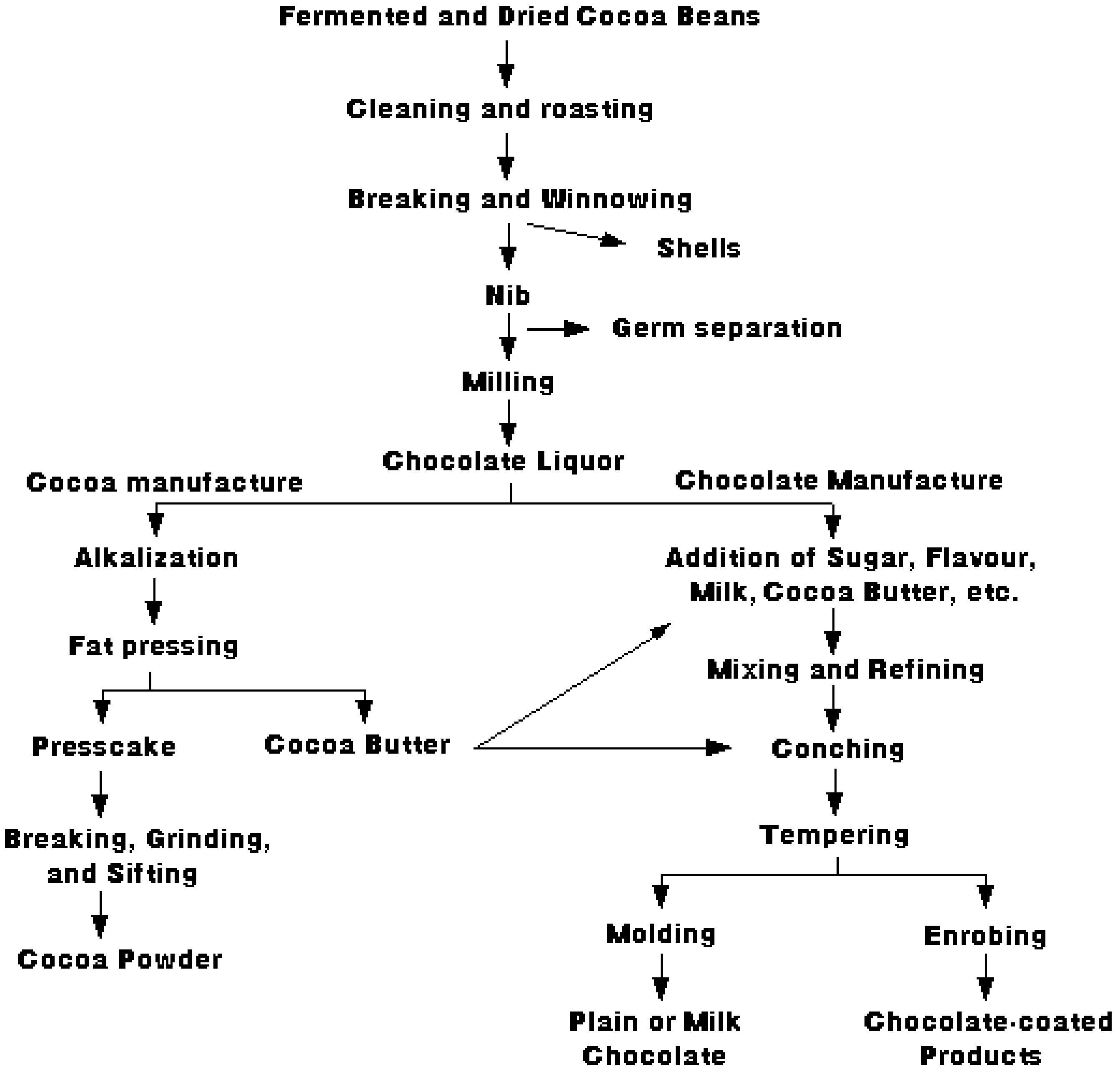
fat removed from chocolate liquor, narrow melting range 30 to 36° C

Cocoa:

after the cocoa butter is pressed from the chocolate liquor, the remaining press cake is now material for cocoa manufacture

The amount of fat remaining determines the cocoa grade:

- medium fat cocoa 20-24% fat
- low fat 10-12% fat



According to the **Canada Food and Drugs Regulations**:
Chocolate (Plain chocolate, Bitter chocolate, Chocolate liquor) shall be obtained by grinding cacao nibs and shall contain not less than 50% cacao butter, etc.
When cocoa is made, the processing of the liquor is continued until only 15 - 25 percent of the fat remains. In Canada where cocoa contains 22% or more cocoa butter it may be designated as **Breakfast Cocoa**. If it contains less than 10% cacao butter it must be called **Low Fat Cocoa**.

There are two types of cocoa or chocolate, namely, **American** (domestic) and **Dutch**. The latter is treated with an alkali (sodium hydroxide, etc.) to increase solubility, darken the colour, and modify the flavour. The Dutch type is usually preferred in ice cream because it gives a deeper colour but the choice depends upon:

- consumer preference
- desired color (Blackshire cocoa may be used to darken color)
- strength of flavour

- fat content

There are many types of chocolate that differ in the amounts of chocolate liquor, cocoa butter, sugar, milk, other ingredients, and vanilla.

Imitation chocolate

replacing some or all of the cocoa fat with other vegetable fats. Improved coating properties, resistance to melting

White chocolate

cocoa butter, MSNF, sugar, no cocoa or liquor

In chocolate ice cream manufacture, cocoa is more concentrated for flavouring than chocolate liquor (55% fat) because cocoa butter has relatively low flavour.

A good chocolate ice cream will be made if the syrup is added to the vat and homogenized with the rest of the mix. An excellent chocolate ice cream may be made by combining all the ingredients in the pasteurizer. Chocolate mixes have a tendency to become excessively viscous so **stabilizer** content and homogenizing pressure need to be adjusted.

One problem is called **chocolate specking**. It can occur in soft serve, when cocoa fibres become entrapped in the churned fat.

If you are still hungry for more chocolate information, check out the Chocolate Resource Center at Godiva. Besides chocolate history, trivia, recipies etc., you can even order some Godiva Chocolates!!! They also have an ice cream soda fountain, bursting with recipes.

Fruit Ice Cream

Fruit for Ice Cream is available in the following forms:

1. Aseptically Processed Fruit
   - Improved flavour
   - Improved colour
   - Reduced loss of ingredients
   - More consistent product
   - No preservatives
   - Longer shelf life
2. Open Kettle Processed Fruit
3. Raw Frozen Fruit
4. Fresh Fruit

Advantages of processed fruits:

1. Purchasing year round supply: problems of procurement and storage transferred to fruit processor
2. Availability: blending of sources from around the world in RTU form, no thawing, straining, etc.
3. Quality control: processor adjusts for quality variations

4. Ice Cream quality: fruit won't freeze in ice cream, usually free of debris, straw, pits.
5. Microbial Safety
6. Convenience

Fruit feeders are used with continuous freezers to add the fruit pieces, while any fruit juice is added directly to the mix.

Nuts in Ice Cream

Commonly used are **walnuts**, **pecans**, **filberts**, **almonds** and **pistachios**. Brazil nuts and cashews have been tried without much success.

Quality Control of Nutmeats for Ice Cream

1. Extraneous and Foreign Material:
   Requires extensive cleaning, Colour Sorter, Destoner, X-rays, Aerator, Hand-Picking, Screening
2. Microbiological Testing:
   Aflatoxin contamination can be a hazard with Peanuts, Pistachios, Brazils. All nutmeats should receive random testing for: Standard Plate Count, Coliform, E. Coli, Yeast and Mold, Salmonella.
3. Bacteria Control:
   Nuts must be processed in a clean sanitary premise following good manufacturing practices. Nuts should be either oil roasted or heat treated to reduce any bacteria.
4. Sizing:
   Some nutmeats require chopping to achieve a uniform size in order to fit through the fruit feeder, i.e.: Pecans, Almonds, Peanuts, Filberts
5. Storage Nutmeats should be stored at 34-38° F to maintain freshness and reduce problems with rancidity.

Colour in Ice Cream

Ice cream should have a delicate, attractive colour that suggests or is closely associated with its flavour. Almost all ice creams are slightly coloured to give them the shade of the natural product 15% fruit produces only a slight effect on colour. However, most suppliers, would include some colour in the fruit to save the processor time i.e. solid pack strawberries include colour. Most colours are of synthetic origin, must be approved, purchased in liquid or dry form. Solutions can easily become contaminated and therefore must be fresh.

Colours are used in ice cream to create appeal. If used to excess they indicate cheapness. The choice of shade is dictated by flavour, i.e. red for strawberry, light green for mint, purple for grape, etc.

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OVERRUN CALCULATIONS

Figuring plant overrun by volume, no particulates :

% Overrun = (Vol. of ice cream - Vol. of mix used)/Vol. of mix used x 100%

Example : 500 L mix gives 980 L ice cream,
(980 - 500)/500 x 100% = 96% Overrun

80 L mix plus 10 L chocolate syrup gives 170 L chocolate ice cream,

(Note : any flavours added such as this chocolate syrup which become homogeneous with the mix can incorporate air and are thus accounted for in this way :)

(170 - (80 + 10))/(80 + 10) x 100% = 88.8% Overrun

Figuring plant overrun by volume, with particulates :

Example : 40 L mix plus 28 L pecans gives 110 L butter pecan ice cream,
110 - 28 = 82 L actual ice cream.

% Overrun = (Vol. of ice cream - Vol. of mix used)/Vol. of mix used
= (82 - 40)/40 x 100% = 105%

(Note : The pecans do not incorporate air.)

Figuring package overrun by weight, no particulates :

% Overrun = (Wt. of mix - Wt. of same vol. of ice cream)/Wt. of same vol. of ice cream x 100%

Must know density of mix (wt. of 1 L), usually 1.09 - 1.1 kg. /L.

(see example below)

Example : If 1 L of ice cream weighs 560 g,
% Overrun = (1090 - 560)/560 x 100% = 94.6% Overrun

(Note : Figuring package overrun by weight if the ice cream has particulates in it gives very little

information because both the ratio of ice cream to particulates and the air content of the ice cream affect the final weight.)

Figuring mix density :

The density of mix can be calculated as follows:

Wt. per litre of water / (% fat/100 x 1.07527) + ((% T.S./100 - % Fat/100) x 0.6329) + (% Water/100) = Wt./ litre mix

Example - Calculate the weight per litre of mix containing 12% fat, 11% serum solids, 12% sugar, 5% corn syrup solids, 0.30% stabilizer, and 38.3% T.S.

1.0 kg/L / ((0.12 x 1.07527) + ((0.383 - 0.12) x 0.6329) + 0.617) = 1.0959 kg/L of mix

---

Figuring target package weights, no particulates :

Weight of given vol. of ice cream = Wt. of same vol. of mix / (Desired overrun / 100 + 1)

Example : Desired 90% Overrun, mix density 1.09 kg/L
net wt. of 1 L = 1.09 kg / (90/100 + 1) = 573.7 g

Also, density of ice cream = density of mix / (Overrun/100 + 1)

Example: Density of mix 1100 g/L,

@100% Overrun, density of ice cream = 1100 g/L / (100/100 + 1) = 550 g/L

Figuring target package weights, with particulates :

Example : Butter brickle ice cream; density of mix 1.1 kg/L; overrun in ice cream 100%; density of candy 0.748 kg/L; candy added at 9% by weight, (i.e. 9 kg to 100 kg final product)

In 100 kg final product, we have:

9 kg of candy (or 9 kg / 0.748 kg/L = 12.0 L)

91 kg of ice cream (or 91 kg / (1.1 kg/L / (100/100 + 1)) = 165.4 L)

So, 100 kg gives a yield of 12 + 165.4 = 177.4 L

1 L weighs 100 kg / 177.4 L = 564 grams

(Note : In many cases, ice cream of different flavours is frozen to the same weight. As a result, overrun of actual *ice cream in product varies.)*

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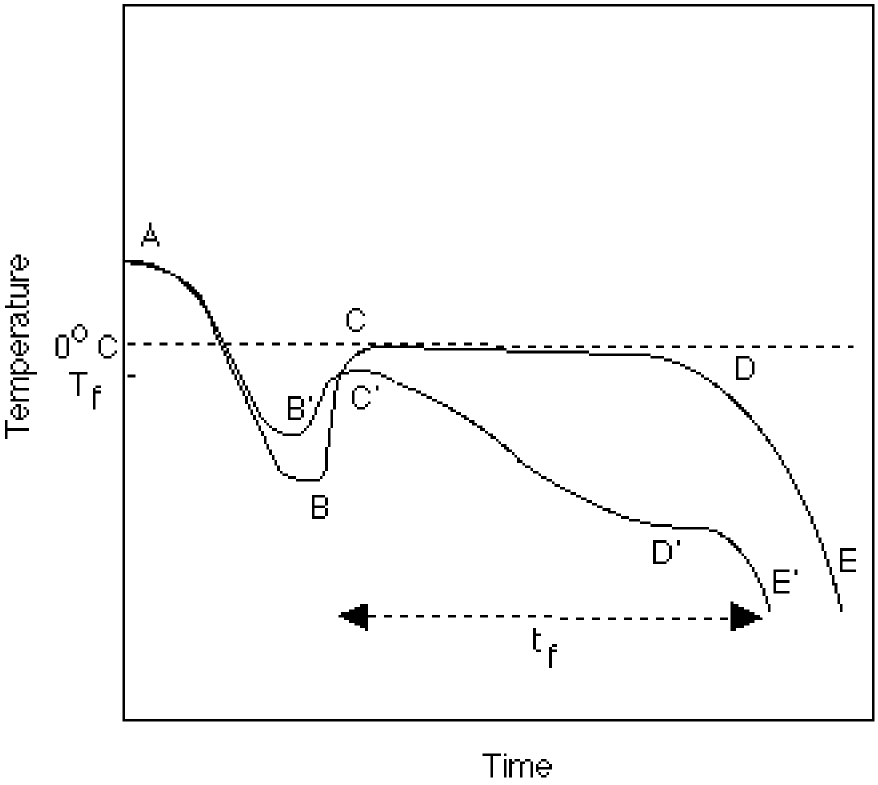
Theoretical Aspects of the Freezing Process

The Process of Crystallization

This section will briefly review the physico-chemical processes that occur during a freezing process. The figure below shows the time-temperature relationship for freezing of pure water (ABCDE) and aqueous solutions (AB'C'D'E'F'). The first thermal event that can be seen from such a diagram is undercooling below the freezing point before the induction of crystallization, from A to B or B' . This is a non-equilibrium, metastable state which is analogous to an activation energy necessary for the nucleation process. Pure water can be undercooled by several degrees before the nucleation phenomenon begins.



Once the critical mass of nuclei is reached, the system nucleates at point B or B' in the figure and releases its latent heat faster than heat is being removed from the system. In aqueous solutions, however, B' is not as low as B, since the added solute will promote heterogeneous nucleation, thereby accelerating the nucleation process. The temperature increases instantly to the initial freezing temperature, Tf, of the solution at Point C or C'. The presence of solutes results in depression of the freezing point based on

Raoult's Law, which relates vapor pressure of the solution to that of pure solvent based on solute concentration. Note that C' is not as high as C, because the initial freezing point is depressed as a result of the solute. Hence, the solute has greatly decreased the amount of undercooling for two reasons: faster nucleation and lowered freezing point. In very concentrated solutions, it is sometimes even difficult to induce undercooling.

In pure water, the time line from C to D in the figure reflects the time during which crystal growth is occurring. Fast freezing rates promote the formation of many small ice crystals during this period. The partially frozen mixture will not cool until all of the "freezable" water has crystallized; hence, the line CD occurs at nearly constant temperature. The freezing time, tf, is defined as the time from the onset of nucleation, C, to the complete removal of latent heat, D. After crystallization is completed, the temperature drops from D to E as sensible heat is released.

During the freezing of the aqueous solution, a freeze-concentration process occurs as water freezes out of solution in the form of pure ice crystals (C'D'). This causes the freezing temperature of the remaining solution to drop. At temperatures well below the initial freezing point, some liquid water remains. Also, a large increase in the viscosity of the unfrozen phase occurs, thus decreasing the diffusion properties of the system and hindering crystallization. At D', one of the solutes may become supersaturated and release its latent heat of crystallization, causing a slight jump in temperature from D' to E'. These points are known as eutectic points. From E' to F', continued crystallization of solvent, and possibly solute, occurs, until the system is completely crystallized or solidified at very low temperatures. It is more difficult to assign a freezing time to this process, but it is usually taken as the time to reach some predetermined temperature below the initial freezing point.

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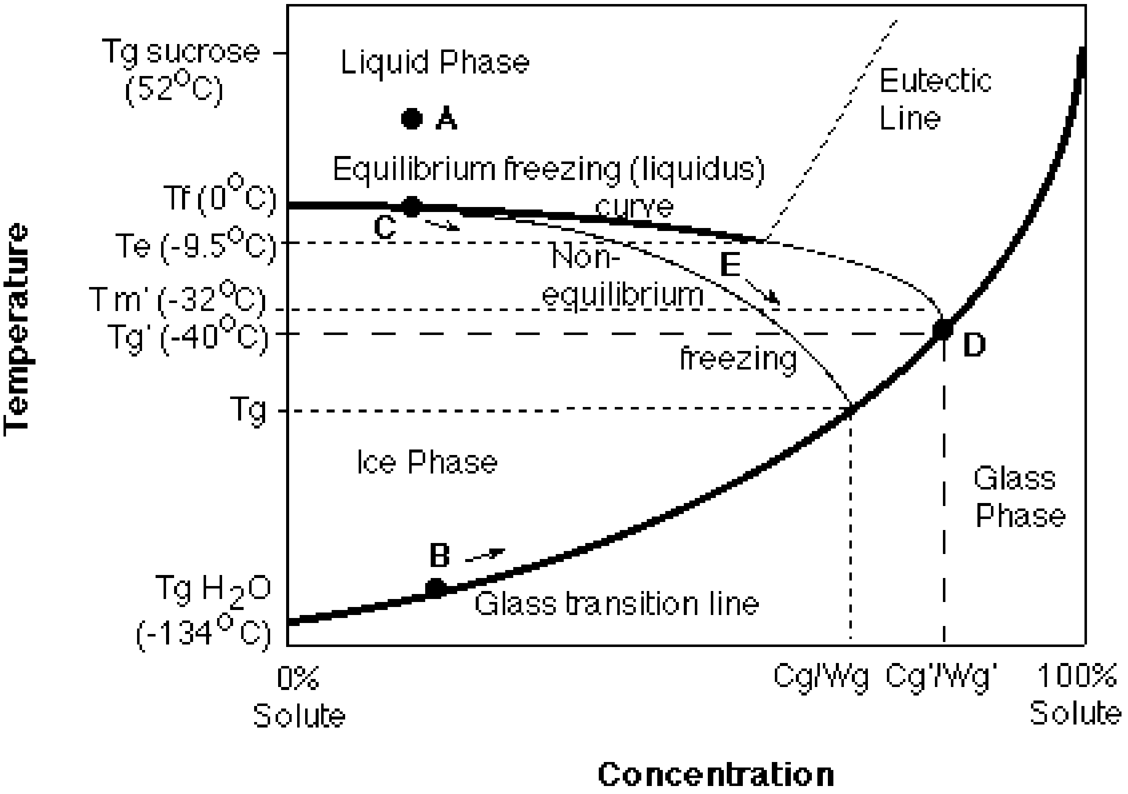
Formation of the Glassy Phase in Frozen Foods

During the freezing of foods, ice is formed as pure water goes through the two-step (nucleation and propagation) crystallization process. As temperature decreases and water is removed from a food in the form of ice, the solutes present in the UFP are freeze-concentrated. An equilibrium freezing temperature exists for each ice/UFP ratio, which is a function of the solute concentration. This equilibrium thermodynamic process can be modelled on a phase diagram as an equilibrium freezing (liquidus) curve (see figure below), which extends from the melting temperature (Tm) of pure water (0oC) to the eutectic temperature (Te) of the solute, the point at which the solute has been freeze-concentrated to its saturation concentration.

As temperature is lowered, it is highly unlikely that solute will crystallize at Te, due to high viscosity from concentration of solute and low temperature, so that freeze-concentration proceeds beyond Te in a non-equilibrium state. The highly-concentrated UFP can then go through a viscous liquid/glass state transition, driven by the reduction in molecular motion and diffusion kinetics as a result of both the very high concentration and low temperature.

A glass is defined as a non-equilibrium, metastable, amorphous, disordered solid of extremely high viscosity (ie., 10 exp10 to 10 exp14 Pa.s), also a function of temperature and concentration. The glass transition curve extends from the glass transition temperature (Tg) of pure water (-134oC) to the Tg of pure solute. The equilibrium phase diagram and the kinetically-derived state diagram can be modelled together on a supplemented state diagram. The supplementary state diagram showing the solid/liquid coexistence boundaries and glass transition profile for a binary sucrose/water system is shown in the figure below. Below and to the right of the glass transition line, the solution is in the amorphous glass state, with or without ice present depending on temperature and freezing path followed, while above and to the left of the glass transition line, the solution is in the liquid state, with or without ice depending on temperature.



As an example, assume a sucrose solution with an initial concentration of 20% at room temperature (point A). The initial Tg of this solution at room temperature before phase separation is marked as point B (if the solution could be undercooled to this temperature without ice formation). However, upon slowly cooling of the system somewhat below its equilibrium freezing point (due to undercooling), nucleation and subsequent crystallization begins at point C and initiates the freeze-concentration process, removing water in its pure form as ice. As ice crystallization proceeds, the continual increase in solute concentration (removal of water) further depresses the equilibrium freezing point of the UFP in a manner which follows the liquidus curve (shown as path C) while the Tg of the UFP moves up the glass transition line (path B; due to increased concentration) with a rapid increase in viscosity in a non-Arrhenius manner, particularly in late stages of the freezing process.

Co-crystallization of solute at the Te is unlikely and thus freeze-concentration continues past Te into a non-equilibrium state since the solute becomes superstaurated. When a critical, solute-dependent concentration is reached, the unfrozen liquid exhibits very resisted mobility and the physical state of the UFP changes from a viscoelastic liquid to a brittle, amorphous solid glass.

The intersection of the non-equilibrium extension of the liquidus curve, beyond Te, and the kinetically-determined glass transition curve, point D in the above figure, represents the solute-specific, maximally freeze-concentrated Tg of the frozen system, denoted Tg', where ice formation ceases within the time-scale of the measurement. The corresponding maximum concentrations of water and sucrose "trapped" within the glass at Tg' and unable to crystallize are denoted the Wg' and Cg' , respectively. It is worth noting that this unfrozen water is not bound in an "energetic" sense, rather unable to freeze within practical time frames.

At the Tg', the supersaturated solute takes on solid properties because of reduced molecular motion, which is responsible for the tremendous reduction in translational, not rotational, mobility. It is this intrinsic slowness of molecular reorganization below Tg' that the food technologist seeks to create within the concentrated phase surrounding constituents of food materials.

However, warming from the glassy state to temperatures above the Tg' results in a tremendous increase in diffusion, not only from the effects of the amorphous to viscous liquid transition but also from increased dilution as melting of small ice crystals occurs almost simultaneously (Tg' = Tm'). The time-scale of molecular rearrangement continually changes as the Tg is approached, so that food technologists can also gain some enhanced stability at temperatures above Tg' by minimizing the delta T between the storage temperature and Tg' , either by reduced storage temperatures or enhaced Tg' through freezing methods or formulation. Hence, knowledge of the glass transition provides a clear indication of molecular diffusion and reactivity, and therefore, shelf-stability.

Formation of a Dilute Glass

Despite the thermodynamic driving force to achieve the unfrozen water content corresponding to Wg', one must also consider the large kinetic factors which "overtake" the freezing process. At sub-zero temperatures, the formation of an amorphous state is time-dependent since the limiting factor of the process (water removal in the form of ice) becomes more difficult as concentration increases. The exponential effect of viscosity on mass transfer properties acts as the limiting factor for growth. In addition, under conditions where heat removal is rapid, a high level of undercooling at the interface will only add to a further decrease in propagation rate. The net result is that freezing becomes progressively slower as ice crystallization is hindered and consequently more time is required for lattice growth at each temperature.

Therefore the kinetic restriction imposed on the system can lead to a situation in which non-equilibrium freezing, resulting in a partial dilute glass, can occur. The typical pathway a system may follow during non-equilibrium freezing is shown in the above figure as the line leading to lower Tg (path E) than Tg' with a corresponding lower sucrose concentration in the glass (Cg) and higher water content in the glass (Wg) due to excess undercooled water plasticized within the glass. This is often referred to as a dilute glass. The magnitude of deviation from the equilibrium curve, and hence the actual path followed, may be regarded as a function of the degree of departure from equilibrium.

Systems possessing this undesirable structure may undergo various relaxation-recrystallization mechanisms in order to maximally freeze-concentrate and minimize the unfrozen water content. As a result, during warming, systems formed under these conditions may lead to one or more low temperature transitions, followed by an exothermic devitrification peak due to crystallization of immobilized water, and finally the onset of ice melting, Tm.

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Ice Cream Defects

If you haven't already done so, check out the Milk Grading and Defects section for a mini-introduction to the senses. This section will cover the following topics:

Flavour Defects

1. **Cooked:** Caused by using milk products heated to too high a temperature or by using excessively high temperatures in mix pasteurization. It can dissipate with time, the same as cooked defect in fluid milk. Caramel-like, scalded milk, oatmeal

2. **Egg:** Caused by using too much egg in an ice cream not specified as a custard ice cream. French vanilla ice cream - resembles cooked

3. **Unnatural Flavouring:** Caused by using flavours which are not typical of the designated flavour ie. wintergreen flavour on vanilla ice cream. esp. vanillin

4. **High Acid:** Use of dairy products with high acidity or holding mix too long and at too high a temperature before freezing.

5. **Lacks Fine Flavour:** May be caused by using harsh vanilla. Good but fals short of ideal. Last resort in trying to describe flavour defect.

6. **Lacks Freshness:** Stale flavour caused by permitting ice cream to remain in hardening room or cabinet too long before sale. Minor, more major- becomes old ingredient or storage

7. **Metallic:** Sometimes develops from oxidized flavour and usually caused by copper or iron contamination. Poor grade of vanilla has been known to cause this flavour. See oxidized, lingers a long time, astringent

8. **Neutralizer:** Results from the use of too much neutralizer in the mix. Soda flavours usually more ojbectionable than lime flavours.

9. **Old Ingredient:** Caused by the use of inferior dairy products in the preparation of the mix. Powders made from poor milk or butter made from poor cream will contribute to old ingredient flavour. Also poor egg. Unpleasant aftertaste

10. **Oxidized:** Caused by oxidation of the fat or lipid material such as phospholipid, similar to fluid milk oxidation. Induced by the presence of copper or iron in the mix. Mono-and-di-glyceride, Polysorbate 80. Various stages - cardboardy, metallic

11. **Rancid:** Caused by rancidity of certain fats. May be due to use of rancid dairy products or to insufficient heat before homogenization of mix. Egg yolk powder may also be the cause. Lipolysis, especially of butyric acid.

12. **Salty:** Ice cream too high in milk solids-not-fat. Too much salt may have been added to the mix. Whey powder, maybe salted butter, whey flavour graham cracker like

13. **Storage:** Usually develops from "Lacks Freshness" and is most pronounced on ice cream which have been held in a stale storage atmosphere. May be described as an "old ice box" flavour.

14. **Unnatural Sweetener** May be confused with a cooked flavour which sometimes produces a caramel taste. May be caused by too much corn syrup especially if corn syrup has strong flavour. Some vanillas also produce a caramel flavour.

Body and Texture Defects

1. **Course Texture:** Due to the presence of ice crystals of such a size that they are noticeable when the ice cream is eaten and may be caused by:

- Insufficient total solids.
- Insufficient serum solids.
- Insufficient sugar.
- Insufficient stabilizer or poor stabilizer.
- High acid mix.
- Insufficient homogenizing pressure.
- Homogenizer not functioning properly.
- Insufficient aging of the mix.
- Slow freezing because of mechanical condition of freezer.
- Incorporation of air as large cells because of physical characteristics of mix or type of freezer used.

- Slow hardening.
- Fluctuating hardening room temperatures.
- Rehardening soft ice cream.
- Pumping ice cream too far from continuous freezer

2. **Crumbly Body:** A flaky or snowy characteristic caused by:

- High overrun.
- Low stabilizer.
- Low total solids.
- Coarse air cells.

3. **Fluffy Texture:** A spongy characteristic caused by:

- Incorporation of large amount of air as large air cells.
- Low total solids.
- Low stabilizer content.
- Freezing ice cream too soft in freezer.

4. **Gummy Body:** This defect is the opposite of Crumbly in that it imparts a pasty or putty-like body. It is caused by:

- Too low an overrun.
- Too much stabilizer.
- Poor stabilizer.

5. **Icy Texture:** This defect is caused by many of the same factors which cause coarse texture, except that defect is much more pronounced.

6. **Sandy Texture:** One of the most objectionable texture defects but easiest to detect. It is caused by Lactose crystals which do not dissolve readily and produce a rough or gritty sensation in the mouth. This can be distinguished from "iciness" because the lactose crystals do not melt in your mouth. This defect can be prevented by:

- hardening the ice cream quickly
- maintaining low hardening room temps.
- preventing temp. fluctuations...from manufacturer to consumer

Lactose crystal formation is further discussed in the Dairy Chemistry and Physics section.

7. **Soggy Body:** Caused by:

- High total solids.
- Low overrun.
- High sugar content.
- High stabilizer content.

8. **Weak Body:** Ice cream lacks "chewiness" and melts quickly into a watery liquid. Gives impression of lacking richness. May be caused by:

- Low total solids.

- High overrun.
- Insufficient stabilizer.

Melting Quality Characteristics

1. **Curdy Melt-Down:** Due to coagulation of the milk proteins so is affected by factors which influence the protein stability such as:

- High acidity.
- Salt balance.
- High homogenizing pressures.
- Over-freezing in the freezer.

2. **Does not Melt:** May be caused by:

- Over stabilization.
- Wrong stabilizer.
- High fat.
- Excessive fat clumping in the mix due to homogenization at too low a temperature or single-stage homogenizer.
- Freezing to too low a temperature at freezer.
- Use of calcium neutralizers.

3. **Wheying off:** The salt balance, protein composition, carrageenan all are factors.

Colour Defects

1. **Colour Uneven:** Applies usually to ice cream in which colour has been used, but may be noticed in vanilla ice cream under some circumstances.

2. **Colour Unnatural:**

- Wrong shade of color used for flavoured ice cream.
- Too much yellow coloring used in vanilla ice cream.
- Grayish color due to neutralization.

Shrinkage

A very troublesome defect in ice cream since there appears to be no single cause or remedy. Defect shows up in hardened ice cream and manifests itself in reduced volume of ice cream in the container usually by pulling away from the top and/or sides of container. Some factors believed associated with the defect are:

- Freezing and hardening at low temperatures.
- Storage temperature. Both low and high appear to contribute.
- Excessive overruns.
- Type of container. More shrinkage in paper than metal containers.
- Partially de-established protein.
- Some emulsifiers seem to enhance shrinkage.
- Smooth ice cream as produced in continuous freezer.
- Season of the year more shrinkage in winter months.
- Use of neutralizers.
- Methods of handling in cabinets.

NOTE: **Retailing:** More so than other frozen products, ice cream requires constant, uninterrupted freezing cycle at low temperatures to avoid problems. Problems at retail level can arise from overfilling of display cabinet, heat from display lamps. hot air from incorrectly positioned circulation fans, displaying ice cream together with semi-frozen goods.

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Homemade Ice Cream

The following information comes from a publication developed by the late Professor A. M. Pearson of the University of Guelph, targeted to the manufacture of ice cream in the home with an old-fashioned hand or electric crank bucket, cooled by ice and salt. Please return to the ice cream page for further details related to commercial ice cream production.

Homemade Ice Cream has not lost any of its good, old-fashioned appeal. There is a delicious homemade ice cream to meet every need: regular, low calorie, non-cooked and one using a non-dairy liquid coffee whitener. Everyone can make a homemade ice cream to suit their need with convenience afforded by packages of ingredients from the supermarket.

Janice Bryant
Prof. A.M. Pearson
University of Guelph, 1980

Ice cream fills a useful place in homes throughout the country. It is a favourite for desserts or snacks incorporating an array of many flavour variations. Ice cream contains many nutrients. With the recipes provided, all should be able to enjoy some type of this tempting food. If the regular recipe does not suit your needs, there is the low calorie recipe which contains less than 3% fat for both a cost and calorie saving. The recipe using coffee whitener is significantly less costly than the regular and does not contain milk fat should that be your limitation. So let's mix up a batch of ice cream for anyone and everyone to enjoy!

Ingredients Used

The main constituents of ice cream are fat, milk solids-not-fat (skim-milk powder), sugar, gelatin (or other suitable stabilizer), egg and flavouring.

A variety of milk products can be used: cream, whole milk, condensed milk and instant skim-milk powder. The recipes stated below proved satisfactory using whipping cream (32-35% fat), table cream (18% fat) and whole milk. The fat gives the product richness, smoothness and flavour. Skim-milk powder is used to increase the solids content of the ice cream and give it more body. It is also an important source of protein which will improve the ice cream nutritionally. Use good quality, fresh powder to avoid imparting a stale flavour to the ice cream.

Liquid coffee whitener (usually purchased frozen) is a cream substitute in one of the recipes. It will yield a slightly different flavour which is still very acceptable. The texture of the ice cream is very creamy.

Liquid coffee whitener offers the convenience of being stored frozen in your freezer and is readily available if a quick decision is made to make ice cream.

Sugar is a common ingredient to use as a sweetener. It increases the palatability and improves the body and texture.

The next ingredient, gelatin (or similar substance) assists in absorbing some of the free water in the ice cream mix and helps prevent the formation of large crystals in the ice cream.

It also gives substance or a less watery taste when the ice cream is consumed. The eggs are added to make the fat and water more miscible and also to improve the whipping ability which gives the ice cream greater resistance to melting.

Although vanilla is the flavour added to all of the mixes listed below, you may add flavours to suit you taste.

Preparation of the Ice Cream Mix

The mix (unfrozen ice cream) has to be cooked (pasteurized). For pasteurizing the mix, it is best to use a double boiler to prevent scorching.

Place the liquid ingredients (milk, cream or coffee whitener) in the upper section of the double boiler. Beat in the eggs and the skim-milk powder. Mix the gelatin with the sugar and add to the liquid with constant mixing. While stirring, heat to about 70oC. Place the container in cold water and cool as rapidly as possible to below 18oC.

Aging the Mix

The ice cream mix is best if it is aged (stored in the refrigerator) overnight. This improves the whipping qualities of the mix and the body and texture of the ice cream. If time does not permit overnight aging, let the mix stand in the refrigerator for at least four hours. After the aging process is completed, remove the mix from the refrigerator and stir in the flavouring.

Freezing the Mix

The freezing procedure has a two-fold purpose, the removal of heat from the mix and the incorporation of air into the mix. Heat is removed by conduction through the metal to the salt water brine surrounding the freezing can. This transfer of heat depends upon the temperature of the brine, the speed of the dasher and how well the dasher scrapes the cold mix from the surface of the freezer can. The dasher speed and surface contact are important to achieve complete removal of the frozen ice cream from the wall of the freezer can. A brine made from 500 grams of salt and 5 kilograms of crushed ice (one pail full) makes a good freezing mixture.

Before starting to freeze the ice cream, make sure all parts of the freezer coming in contact with the ice cream are clean and have been scalded. Let the can cool before pouring in the mix. Place the empty can in the freezer bucket and insert the dasher ensuring both the can and the dasher are centred. Pour the cold, aged mix into the freezer can. The can should not be filled over two-thirds full to allow sufficient room for air incorporation.

The recipes listed below will fill the freezer can (5 quart U.S.) to just below the fill line. Attach the motor or crank mechanism, depending on whether your freezer is the electric or hand-cranked style, and latch down securely. Plug in the motor or start turning the crank. Immediately begin adding crushed ice around the can sprinkling it generously with salt. Try to add the salt and ice in the same one to ten proportion to get the proper brine temperature. After the bucket is filled with ice to the overflow hole, pour a little water over the ice to aid in the melting process.

Freeze the mix for 20 to 30 minutes. If the electric motor stalls, immediately unplug it. Remove the motor or crank and take the dasher out of the ice cream. The ice cream will be softly frozen. Scrape the ice cream from the dasher and either scoop into suitable containers or pack in the freezer can. Immediately place the ice cream in the deep freeze to harden.

If freezer facilities are not available, the ice cream can be left in the can, the lid plugged with a cork and placed back into the bucket. Repack the freezer with more ice and salt, cover with a heavy towel and set in a cool place to harden until serving time. This will require further addition of ice and salt depending on the length of time the ice cream is being held. The yield from the recipes listed below should be three to four litres.

Regular Vanilla Ice Cream

Table cream 2 l
Instant skim-milk powder 350 ml
Sugar 450 ml
Gelatin one 7 g pkg.
Egg one med or large
Vanilla 10 ml
Calories per 100 g 230

Low Calorie Vanilla Ice Cream

Whole milk 2 l
Instant skim-milk powder 500 ml
Sugar 350 ml
Gelatin one 7 g pkg.
Egg one med or large
Vanilla 10 ml
Calories per 100 g 125

Milk Substitute Vanilla Ice Cream

Coffee whitener 2 kg
Instant skim-milk powder 350 ml
Sugar 500 ml
Gelatin one 7 g pkg.
Egg one med or large
Vanilla 10 ml
Calories per 100 g 210

Hints for Making Good Ice Cream

1. If the ice cream is very soft, the brine is not cold enough. More salt should be added to reduce the brine temperature.

2. If the ice cream is coarse and ice in less than 20 minutes, the brine has become to too cold too quickly. Too much salt has been used.

3. Make the ice cream mix the day before it is frozen to get a smoother product and a higher yield.

4. Electric freezing takes longer than hand operated.

5. Use crushed ice for freezing.

6. Freeze at least 3 hours before the ice cream is to be served.

7. Be sure dasher is properly centred in the freezer can.

8. Add liquid flavours before freezing but if you want to add fruits or nuts, add them after freezing and before hardening.

9. Use a wire whip to blend ingredients for best results.

10. Clean the salt off all the metal parts of the freezer to prevent corrosion.

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Finding Science in Ice Cream - An Experiment for Secondary School Classrooms

For further information about Finding Science in Ice Cream:

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As the hot weather approaches and students minds begin to drift from the rigors of the school classroom or laboratory, a fun afternoon might be spent making ice cream and in so doing, introducing several aspects of the science and technology "behind the scenes". To suggest that there is no science in ice cream could not be further from the truth. I have made a career out of ice cream research which has taken me into aspects of physical and organic chemistry, microbiology, and chemical engineering to name but a few. Because all of you are from different disciplines and teach in different ways, I will give you enough background information and practice from which you can prepare your own experimental work. You can use the ice cream lab, for example, to demonstrate heat transfer in physics classes, freezing point depression phenomena and emulsions and foams in chemistry classes, or pasteurization and the food use of seaweeds(!) in biology classes. However you use the following information, even if it is for your own family picnic this summer, I hope you enjoy it!

The History of Ice Cream

Once upon a time, hundreds of years ago, Charles I of England hosted a sumptuous state banquet for many of his friends and family. The meal, consisting of many delicacies of the day, had been simply superb but the "coup de grace" was yet to come. After much preparation, the King's french chef had concocted an apparently new dish. It was cold and resembled fresh-fallen snow but was much creamier and sweeter than any other after-dinner dessert. The guests were delighted, as was Charles, who summoned the cook and asked him not to divulge the recipe for his frozen cream. The King wanted the delicacy to be served only at the Royal table and offered the cook 500 pounds a year to keep it that way. Sometime later, however, poor Charles fell into disfavour with his people and was beheaded in 1649. But by that time, the secret of the frozen cream remained a secret no more. The cook, named DeMirco, had not kept his promise.

This story is just one of many of the fascinating tales which surround the evolution of our country's most popular dessert, ice cream. It is likely that ice cream was not invented, but rather came to be over years of similar efforts. Indeed, the Roman Emperor Nero Claudius Caesar is said to have sent slaves to the mountains to bring snow and ice to cool and freeze the fruit drinks he was so fond of. Centuries later, the Italian Marco Polo returned from his famous journey to the Far East with a recipe for making water ices resembling modern day sherbets.

In 1774, a caterer named Phillip Lenzi announced in a New York newspaper that he had just arrived from London and would be offering for sale various confections, including ice cream. Dolly Madison, wife of U.S. President James Madison, served ice cream at her husband's Inaugural Ball in 1813. Commercial production was begun in North America in Baltimore, Maryland, 1851, by Mr. Jacob Fussell, now known as the father of the American ice cream industry. The first Canadian to start selling ice cream was Thomas Webb of Toronto, a confectioner, around 1850. William Neilson produced his first commercial batch of ice cream on Gladstone Ave. in Toronto in 1893, and his company produced ice cream at that location for close to 100 years. The ice cream division of Neilson was recently purchased by Ault Foods of London, Ont.

The Composition of and Ingredients in Ice Cream

Today's ice cream has the following composition : a) greater than 10% milkfat by legal definition, and usually between 10% and as high as 16% fat in some premium ice creams; b) between 9 and 12% milk solids-not-fat, the component which contains the proteins (caseins and whey proteins) and carbohydrates (lactose) found in milk; c) 12% to 16% sweeteners, usually a combination of sucrose and glucose-based corn syrup sweeteners; and d) 0.2% to 0.5% added stabilizers and emulsifiers, necessary components that unfortunately have unfamiliar sounding names that occupy three-quarters of the space of the ingredient listing and that will be described subsequently. The balance, usually 55% to 64%, is water which comes from the milk. Ice milk is very similar to the composition of ice cream but contains between 3% and 5% milkfat by definition. Light ice cream contains between 8% and 10% milkfat.

The ingredients used to supply this composition include: a) a concentrated source of the milkfat, usually cream or butter; b) a concentrated source of the milk solids-not-fat component, usually evaporated milk or milk powder; c) sugars including sucrose and "glucose solids", a product derived from the partial hydrolysis of the corn starch component in corn syrup; and d) milk.

The fat component adds richness of flavour, contributes to a smooth texture with creamy body and good meltdown, and adds lubrication to the palate as it is consumed. The milk solids-not-fat component also contributes to the flavour but more importantly improves the body and texture of the ice cream by offering some "chew resistance" and enhancing the ability of the ice cream to hold its air. The sugars give the product its characteristic sweetness and palatability and enhance the perception of various fruit flavours. In addition, the sugars, including the lactose from the milk components, contribute to a depressed freezing point so that the ice cream has some unfrozen water associated with it at very low temperatures typical of their serving temperatures, -15º to -18ºC. Without this unfrozen water, the ice cream would be too hard to scoop.

Freezing point depression of a solution is a colligative property associated with the number of dissolved molecules. The lower the molecular weight, the greater the ability of a molecule to depress the freezing point. Thus monosaccharides such as fructose or glucose produce a much softer ice cream than disaccharides such as sucrose. This limits the amount and type of sugar which one can successfully incorporate into the formulation.

The stabilizers are a group of compounds, usually polysaccharides, that are responsible for adding viscosity to the unfrozen portion of the water and thus holding this water so that it cannot migrate within the product. This results in an ice cream that is firmer to the chew. Without the stabilizers, the ice cream would become coarse and icy very quickly due to the migration of this free water and the growth of existing ice crystals. The smaller the ice crystals in the ice cream, the less detectable they are to the tongue. Especially in the distribution channels of today's marketplace, the supermarkets, the trunks of cars, and so on, ice cream has many opportunities to warm up, partially melt some of the ice, and then refreeze as the temperature is once again lowered. This process is known as heat shock and every time it happens, the ice cream becomes more icy tasting. Stabilizers help to prevent this.

Gelatin, a protein of animal origin, was used almost exclusively in the ice cream industry as a stabilizer but has gradually been replaced with polysaccharides of plant origin due to their increased effectiveness and reduced cost. The stabilizers in use today include: a) carboxymethyl cellulose, derived from the bulky components of plant material; b) locust bean gum which is derived from the beans of exotic trees grown mostly in Africa (Note: locust bean gum is a synonym for carob bean gum, the beans of which were used centuries ago for weighing precious metals, a system still in use today, the word carob and Karat having similar derivation) ; c) guar gum, from the guar bush, a member of the legume family grown in India for centuries and now grown to a limited extent in Texas; d) carrageenan, an extract of Irish Moss or red algae, originally harvested from the coast of Ireland, near the village of Carragheen; or e) sodium alginate, an extract of another seaweed, brown kelp. Often, two or more of these stabilizers are used in combination to lend synergistic properties to each other and improve their overall effectiveness.

The emulsifiers are a group of compounds in ice cream which aid in developing the appropriate fat structure and air distribution necessary for the smooth eating and good meltdown characteristics desired in ice cream. Emulsifiers are characterized by having a molecular structure which allows part of the molecule to be readily solubilized in a polar compound such as water, and another part of the molecule to be more readily solubilized in non-polar solvents such as fats. As a result, emulsifiers reside at the interface between fat and water, and lower the free energy or tension associated with two immiscible liquids in contact with each other. Their action will be more fully explained in the section below on emulsions and foams.

The original ice cream emulsifier was egg yolk, which was used in most of the original recipes. Today, two emulsifiers predominate most ice cream formulations: a) mono- and di-glycerides , derived from the partial hydrolysis of fats or oils of animal or vegetable origin; and b) Polysorbate 80, a product consisting of a glucose molecule bound to a fatty acid, oleic acid. Both of these compounds have hydrophobic regions (the "fat loving" part), the fatty acids, and hydrophilic regions (the "water loving" part), either glycerol or glucose. All of the compounds mentioned above are either fats or carbohydrates, important components in most of the foods we eat and need.

Together, the stabilizers and emulsifiers make up less than one half percent by weight of our ice cream. They are all compounds which have been exhaustively tested for safety and have received the "generally recognized as safe" or GRAS status.

The Manufacturing Process

Ingredients are chosen by the manufacturer on the basis of desired quality, availability, and cost. The ingredients are blended together and produce what is known as the "ice cream mix". The mix is first pasteurized. Pasteurization is a process which is designed to kill all of the possible pathogens (disease causing organisms) that may be present. Organisms such as Mycobacterium tuberculosis, Salmonella, Staphylococcus, Listeria, and others that cause human disease can be found associated with farm animals and thus raw milk products must be pasteurized. In addition to this very important function, pasteurization also reduces the number of spoilage organisms such as psychrotrophs, and helps to "cook" the mix. The mix is also homogenized which forms the fat emulsion by breaking down or reducing the size of the fat globules found in milk or cream to less than 1 µm. Homogenization helps to produce a smooth product when frozen. The mix is then aged for at least four hours and usually overnight. This allows time for the fat to cool down and crystallize, and for the proteins and polysaccharides to fully hydrate.

Following mix processing, the mix is drawn into a flavour tank where any liquid flavours, fruit purees, or colours are added. The mix then enters the dynamic freezing process which both freezes a portion of the water and whips air into the frozen mix. The "barrel" freezer is a scraped-surface, tubular heat exchanger, which is jacketed with a boiling refrigerant such as ammonia or freon. Mix is pumped through this freezer and is drawn off the other end in a matter of 30 seconds, (or 10 to 15 minutes in the case of batch freezers) with about 50% of its water frozen. There are rotating blades inside the barrel that keep the ice scraped off the surface of the freezer and also dashers inside the machine which help to whip the mix and incorporate air. Ice cream contains a considerable quantity of air, up to half of its volume. This gives the product its characteristic lightness. Without air, ice cream would be similar to a frozen ice cube.

As the ice cream is drawn with about half of its water frozen, particulate matter such as fruits, nuts, candy, cookies, or whatever you like, is added to the semi-frozen slurry which has a consistency similar to soft-serve ice cream. In fact, almost the only thing which differentiates hard frozen ice cream from soft-serve, is the fact that soft serve is drawn into cones at this point in the process rather than into packages for subsequent hardening. After the particulates have been added, the ice cream is packaged and is placed into a blast freezer at -30º to -40ºC where most of the remainder of the water is frozen. Below about -25ºC, ice cream is stable for indefinite periods without danger of ice crystal growth; however, above this temperature, ice crystal growth is possible and the rate of crystal growth is dependant upon the temperature of storage. This limits the shelf life of the ice cream.

Salt and ice

Making ice cream at home requires the use of an ice cream machine. The "homemade" or hand-crank freezer used was the forerunner to today's modern equipment. Many people enjoy fond memories of hot summer days spent preparing the ice cream mix, loading the bucket with ice and salt, and cranking the freezer for a half hour until it was considered too stiff to continue or until one's hunger got the best of them. All of the various steps in making ice cream via the bucket are similar to the commercial processing stages. The mix is prepared and pasteurized, aged, dynamically whipped and frozen in a freezer equipped with blades and dashers, and then hardened prior to consumption. Ice and salt are used, however, rather than the ammonia or Freon jacket in the commercial freezer above.

The concept of melting ice with salt is not new to anyone in this latitude. Indeed, our roads, driveways, and sidewalks are kept bare in the winter by such a process. As salt is applied to ice, the ice crystal sructure is broken due to the depressed freezing point of the resulting brine solution. As the salt continues to dissolve more ice melts to accommodate this concentrated salt solution with its very low melting point. At the same time, both the heat of solution of the dissolving salt, and the latent heat of fusion of the melting ice are adsorbed from the ice itself, thereby lowering the temperature of the salt, ice and brine mixture. The temperature of this mixture can be controlled by the amount and ratio of salt and ice present. The lowest temperature which can be achieved with a sodium chloride brine is -21ºC, at a concentration of 23% salt. Higher concentrations result in salt crystallization.

This brine, in turn, is adsorbing heat from the freezing ice cream inside the can, and thus ice and salt need to be continually added to keep the ice temperature low enough to freeze the ice cream. (Bear in mind that the freezing temperature of the ice cream is depressed below 0o due to the presence of dissolved sugars.) This process is a lesson in heat transfer in itself!

The Structure of Ice Cream - Emulsions and Foams

An emulsion is defined as liquid droplets dispersed in another immiscible liquid. The dispersed phase droplet size ranges from 0.1-10 µm. Important oil-in-water food emulsions, ones in which oil or fat is the dispersed phase and water is the continuous phase, include milk, cream, ice cream, salad dressings, cake batters, flavour emulsions, meat emulsions, and cream liqueurs. Examples of food water-in-oil emulsions are butter or margarine. Emulsions are inherently unstable because free energy is associated with the interface between the two phases. As the interfacial area increases, either through a decrease in particle size or the addition of more dispersed phase material, i.e. higher fat, more energy is needed to keep the emulsion from coalescing. Some molecules act as surface active agents (called surfactants or emulsifiers) and can reduce this energy needed to keep these phases apart.

A foam is defined as a gas dispersed in a liquid where the gas bubbles are the discrete phase. There are many food foams including whipped creams, ice cream, carbonated soft drinks, mousses, meringues, and the head of a beer. A foam is likewise unstable and needs a stabilizing agent to form the gas bubble membrane.

Ice cream is both an emulsion and a foam. The milkfat exists in tiny globules that have been formed by the homogenizer. There are many proteins which act as emulsifiers and give the fat emulsion its needed stability. The emulsifiers discussed above in the Ingredients section which are added to ice cream actually reduce the stability of this fat emulsion because they replace proteins on the fat surface. When the mix is subjected to the whipping action of the barrel freezer, the fat emulsion begins to partially break down and the fat globules begin to flocculate. The air bubbles which are being beaten into the mix are stabilized by this partially coalesced fat. If emulsifiers were not added, the fat globules would have so much ability to resist this coalescing due to the proteins being adsorbed to the fat globule that the air bubbles would not be properly stabilized and the ice cream would not have the same smooth texture (due to this fat structure) that it has.

This fat structure which exists in ice cream is the same type of structure which exists in whipped cream. When you whip a bowl of heavy cream, it soon starts to become stiff and dry appearing and takes on a smooth texture. This results from the formation of this partially coalesced fat structure stabilizing the air bubbles. If it is whipped too far, the fat will begin to churn and butter particles will form. The same thing will happen in ice cream which has been whipped too much.

Also adding structure to the ice cream is the formation of the ice crystals. Water freezes out of a solution in its pure form as ice. In a sugar solution such as ice cream, the initial freezing point of the solution is lower than 0^{o}C due to these dissolved sugars. As ice crystallization begins and water freezes out in its pure form, the concentration of the remaining solution of sugar is increased due to water removal and hence the freezing point is further lowered. This process, known as freeze concentration, continues to very low temperatures. Even at the typical ice cream serving temperature of -16^{o}C, only about 72% of the water is frozen. The rest remains as a very concentrated sugar solution. This helps to give ice cream its ability to be scooped and chewed at freezer temperatures. The air content also contributes to this ability as mentioned above in discussing freezing.

Thus the structure of ice cream can be described as a partly frozen foam with ice crystals and air bubbles occupying a majority of the space. The tiny fat globules, some of them flocculated and surrounding the air bubbles also form a dispersed phase. Proteins and emulsifiers are in turn surrounding the fat globules. The continuous phase consists of a very concentrated, unfrozen solution of sugars.

One gram of ice cream of typical composition contains 1.5 x 1012 fat globules of average diameter 1 µm that have a surface area of greater than 1 square meter (in a gram!), 8 x 106 air bubbles of average diameter 70 µm with a surface area of 0.1 sq. m., and 8 x 106 ice crystals of average diameter 50 µm with a surface area of another 0.1 sq. m. The importance of surface chemistry becomes obvious!

The Logistics of the Experiment

Depending on the available resources, an old-fashioned hand-crank or electric type freezer can be used. Please see my Homemade Ice Cream page for directions.

However, there are alternatives. Here is directions from a clever experiment I received from a sceince enrichment Grade 1-4 teacher:
each student places in a small zip loc baggy (the heavy-duty, freezer type) - 1 T sugar, 1/2 t vanilla, 1/2 cup milk. Secure zip loc and place small baggy in a larger zip loc baggy (also the heavy duty kind). Surround the small baggy with ice to 1/2 large baggy full and put in 6 T salt on ice. Next, shake the baggies 5-10 minutes and the students have made their own serving of ice cream. Chocolate syrup on top is really good. Further details of a similar experiment can be found here.

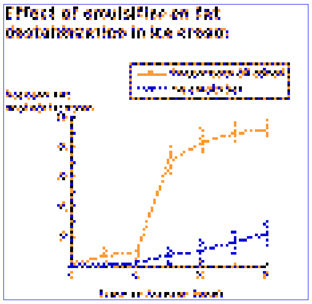
An alternative is to use liquid nitrogen for the freezing. Use a mix opf standard recipe (see homemade ice cream page). Place the mix on a very large stainless steel bowl, about 1/3 full, and have a student stir the mix very quickly with a wire whisk (very quickly!). Have someone else pour a small quantity of liquid nitrogen into the mix while being stirred (stir as long and as fast as you possibly can). It will freeze instantly. Let the ice cream sit for a few minutes to ensure there is no liquid nitroegn left, and then eat when it is at the right consistency. A few words of caution - this experiment is pretty safe for older children (I have done it many times in high school classes), but liquid nitrogen needs to be handled cautiously. Wear gloves, don't spill on skin, etc.

I hope you have enjoyed this overview of ice cream processing and chemistry and have gained some useful insights into the field of Food Science, and that from this overview you might be able to have some fun with your students and pass along to them some of our enthusiasm for this field. In today's world of rapidly expanding technology, evident even on the grocery store shelf, we need students who are willing to learn and apply new and existing technologies to the stable, exciting, vital, and profitable food industry.

Professor Doug Goff
Dept. of Food Science
University of Guelph

Structure of Ice Cream

Ice cream is both an ***emulsion*** and a ***foam***. The milkfat exists in tiny globules that have been formed by the homogenizer. There are many proteins which act as emulsifiers and give the fat emulsion its needed stability. The emulsifiers are added to ice cream to actually reduce the stability of this fat emulsion by replacing proteins on the fat surface. When the mix is subjected to the whipping action of the barrel freezer, the fat emulsion begins to partially break down and the fat globules begin to **flocculate** or destabilize. The air bubbles which are being beaten into the mix are stabilized by this partially coalesced fat. If emulsifiers were not added, the fat globules would have so much ability to resist this coalescing, due to the proteins being adsorbed to the fat globule, that the air bubbles would not be properly stabilized and the ice cream would not have the same smooth texture (due to this fat structure) that it has.



Effect of emulsifier on fat destabilization in ice cream 17 KB

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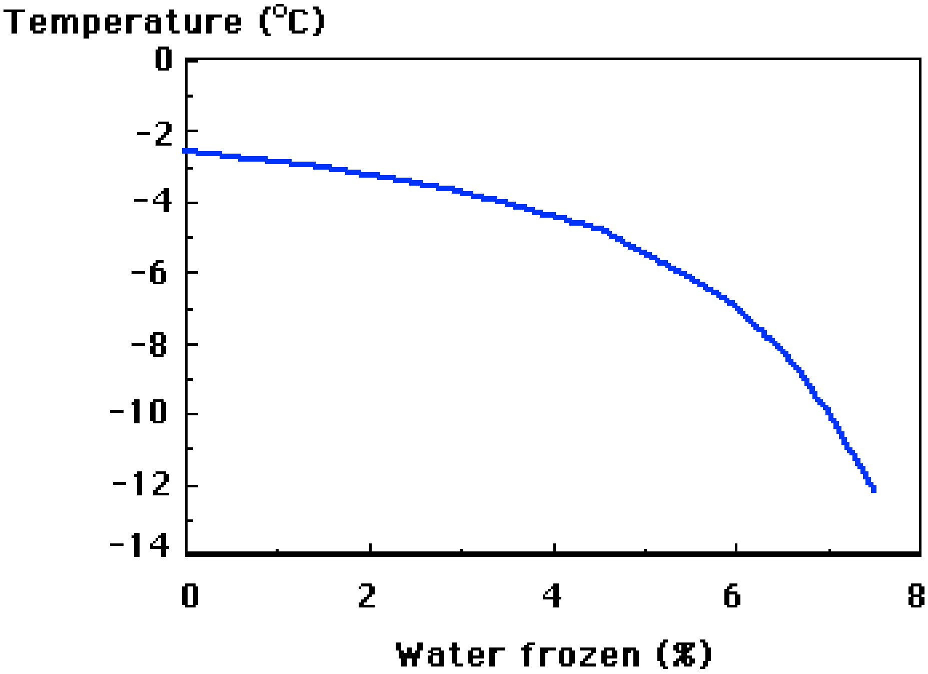
A primer on the theoretical aspects of freezing will help you to fully understand the freezing process.



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Before we leave ice cream structure, I want to draw your attention to the following address: "Foods Under the Microscope". This is a link to an absolutely marvellous website developed by my good friend Dr. Milos Kalab, with many high-quality images of the structure of milk and dairy products obtained during Dr. Kalab's long and outstanding career as a food microscopist with Agriculture and Agri-Food Canada in Ottawa. Dr. Kalab asked me to contribute microscopic images of ice cream structure as a guest microscopist. You can find my contribution under "Guest microscopists", and I have also copied it here.

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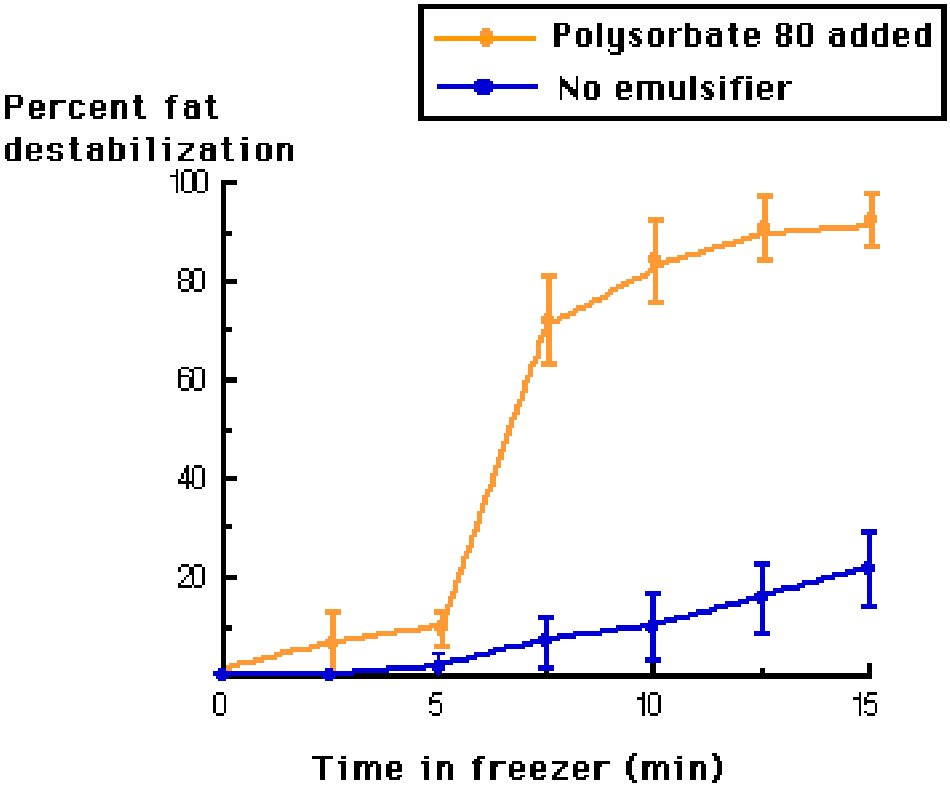
Effect of emulsifier on fat destabilization in ice cream



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Butter Manufacture

Introduction

This material has been condensed from the Alfa-Laval Dairy Handbook.

Butter is essentially the fat of the milk. It is usually made from sweet cream and is salted. However, it can also be made from acidulated or bacteriologically soured cream and saltless (sweet) butters are also available.

Well into the 19th century butter was still made from cream that had been allowed to stand and sour naturally. The cream was then skimmed from the top of the milk and poured into a wooden tub. Buttermaking was done by hand in butter churns. The natural souring process is, however, a very sensitive one and infection by foreign micro-organisms often spoiled the result.

Today's commercial buttermaking is a product of the knowledge and experience gained over the years in such matters as hygiene, bacterial acidifying and heat treatment, as well as the rapid technical development that has led to the advanced machinery now used.

The principal constituents of a normal salted butter are fat (80 - 82%), water (15.6 - 17.6%), salt (about 1.2%) as well as protein, calcium and phosphorous (about 1.2%). Butter also contains fat-soluble vitamins A, D and E.

Butter should have a uniform colour, be dense and taste clean. The water content should be dispersed in fine droplets so that the butter looks dry. The consistency should be smooth so that the butter is easy to spread and melts readily on the tongue.

Buttermaking

The buttermaking process involves quite a number of stages. The continuous buttermaker has become the most common type of equipment used.

The cream can be either supplied by a liquid milk dairy or separated from whole milk in the creamery.

If the cream is separated at the creamery, the whole milk is preheated to the required temperature in a skim milk pasteurizer before being passed through a separator. The cream is cooled and led to a storage tank where the fat content is analyzed and adjusted to the desired value, if necessary. The skim milk from the separator is pasteurized and cooled before being pumped to storage.

From the intermediate storage tanks, the cream goes to pasteurization at a temperature of 95oC or more. The high temperature is needed to destroy enzymes and micro-organisms that would impair the keeping quality of the butter.

Vacuum deaeration can also be included in the line if the cream has an undesirable, volatile flavour or aroma, e.g. onion taste. Any flavouring gets bound in the fat and will be transmitted to the butter unless removed. There are, however, investigations that imply that vacuum deaeration has an unfavourable effect on the consistency of the butter and the yield, so it is better to avoid this treatment if possible.

In the ripening tank the cream is subjected to a program of heat treatment designed to give the fat the required crystalline structure when it solidifies on cooling. The program is chosen to accord with factors such as the composition of the butterfat, expressed, for example, in terms of the iodine value which is a measure of the unsaturated fat content. The treatment can even be modified to obtain butter with good consistency despite a low iodine value, i.e. when the unsaturated proportion of the fat is low.

As a rule, ripening takes 12 - 15 hours. From the ripening tank, the cream is pumped to the churn or continuous buttermaker via a plate heat exchanger which brings it to the requisite temperature. In the churning process the cream is violently agitated to break down the fat globules, causing the fat to coagulate into butter grains, while the fat content of the remaining liquid, the buttermilk, decreases.

Thus the cream is split into two fractions: butter grains and buttermilk. In traditional churning, the machine stops when the grains have reached a certain size, whereupon the buttermilk is drained off. With the continuous buttermaker the draining of the buttermilk is also continuous.

After draining, the butter is worked to a continuous fat phase containing a finely dispersed water phase. It used to be common practice to wash the butter after churning to remove any residual buttermilk and milk solids but this is rarely done today. If the butter is to be salted, salt is spread over its surface, in the case of batch production. In the continuous buttermaker, a salt slurry is added to the butter.

After salting, the butter must be worked vigorously to ensure even distribution of the salt. The working of the butter also influences the characteristics by which the product is judged - aroma, taste, keeping quality, appearance and colour.

The finished butter is discharged into the packaging unit, and from there to cold storage.

Heat treatment

Before churning, cream is subjected to a program of heat treatment designed to control the crystallization of the fat so that the resultant butter has the right consistency. The consistency of butter is one of its most important quality-related characteristics, both directly and indirectly, since it affects the other characteristics - chiefly taste and aroma. Consistency is a complicated concept and involves properties such as hardness, viscosity, plasticity and spreading ability.

The relative amounts of fatty acids with high melting point determine whether the fat will be hard or soft. Soft fat has a high content of low-melting fatty acids and at room temperature this fat has a large continuous fat phase with a low solid phase, i.e. crystallized, high-melting fat. On the other hand, in a hard fat, the solid phase of high-melting fat is much larger than the continuous fat phase of low-melting fatty acids.

In buttermaking, if the cream is always subjected to the same heat treatment it will be the chemical composition of the milk fat that determines the butter's consistency. A soft milk fat will make a soft and greasy butter, whereas butter from hard milk fat will be hard and stiff. If, however, the heat treatment is modified to suit the iodine value of the fat, the consistency of the butter can be optimized. For the heat treatment regulates the size of the fat crystals, and the relative amounts of solid fat and the continuous phase - the factors that determine the consistency of the butter.

Butterfat crystallization

Pasteurization causes the fat in the fat globules to liquefy. And when the cream is subsequently cooled a proportion of the fat will crystallize. If cooling is rapid, the crystals will be many and small; if gradual the yield will be fewer but larger crystals. The more violent the cooling process, the more will be the fat that will crystallize to form the solid phase, and the less the liquid fat that can be squeezed out of the fat globules during churning and working.

The crystals bind the liquid fat to their surface by adsorption. Since the total surface area is much greater if the crystals are many and small, more liquid fat will be adsorbed than if the crystals were larger and fewer. In the former case, churning and working will press only a small proportion of the liquid fat from the fat globules. The continuous fat phase will consequently be small and the butter firm. In the latter case, the opposite applies. A larger amount of liquid fat will be pressed out; the continuous phase will be large and the butter soft.

So by modifying the cooling program for the cream, it is possible to regulate the size of the crystals in the fat globules and in this way influence both the magnitude and the nature of the important continuous fat phase.

Treatment programming

As we have seen, the heat treatment must be adapted to suit the iodine value of the milk fat if a uniform butter consistency is to be obtained.

Treatment of hard fat

For optimum consistency where the iodine value is low, i.e. the butterfat is hard, as much as possible of the hardest fat must be converted to as few crystals as possible, so that little of the liquid fat is bound to the crystals. The liquid fat phase in the fat globules will thereby be maximized and much of it can be pressed out during churning and working, resulting in butter with a relatively large continuous phase of liquid fat and with the hard fat concentrated to the solid phase.

The program of treatment necessary to achieve this result comprises the following stages:
- rapid cooling to about 8oC and storage for about 2 hours at this temperature;
- heating gently to 20 - 21oC and storage at this temperature for at least 2 hours (water at 27 - 29oC is used for heating);
- cooling to about 16oC.

Cooling to about 8oC causes the formation of a large number of small crystals that bind fat from the liquid continuous phase to their surface.

When the cream is gently heated to 20 - 21oC the bulk of the crystals melt, leaving only the hard fat crystals which, during the storage period at 20 - 21oC, grow larger.

After 1 - 2 hours most of the hard fat has crystallized, binding little of the liquid fat. By dropping the temperature now to about 16oC, the hardest portion of the fat will be fixed in crystal form while the rest is liquefied. During the holding period at 16oC, fat with a melting point of 16oC or higher will be added to the crystals. The treatment has thus caused the high-melting fat to collect in large crystals with little adsorption of the low-melting liquid fat, so that a large proportion of the butter oil can be pressed out during churning and working.

Treatment of medium-hard fat

With an increase in the iodine value, the heating temperature is accordingly reduced from 20-21oC. Consequently a larger number of fat crystals will form and more liquid fat will be adsorbed than is the case with the hard fat program. For iodine values up to 39, the heating temperature can be as low as 15oC.

At the lower temperatures the souring time is extended.

Treatment of very soft fat

Where the iodine value is greater than 39-40 the "summer method" of treatment is used. After pasteurization the cream is cooled to 20oC and soured at this temperature for about 5 hours. When the acidity is about 22oSH it is cooled. If the iodine value is around 39 - 40 the cream is cooled to about 8oC, and if 41 or greater to 6oC. It is generally held that souring temperatures below the 20o level will give a soft butter. The same thing applies for higher cooling temperatures after souring.

Continuous Buttermaking

Methods of continuous buttermaking were introduced at the end of the nineteenth century but their application was very restricted. In the 1940's the work was resumed and resulted in three different processes, all based on the traditional methods - churning, centrifuging and concentration or emulsifying.

One of the processes based on conventional churning was the Fritz method which is the one now used predominantly in Western Europe. In machines based on this method, butter is made in generally the same way as by traditional methods. The butter is basically the same, except that it somewhat matt and denser as a result of uniform and fine water dispersion.

The manufacturing process

The cream is prepared in the same way as for conventional churning before being fed continuously from the ripening tanks to the buttermaker.

The cream is first fed into a churning cylinder fitted with beaters that are driven by a variable speed motor.

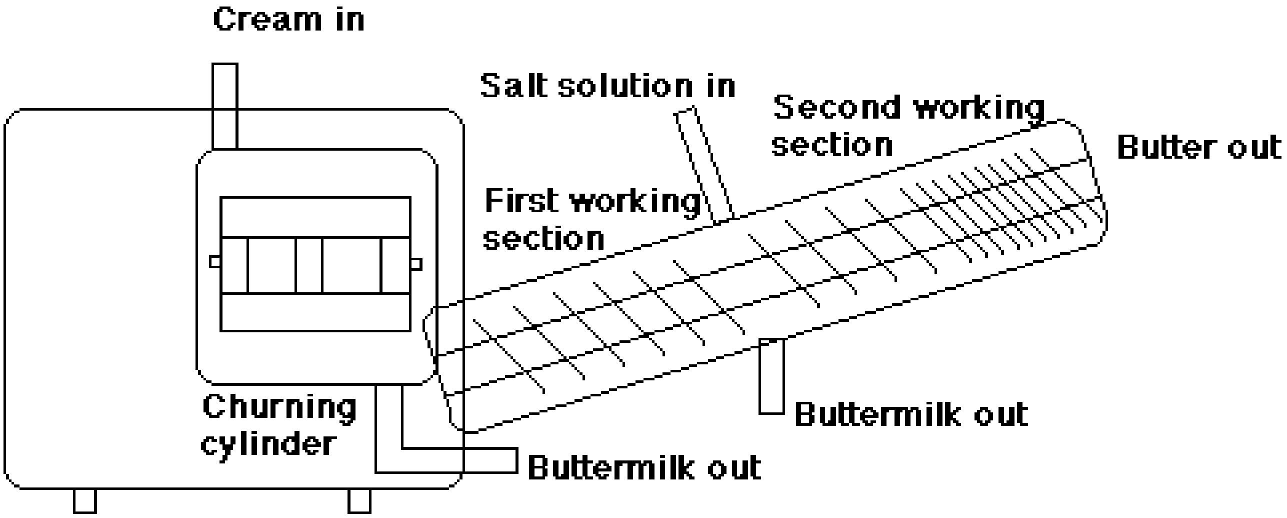
Rapid conversion takes place in the cylinder and, when finished, the butter grains and buttermilk pass on to a draining section. The first washing of the butter grains sometimes takes place en route - either with water or recirculated chilled buttermilk. The working of the butter commences in the draining section by means of a screw which also conveys it to the next stage.

On leaving the working section the butter passes through a conical channel to remove any remaining buttermilk. Immediately afterwards, the butter may be given its second washing, this time by two rows of adjustable high-pressure nozzles. The water pressure is so high that the ribbon of butter is broken down into grains and consequently any residual milk solids are effectively removed. Following this stage, salt may be added through a high-pressure injector.

The third section in the working cylinder is connected to a vacuum pump. Here it is possible to reduce the air content of the butter to the same level as conventionally churned butter.

In the final or mixing section the butter passes a series of perforated disks and star wheels. There is also an injector for final adjustment of the water content. Once regulated, the water content of the butter deviates less than +/- 0.1%, provided the characteristics of the cream remain the same.

The finished butter is discharged in a continuous ribbon from the end nozzle of the machine and then into the packaging unit.



Continuous Butter Churn

Anhydrous Milkfat

Cream as the raw material

The processes for the production of anhydrous fat, using cream as the raw material, are based on the emulsion splitting principle. In brief, the processes consist of the cream first being concentrated and the fat globules then being broken down mechanically, so that the fat is liberated. This forms a continuous fat phase containing dispersed water droplets which can be separated from the fat phase.

Either the Clarifixator or the Centrifixator is used for mechanically liberating the fat and thus allowing for the phase conversion, and these two process lines derive their names from the corresponding units.

The Clarifixator line has been used commercially for a number of years. One of the key machines in the system - the Clarifixator - is a centrifugal separator equipped with a serrated disc which simultaneously homogenizes the milk. The disc normally breaks down the fat globules into smaller globules, although in the production of anhydrous milk fat, the disc breaks down the emulsion, so that the liquid leaving the machine is a continuous oil phase, with dispersed water droplets and buttermilk. After phase inversion, the fat is concentrated in a hermetic separator.

Clarifixator lines with capacities between 500 and 1000 kg of butter oil per hour are available.

The Centrifixator line has an appreciably higher capacity of 1500 - 2000 kg of butter oil per hour and offers opportunities for planning production rates of 4000 - 6000 kg of butter oil per hour. In this case, the emulsion is split in a unit of special design - known as the Centrifixator - which contains a motor-driven serrated disc. The fat is concentrated in a hermetic solids-ejecting separator. Solids-ejecting machines are also used in the second centrifugal separation stage, and the line is thus capable of operating for long periods and can be cleaned in place.

Fractionation of anhydrous milk fat

Milk fat is a complicated mixture of triglycerides which contain numerous fatty acids of varying carbon chain lengths and degrees of saturation. The proportions of the various fatty acids present will also vary depending on the conditions surrounding the production of milk.

The mixture can be separated into fractions on the basis of their melting point. The technique consists of melting the entire quantity of fat and then cooling it down to a predetermined temperature. The triglycerides with the higher melting point will then crystallize and settle out.

In the modern fractionation method, sedimentation by gravity is replaced by centrifugal separation. Since a modern separator generates a force which is thousands of times greater than the force of gravity and since the sedimentation distances are very short, the process is incomparably faster. The crystallizing stage can also be accelerated, since the crystals need not be large if centrifugal separation is employed.

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