EVAPORATED AND CONDENSED MILK *

J. C. T. VAN DEN BERG **

Introduction

Condensed milk is the product obtained by evaporating part of the water of whole milk or fully or partly skimmed milk, with or without the addition of sugar. Though the product is supplied in bulk as a raw material for the food industry, it is mainly prepared for direct consumption, in which case it is packed in relatively small quantities in sealed tins or in bottles.

In the countries or areas where enough milk is available, the consumption of condensed milk packed in small units is as a rule relatively small and mainly confined to some applications for which the concentrated form has special advantages, such as use in beverages. Condensed milk is of far greater importance for the milk supply in remote areas with a shortage of milk; the concentrated form gives a considerable saving in cost of packing, transport and storage.

As bacteriological contamination of milk cannot be prevented by evaporating only part of the water, separate measures should be taken for the preservation of concentrated milk.

This preservation is done mainly by two methods which also determine the nature of the finished product, namely:

(1) Sweetened condensed milk or, for short, condensed milk—a milk concentrate, the watery phase of which, owing to the addition of sugar, has such a high osmotic pressure that no micro-organisms can develop.

(2) Sterilized condensed milk or, for short, evaporated milk—a sterile product obtained by heating the tinned concentrated product at high temperatures.

Condensed milk is a relatively young dairy product. The Frenchman Appert was the first to prepare evaporated milk by way of an experiment. In 1810 a patent was issued in England on the concentration of milk in open vats with subsequent preservation by adding sugar. In 1856 the American

* Illustration of manufacturers' products does not imply that they are endorsed or recommended in preference to other products of a similar nature that are not illustrated.

** Government Dairy Adviser for Milk Products, Ministry of Agriculture and Fisheries, The Hague, Netherlands.

Gail Borden took out the first patent for the commercial preparation of unsweetened condensed milk by evaporation in a vacuum. Because of its limited keeping qualities, unsweetened condensed milk, unlike sweetened condensed milk, remained of little significance.

In 1884 the Swiss Meyenberg patented his method for sterilizing unsweetened condensed milk in tins with steam under pressure, which started the enormous development of the preparation of evaporated milk.

In contrast to butter and cheese, condensed milk and evaporated milk are manufactured mainly by big dairy factories and concerns, which often spend large sums on research and put their products on the market as branded lines. It is, no doubt, due to competitive considerations that so little has been published about this branch of dairying.

Though condensed milk is made with different milk-fat and milk-solids contents, the standards given in the table have been generally accepted.

STANDARDS FOR CONTENT OF CONDENSED MILK

Type of milk	Percentage milk-fat		Percentage milk-solids (including fat)	
	UK	USA	UK	USA
Full cream unsweetened	9.0	7.9	31.0	25.9
Full cream sweetened	9.0	8.5	31.0	28.0
Skim unsweetened	—	—	20.0	20.0
Skim sweetened	—	—	26.0	24.0

UK = United Kingdom standards; USA = USA standards.

Sometimes the statement of contents on the tin indicates the number of pints/litres of milk of standard composition which have been condensed. A dilution clause indicates the number of pints/litres of a certain standard composition (the butter-fat content of which may likewise be stated) that can be prepared from the contents of the tin.

Pre-Treatment of Milk [1]

Raw milk should meet very high requirements, particularly with regard to the stability of the milk colloids. This stability is determined by the acidity and the salt balance of the milk, among other factors. The simplest method for determining the stability of fresh milk is the alcohol test, according to which the milk should not curdle when mixed with equal parts of alcohol of 75 %-80 %. This stability, however, need not run parallel to the stability of the concentrated product, so that the alcohol test does not provide a reliable forecast concerning the heat-stability of this milk during sterilization or the tendency to age-thickening.

[1] See also chapter by Barber, page 303.

Other criteria for judging the raw supply may be flavour, aroma, and methylene blue reduction tests (recommended reduction time more than 2.5 hours). The odour and flavour should be those of natural milk: a slight feed odour is not objectionable, but there should be no odours associated with acid development. Titratable acidity should be normal for the area, the appearance should be normal (no flakes, clots, curdling, or insect parts), and " off-bottom " sediment tests should not exceed an 0.3 mg disk standard. For sweetened condensed milk, the methylene blue reduction test should have a reduction time of more than 3.5 hours, and the one-hour resazurin test should give a reading of PBP 7/5.5 or less; direct microscopic clump counts should not exceed one million per millilitre. While these standards may appear lenient in comparison with fluid milk standards, it should be stressed that the more care that is taken in the production of milk the better will be the quality of the final product.

Pre-heating

To prevent deterioration the milk is pasteurized immediately on delivery and/or cooled in anticipation of processing. Pasteurization not only reduces the bacterial count of the milk, but also must destroy pathogenic bacteria that may be present and enzymes that may cause undesirable conversions in the product.

In this connexion it may be observed that, with condensed milk, after pasteurization the concentrated product is not sterilized, as is done in the preparation of evaporated milk.

Pre-heating is not only of importance for the destruction of micro-organisms and enzymes but also affects the physical qualities of the finished product, including viscosity and stability. The viscosity of condensed milk and evaporated milk should be high enough to give the consumer a good impression of the richness of the product. [1] Further, the viscosity should invariably be the same and should not change during storage.

The tendency of condensed milk to age-thickening—that is, an increase of viscosity during storage—can be controlled by choosing the right pre-heating temperature, which should be above 80°-85°C, because only then may it be reasonably expected that most harmful micro-organisms, non-spore-formers, and enzymes will be destroyed.

In the choice of the most suitable temperature it should be taken into account that age-thickening is closely related to seasonal fluctuations of the composition of the milk. Pre-heating at temperatures above 100°C reducing the age-thickening tendency, temperatures below 100°C being no absolute safeguard. As, however, too high temperatures may cause the opposite effect—namely, age-thinning—the pre-heating temperature is so chosen that it varies with the natural stability of the milk, so that in periods

[1] In recent years some consumers have shown increasing interest in relatively thin liquid condensed milk.

of little stability higher temperatures are applied than in periods of great stability.

In the manufacture of evaporated milk several factors determine the period during which, and the temperature at which, the milk must be preheated—on the one hand, to obtain a final product with sufficient viscosity and, on the other, to prevent heat-coagulation during sterilization, so as to produce milk of sufficient heat-stability. As a rule a relatively short pasteurization at a high temperature will give a higher heat-stability than a relatively prolonged pasteurization at a low temperature. The intention is not, however, to attain a maximum heat stability, as the product would then be insufficiently viscous. Temperatures below boiling-point, for example, 90°-100°C for 10-25 minutes, as well as above boiling-point, for example, 100°-120°C for 3-10 minutes or above 120°C for half a minute and shorter, are applied. In the last few years a very short pasteurization time at high temperatures has been proposed. The finished product then has a very good heat stability but, if no special measures are taken, is seriously lacking in body.

Standardization

To obtain a concentrated product of a given composition the fluid milk must be standardized in the ratio of fat to milk-solids-not-fat desired in the finished product. One of two processes may be necessary: (*a*) the butter-fat content of the fluid milk may be too low, in which case cream is added, and (*b*) the butter-fat content of the fluid milk may be too high, in which case skimmed milk is added.

Care should of course be taken to ensure that the skimmed milk or cream used for standardization is of the same hygienic quality as the milk itself.

For standardization the following formula can be used:

$$O_s = 100 \frac{V_d \cdot D - 100\,V}{100\,V_s - V_d \cdot D_s}, \text{ in which}$$

O_s = kg of cream or skim milk to be added to 100 kg of fluid milk
V = milk-fat content (%) of fluid milk
D = solids content (%) of fluid milk
V_d = ratio of fat to milk-solids in finished product
V_s = fat content (%) of cream or skimmed milk
D_s = solids content (%) of cream or skimmed milk

Addition of sugar

Hunziker (1949) recommends a high-grade granulated sucrose for the preparation of canned goods, and is of the opinion that the presence of dextrose makes the product more susceptible to brown discoloration and age-thickening, especially at high temperatures. Kunziker states, however, that in condensed milk to be used for the manufacture of ice-cream or confectionery it appears practicable to replace part of the sucrose by dextrose.

Where reference is later made here to sugar, it should be taken to mean sucrose.

The sugar should be bacteriologically and chemically pure and should be stored in suitable packing away from dust and from the risk of insect or rodent contamination, and in dry conditions to avoid contamination and absorption of moisture.

To prevent bacterial spoilage the water in the concentrated milk should have a high sugar content. Hunziker (1949) recommends a sugar-in-water concentration of not less than 63.5 %, but remarks that this does not provide an absolute guarantee against the occurrence of certain defects caused by heavy contamination with sucrose-fermenting yeasts, moulds and other quality-damaging bacteria. For this purpose hygienic preparation, especially good pasteurization and prevention of contamination, are necessary.

Though the preserving action is better with higher sugar contents, a certain limit may not be exceeded, as the sugar may then crystallize at lower temperatures. Hunziker therefore recommends a sugar-in-water concentration of not higher than 64.5 %, which is equal to a sugar-in-condensed-milk concentration of $(100 - 31) \times \frac{64.5}{100} = 44.5\ \%$, when the product has a total solids content of 31 %.

The quantity of sugar to be added to the fluid milk may be calculated with the following formula:

$$K = \frac{D\,(100 - Dc)\,S}{100\ Dc}, \text{ in which}$$

K = kg of sugar to be added to 100 kg of standardized fluid milk,
D = solids content (%) of standardized fluid milk,
Dc = solids content (%) of finished product,
S = desired percentage of sugar in water concentration.

The sugar may be added in various stages of the process. The presence of sugar during pre-heating, however, increases the chance of age-thickening of the finished product. Therefore, the sugar may be added only at the end of the condensing process as a hot concentrated solution (60 %-80 %), which is first sieved to remove extraneous matter.

When condensed milk is prepared in bulk for industrial processing, the sugar may be dissolved in the hot pasteurized milk. As a rule the storage period of condensed milk in bulk is shorter and/or the storage conditions are better controlled than in the case of retail packings intended for domestic use.

Sometimes pre-heating is done in two stages: in the first the milk is warmed to 50°-60°C and sugar is added; when the sugar is completely dissolved, pre-heating is continued in the second stage.

Condensing of Milk

The milk is concentrated by evaporating. This evaporation might be done by boiling the milk to the air, in which case the temperature would, however, be too high. A prolonged temperature adversely affects the quality of the milk, especially when the milk is concentrated.

To meet this disadvantage and accelerate evaporation the milk is condensed under low pressure, so that it boils at a lower temperature. In itself this procedure does not effect a saving of heat. Nevertheless, evaporation in vacuum, as it is done in practice, has economical advantages, resulting from the possibility of using the exhaust steam or applying steam-saving systems.

Milk evaporation plants comprise mainly the following parts:

(1) the milk-heater
(2) the vapour-separator
(3) the condenser
(4) the milk discharge pump and the vacuum pump.

The heater

In the milk-heater the heat required for evaporation is transmitted to the milk so that part of the water can evaporate. The oldest forms consisted of a pan with a steam jacket and, later, steam coils were used. The more recently developed heaters use pipes fitted in a steam-heated body, while today heaters with plates are also in use. The condensate formed in the steam space is constantly drawn off by means of a special condensate pump.

The vapour-separator

The heat applied to the milk evaporates the water in the milk. The vapour formed is separated from the milk in the vapour-separator, where, owing to the relatively large space, the vapour has a small velocity so that small milk droplets carried along with it are not lost. The milk flows back to the heater to be heated again.

The condenser

The vapour released in the separator must be constantly discharged. This purpose is served by the condenser, which is connected with the vapour-separator by means of a wide pipe, and in which the vapour is condensed by passing through sprays of cold water (spray condenser) or by being brought into contact with cold metal surfaces (surface condenser). In the case of a spray-condenser the cooling water and the vapour condensate are discharged by means of a barometric drain (barometric condenser) or a wet vacuum pump. Also, the non-condensable gases, such as air, which get into the pan through leaks and are introduced with the milk, must be removed, as otherwise the vacuum would gradually run off.

Types of vacuum milk evaporators

Scott (1952) discusses the principle of the main types of evaporator used in the dairying industry. The type used by Borden is still employed, although in an improved form, especially for the sweetened product but also for the unsweetened product. It consists of a vacuum pan of which the lower part serves as milk-heater and the upper part as vapour-separator (see Fig. 1).

The heating surface of the heater may be a steam jacket, steam coils or milk tubes in a steam chest. The heating surface transmits the heat of the steam to the milk. As hot milk has a lower specific weight than cold milk, it will rise to the surface and here release the vapour formed. As a result of the evaporation the milk becomes specifically heavier and sinks again to be heated and to rise afresh. Against the liquid reduction resulting from the evaporation of the water, fresh milk is constantly drawn in. The solids content of the milk in the evaporator gradually rises, and this continues till the desired solids content has been reached. A disadvantage of this system is its lack of continuity, as a result of which the evaporation process must repeatedly be interrupted.

Continuous production of concentrated milk may be achieved by constantly drawing off the concentrated milk with a milk discharge pump and uninterruptedly supplying fresh milk so that the solids content remains constant. This method is seldom applied in the manufacture of condensed milk (see page 330).

In a further development of milk-evaporators specially designed for continuous manufacture, the vapour-separator is fitted next to the heater (see Fig. 2). Here the heated milk flows from the top of the heater to the separator, where it releases the vapour formed and flows back into the heater at its base, where it is re-heated, and caused to rise again. Sometimes milk and vapour are already separated in the heater and then the specifically heavier milk travels down through one or more wide pipes fitted in the heater. In this case only a small part of the milk which is carried off with the vapour reaches the separator.

The evaporators described above have a high steam consumption—namely, 1-1.2 kg of steam for the evaporation of 1 kg of water—while much vapour is carried off to the condenser. For the utilization of the thermal energy contained in this vapour several evaporators have been constructed—namely, the multi-effect evaporator, the thermo-compression evaporator and the mechanical vapour-compression evaporator.

The multi-effect evaporator consists of two or more effects and for each effect it has a heater with a separator. From the first effect partly concentrated milk flows to the second effect and from there to the third, etc. The vapour produced in the first effect is used to heat the milk in the second effect,

FIG. 1
BATCH EVAPORATOR

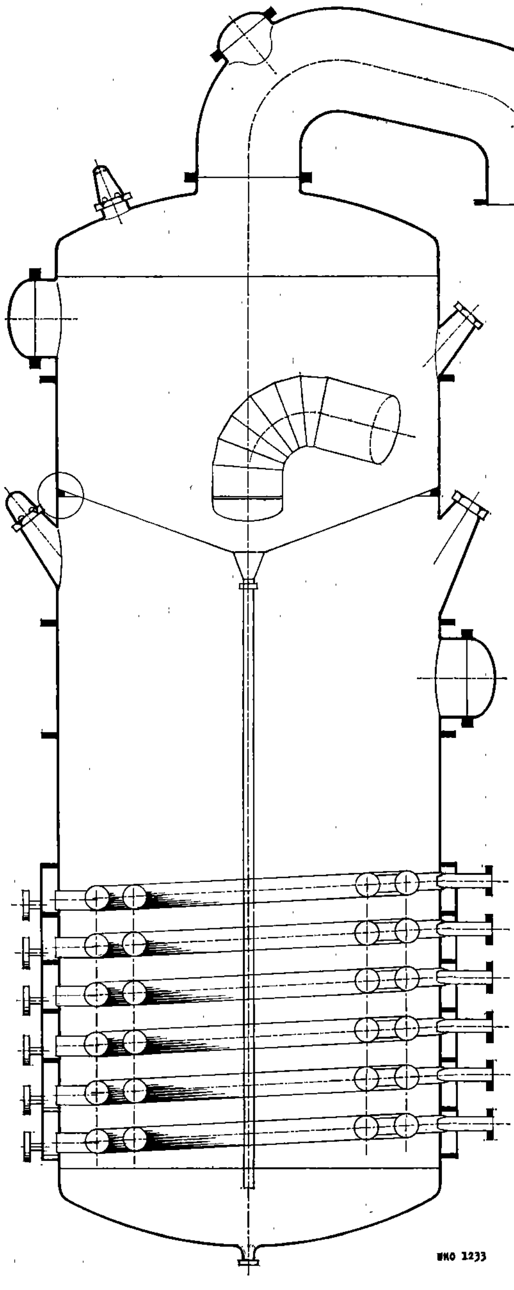
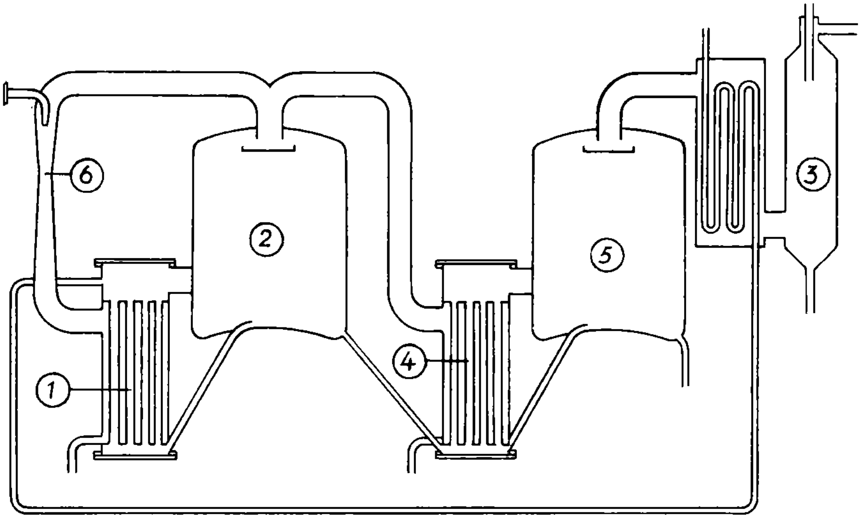


FIG. 2
TWO-STAGE MILK EVAPORATOR



1 = Heater (first effect)
2 = Vapour-separator (first effect)
3 = Condenser
4 = Heater (second effect)
5 = Vapour-separator (second effect)
6 = Thermo-compressor

and so on. As the temperature of the vapour used for heating in a given effect must be higher than that at which the milk in that effect boils, each succeeding effect of the multi-effect evaporator is operated at a lower temperature —for example, at 65°C in the first effect and at 48°C in the second. The vapour produced in the last effect is carried to a condenser.

By another system, part of the vapour is mixed with live steam in a thermo-compressor. The temperature of the vapour-steam mixture is then high enough to bring the milk in the heater of the same effect to boiling point. The part of the vapour that has not been compressed with live steam is carried off to the condenser.

For the evaporation of 1 kg of water in a double-effect evaporator or in a single-effect evaporator with thermo-compression, 0.6 or 0.7 kg of steam is required. The two systems may also be combined. The double-effect evaporator with thermo-compression is widely used. The steam consumption of this combination is about 0.40-0.45 kg. Besides a saving in steam the systems described above give saving in cooling-water because less vapour is carried to the condenser for condensation.

The vapour can also be compressed in a mechanical thermo-compressor, with which the energy applied is converted into an increase of the vapour temperature. According to this system, which can only be applied with low-cost power, all vapour is used for the heating of the milk and no condenser is needed.

All systems dealt with above involve a large liquid content in the evaporators and, in consequence, a long average stay of the milk in them. This is not the case with the falling- and climbing-film evaporators which have been constructed for continuous operation.

The falling-film evaporator has a steam chest with relatively long pipes. The milk is distributed in a special way at the top of the heater and flows down along the walls of these pipes, where it is heated and loses its vapour. A separator at the base separates the milk from the vapour, and these are then carried off. The chief characteristic of this plant is that there is very little milk in the pipes and the separator, and the milk passes through the pipes once only. The result of this is that the milk remains for a very short while in the plant. The heat economy is favourably influenced by placing more effects behind one another (see Fig. 3, 4).

The climbing-film evaporator also contains very little milk. The liberated vapour presses the milk film upwards through long narrow pipes fitted in the steam chest.

In the case of plate-evaporators the milk is heated in a plate-exchanger. These evaporators may operate on the recirculation system as well as on the single-pass principle.

Operation of the vacuum pan

The evaporator is steamed before the milk is drawn in; the condenser and the vacuum pump or ejectors are then started. When the vacuum is high enough, the milk is fed in at pasteurization temperature. When, however, the milk is pre-heated at high temperatures, for instance above 95°-100°C, it may be desirable first to cool the milk to a lower temperature. As soon as the whole heating surface is covered with milk, the steam is admitted, after which evaporation proper starts. The discontinuous method differs from the continuous one.

Discontinuous pan operation. As soon as the milk boils regularly so much fresh milk is continuously drawn in that the quantity of liquid in the pan remains the same. Normally, the total quantity of milk to be drawn in should, after concentration to the desired composition, just fill the pan. When all the milk—and, in the case of condensed milk, the sugar also—has been drawn in, condensation will be nearly completed. Boiling is continued for a short time to remove the last of the water.

By the end of the evaporation the concentration rises quickly and the product becomes very viscous, especially in the case of condensed milk. The high viscosity may cause the milk to cake on to the heating surface and give rise to super-heating. The steam pressure is therefore sometimes reduced at the end of the process, which also reduces the rate of evaporation,

FIG. 3
FALLING-FILM EVAPORATOR, THREE EFFECTS

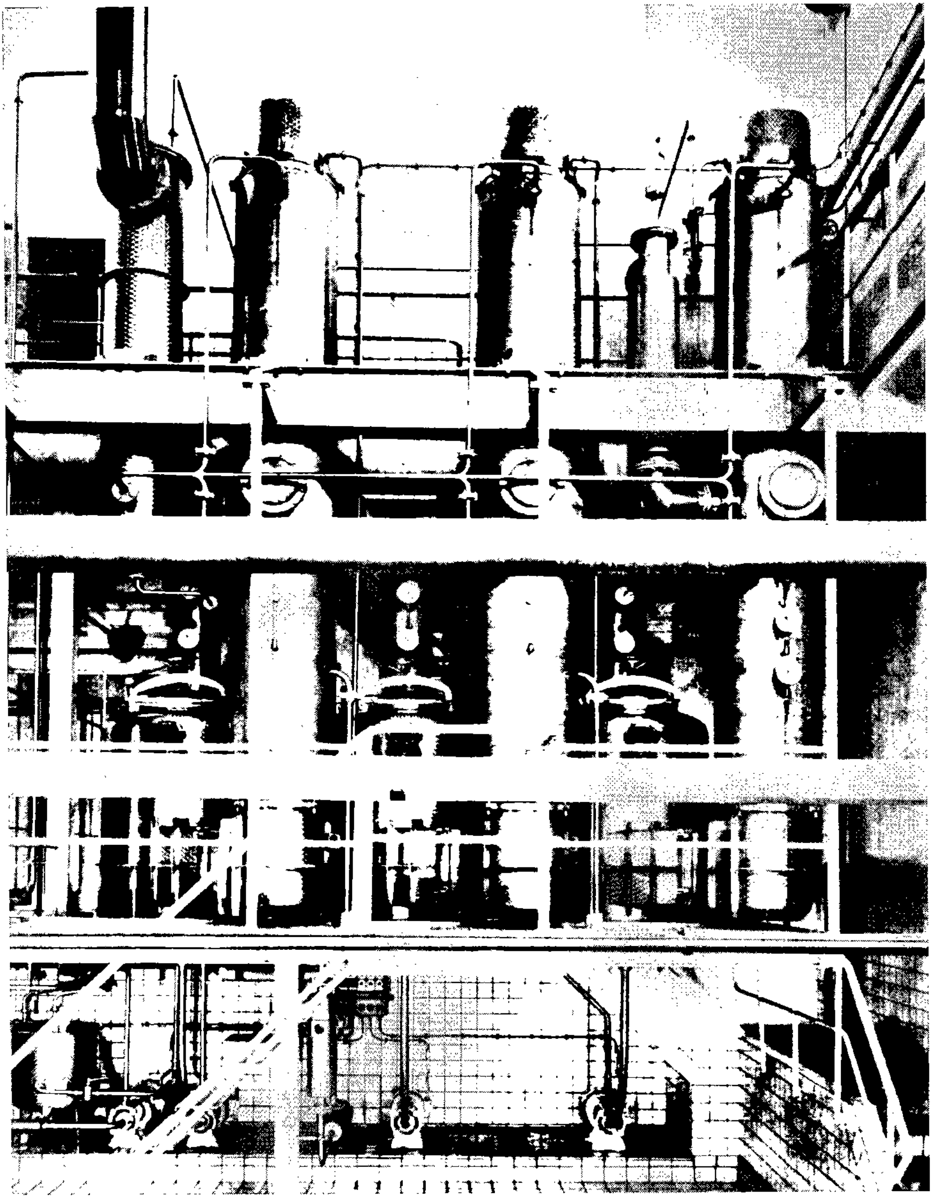
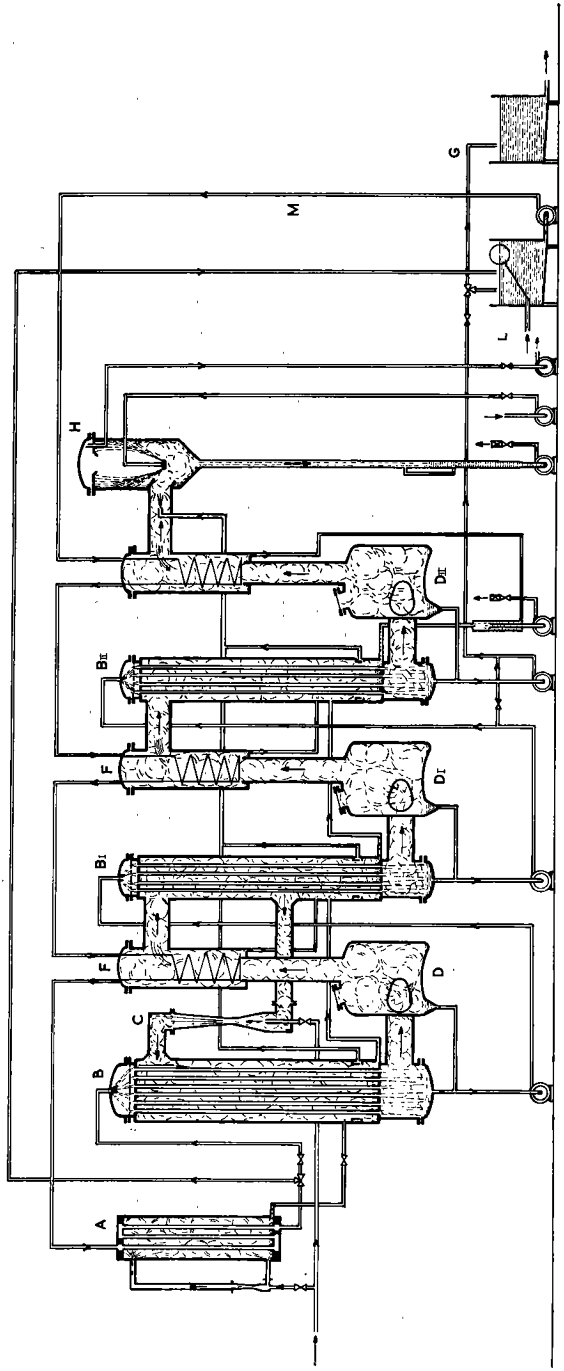


FIG. 4
CONTINUOUS THREE-STAGE FALLING-FILM EVAPORATOR



A = Pasteurizer
B = Heater (I), (II), etc.
C = Thermo-compressor
D = Vapour separator (I), etc.
E = Milk pump
F = Vapour pre-heater
G = Milk outlet
H = Condenser
I = Condensate pump
J = Waste water pump
K = Cooling water pump
L = Air pump
M = Milk inlet

and along with it the danger of over-condensing. All these factors, and especially the difficulty of concentrating to the desired solids content, make the continuous system of evaporating less suited for the manufacture of condensed milk. To turn to account here also the advantages of the continuous multi-effect evaporators, the milk is sometimes as far as possible pre-concentrated in evaporators of this type, after which it is boiled off to the desired solids content in a batch evaporator (see Fig. 1, page 328).

Continuous pan operation. Continuous operation is especially applied to evaporated milk and in the pre-concentration of condensed milk. After the milk in the vacuum pan has reached the desired composition, so much concentrated milk is continuously discharged and fresh milk supplied that the composition of the product remains constant.

Cooling of Condensed Milk

After evaporation the condensed milk should be cooled as quickly as possible, because prolonged storage at relatively high temperature promotes age-thickening and discoloration. From the bacteriological aspect, also, quick cooling is desirable. Wrong cooling may cause the product, which is smooth at first, to become sandy after 12-24 hours. This defect is usually due to the presence of big lactose crystals.

At the evaporation temperature the water in the condensed milk forms a saturated solution of lactose. When the condensed milk is cooled, the solution will increasingly become oversaturated and at a given moment crystallization of the lactose will be inevitable. When this cooling is done slowly, the excess lactose will increase only slowly and this will result in the formation of relatively few crystal nuclei, which slowly grow into big lactose crystals. Crystallization could be accelerated by quickly cooling to a very low temperature, with a consequent high degree of oversaturation, if it were not for the retarding effect of the viscosity, which increases owing to the low temperature. The optimum condition for crystallization is reached at about 30°C. Therefore, immediately on discharge from the vacuum, the condensed milk is quickly cooled to about 30°C. A small quantity (0.1 %-0.3 %) of very fine lactose crystals is added and this starts the crystallization of the oversaturated lactose. At the same time the condensed milk is vigorously stirred, which causes the formation of a great number of crystal nuclei (for a smooth product, about 400 000 per ml). During crystallization, which generally lasts at least one hour, the temperature of the moving mass is kept constant; it is then reduced to 15°C and stirring is continued for a considerable time.

The lactose crystals serving as seed material should be very fine and sharp; if they are too big they may cause the defect of sandiness. In addition, more lactose might have to be added, which would mean an increase in the total quantity. For seeding purposes, either special seed lactose or commercial lactose specially ground in a colloid mill, or a small quantity of the product that was prepared the previous day, of which the lactose has already crystallized, may be used.

Evenhuis (1957) discusses a new method by which as many crystal nuclei are added to the condensed milk as crystals are wanted in the finished product (that is at least 400 000 per ml), thus allowing the process to be independent of the formation of nuclei during cooling, and the precise method of cooling to be of less account. The crystals added should, of course, be very small (not bigger than one cubic micron). British Patents 683.007 (1952) and 696.287 (1953) give methods for the preparation of such fine seed material.

The condensed milk is cooled in batch coolers or in continuous coolers. A batch cooler consists of a cylindrical jacketed vat, containing a rotating agitator with scrapers against the side. The agitator, which can operate at various speeds, keeps the contents in violent motion and continuously scrapes the cooled milk off the wall. The rate of cooling depends on the quantity and the temperature of the water circulating through the jacket.

For large quantities tubular coolers are used, through which the milk passes under high pressure (10-15 atmospheres) and with great speed. The tubes are cooled with water. A layer of crystalline lactose settles against the wall of the cooler and inoculates the fresh milk so that separate seed material is not needed. At the end of the production the cooler is not emptied but kept filled till the next day. By re-circulation this final quantity of condensed milk is also cooled and well-crystallized. A very high initial pressure is required to pump the cold, very viscous milk out of the cooler as cooling recommences. The coating of crystalline lactose on the walls of the tubes becomes gradually thicker so that the passage becomes smaller. The cooler should therefore be emptied and cleaned regularly. After cleaning, well-crystallized condensed milk is first pumped into the cooler to provide seed material.

Combinations of batch cooler and tubular cooler are also used.

The vacuum cooler works on quite another principle. It consists of a tank with an agitator. Into this tank, which can be brought under high vacuum, a full charge of condensed milk is drawn. As a result of the high vacuum, which is maintained with a condenser for the discharge of the water vapour and usually multi-stage ejectors for non-condensable gases, the concentrated milk begins to boil. The heat required for this boiling is withdrawn from the milk itself, which cools off in consequence. The higher the vacuum, the cooler the milk becomes. When the temperature has fallen to about 30°C the milk is inoculated, and is stirred at this temperature for about 30 minutes, after which it is cooled to room temperature. With this method of cooling the milk is in violent agitation, caused by the mechanical stirring. It should be taken into account that during this boiling some water evaporates.

Standardization of the Condensed Milk

After cooling, the condensed milk is stored in tanks. At this stage it is still possible to check the composition. When the milk is over-condensed, it can be standardized by adding water. This should be done with great care so that the water is evenly distributed through the mass. If this is not done, some parts of the batch not only will have a wrong composition, but also will be more susceptible to deterioration because their sugar concentration is too low.

Standardization is also possible by mixing several batches.

Packaging of Condensed Milk

As the packaging material is relatively expensive, it would appear to be profitable to concentrate the milk to a very high solids content. This, however, has two disadvantages; in the first place, the danger of certain defects, especially age-thickening, and, in the second place, the consumer's impression that he gets less value for his money.

For the packing of condensed milk for industrial purposes use is generally made of containers of various material, such as steel drum containers with a removable end, suited for re-use.

Retail packaging is done in hermetically sealed tins which are delivered ready-made by a tinplate works, or are made at the condensed milk factory itself—this, however, pays only in big factories. Most tins used are open-top tins, the top end of which is clinched on to it after filling. The tins are filled in automatic filling machines which may have a great capacity. The fillers are generally of the plunger type, and the quantities measured by the plungers are adjustable. The tins should be filled as completely as possible to ensure that hardly any air remains. The usual quantities contained are 12 oz (340 g) for the skimmed product and 14 oz (397 g) for the full-cream product.

To prevent contamination of the milk the filling operation should take place in a separate sanitary room, of which the air should be filtered and where the temperature should be around 16°C (60°F). The tins and lids should be sterilized by means of gas-flames, superheated steam or ultraviolet radiation. After filling and closing the tins are automatically labelled.

They are then transported on conveyors which take both the empty tins to the filling machine and the filled tins to the lid-seamer, the labeller, and finally to store.

Bacteriological Defects of Condensed Milk

Since, after pre-heating, condensed milk is not subjected to any further heat treatment, the greatest possible hygiene should be observed. All apparatus and piping should be thoroughly cleaned and disinfected after every production period. The layout of pipes and equipment should be planned to avoid the occurrence of valve leakage, pockets of warm milk in the line, etc., since it is here that contamination may take place. There are many parts of the equipment that are difficult to clean, and the temperatures used in the process may cause the build-up of milk solids which become " burned-on ". Thorough rinsing of equipment with hot water, followed by acid cleaners and alkaline detergents, will do much to prevent this accumulation of solids; after cleaning, a steam treatment or a chlorine rinse (600 parts per million) helps to keep the vacuum pan in a sanitary condition. Special attention should be given to the filling machine (which may be an important source of contamination unless it is washed, steamed and dried at the end of each day's run) and to the empty tins.

In spite of the most extensive precautions, micro-organisms will occur in the finished product. Its bacteriological examination in the can is an important stage in the hygienic control of sweetened condensed milk. Cans are aseptically opened and samples are carefully taken for total, coliform, yeast and mould counts—the last three being especially important since in spoilage outbreaks it is often these types of organism which are involved. Direct microscopic examinations may be of value. (Smears are prepared from 1: 5 dilutions of the product with distilled water to avoid the risk of interference of sugar crystals in staining.) Since the product is not sterile, total counts may range from a few hundred to over 100 000 per gram and yeasts, moulds, micrococci, coliforms and spore-forming aerobes may be found. The quantity of micro-organisms present shortly after preparation may be considered a yardstick for the bacteriological effect of pre-heating and the hygiene during production. During storage the bacterial count of condensed milk may either increase or decrease· sometimes there is first an increase, which is followed by a rather rapid decrease. Besides the temperature during storage, the sugar-content of the product is important at this point—it should reach a sufficiently high level, as with a decreasing sugar content more and more groups of organisms will be able to develop with an increasing chance of defects. The occurrence of defects is, however, determined not only by the number of micro-organisms that will develop, but also by the nature of these organisms as not all species are harmful to the product.

According to Hammer & Babel (1957), who give a survey of the literature, the commonest bacteriological defects are gas formation, thickening, and growth of moulds.

Gas formation

Gas may be suddenly developed in the product—sometimes even after as little as 10 days, usually, however, after some weeks. Gas formation, which is generally caused by a certain yeast, the *Torulopsis lactis-condensi,* may be of such a serious nature that not only do the ends of the tins bulge, but the tins even burst open along the seams. The oxygen needed for the development of the yeasts is withdrawn from the head space in the tins. So, in this respect, it is necessary to fill the tins as completely as possible.

As the yeasts are generally insufficiently resistant to the pre-heating temperatures applied, their presence must be due to contamination. It has been found that sugar may be a source of contamination, especially when moist.

Growth of moulds

Like yeasts, moulds need oxygen for their growth, so that their development can be checked by lack of oxygen; a low storage temperature also has a retarding effect. Sometimes, however, mould colonies will develop (diameter 1 cm and more) which are clearly visible because the milk coagulates in such places and forms so-called " buttons ". When the moulds have lost their activity owing to lack of oxygen these " buttons " still continue to grow, owing to the activity of enzymes. They usually have a disagreeable taste, and are of a dark, brownish colour. The commonest moulds belong to the genus *Aspergillus.*

Thickening

Bacteriological thickening is generally attended with taste defects. In the literature many species of bacteria are mentioned, including cocci and spore-formers, which have been found in age-thickened milk. Except when sugar contents are low, the growing conditions are rather unfavourable and thickening will proceed slowly. Bacterial thickening may be accompanied by acid formation.

Non-bacteriological Defects of Condensed Milk

The presence of crystals

Sandiness is caused by the presence of big lactose crystals which feel sharp on the tongue. The texture of the product does not possess the required smoothness. In this case the product has not been cooled in the right way.

Sucrose crystals may also be found. In this case the watery sucrose solution contains more than 64.5 % sucrose, which may cause supersaturation and crystallization. Crystals which are too large in size will settle. This may be retarded by increasing the viscosity.

Age-thickening

Age-thickening is a very serious defect of condensed milk, by which the viscosity gradually increases till a stiff pudding-like consistency has been formed. This may happen in some weeks but also may take some years.

Age-thickening may be caused by the following factors:

(1) *The composition of the milk.* The stability of the milk, and along with it the tendency for age-thickening, depends on seasonal influences. Especially in spring, but also in autumn, the stability is low. Though the increased content of whey proteins may be of some influence here, the main cause seems to lie in the salt balance.

There is a maximum stability when there is a certain balance of calcium and magnesium bases against phosphate and citrate radicals. A change in this balance may reduce the shelf stability. Though there may be variation up and down, there will usually be an excess of calcium and magnesium. Therefore, stabilizers such as sodium citrate are sometimes added before pre-heating, the method of which affects the salt balance. From this it follows that the alcohol test on the platform is of little value for predicting the tendency towards age-thickening.

(2) *The solids-not-fat content.* The tendency for age thickening becomes greater as the solids-not-fat content of the milk is higher. Therefore, the milk should not be further concentrated than has been statutorily prescribed. Like the evaporation at high temperatures the addition of sucrose before pre-heating reduces the stability. Also an increased acidity has an unfavourable effect. Age-thickening can be reduced by storing the product at low temperature.

(3) *The pre-heating temperature.* The temperature of pre-heating is the most important factor determining age-thickening (see page 323). When this temperature is raised, the tendency towards age-thickening will decrease. Too-high temperatures, however, may cause the opposite effect—namely, age-thinning—which not only gives the consumer an insufficient impression of the richness of the product, but also increases the tendency towards the separation of fat and the settling of crystals.

Other defects

When the milk is stored at high temperatures—for example, at 30°C—a brown colour, which intensifies with higher temperatures, may develop. There will be hardly any discoloration when the product is stored at 15°C or lower.

Fat may separate when the fat globules are too big, especially when the viscosity is low.

The defect of "tallowy" flavour, mainly caused by the presence of copper in the milk, has been reduced by the use of stainless steel in the construction of the apparatus.

Homogenization and Cooling of Evaporated Milk

Homogenization

Between evaporation and cooling, the concentrated milk is homogenized in order to get such a stable dispersion of fat that there is no fat separation in the finished product. Further, homogenization increases the viscosity of the finished product, which also promotes the stability of the fat dispersion. The increase in viscosity is greater as the homogenization pressure is higher.

Homogenization of milk under high pressure may cause fat clustering, and, further, fat separation. This may be prevented by carrying out a second homogenization at a much lower pressure, which disperses the fat clusters again.

When the milk has been efficiently homogenized the fat globules will not be bigger than 2 microns. The pressure during homogenization generally varies from 175 to 250 atm.; for the second homogenization a pressure of about 50 atm. is sufficient.

Cooling and standardization

After homogenization the milk is cooled, for which by preference continuous-flow coolers are used. Before canning the cooled milk is stored in tanks with agitators. In the case of prolonged storage, relatively low temperatures should be maintained to prevent fermentative conversions in the product.

While in the storage tanks the concentrated milk can be standardized; some manufacturers over-condense slightly, after which the milk, with an accurately calculated quantity of water, is brought to the required solids content. It should be remembered that the water used for reconstituting the concentrate may be a source of contamination, causing spoilage of the reconstituted milk, even if it is held at refrigeration temperatures. Any chemical stabilizers may be dissolved in this water. Before evaporation the fresh milk should be standardized to the right ratio of fat to solids-not-fat.

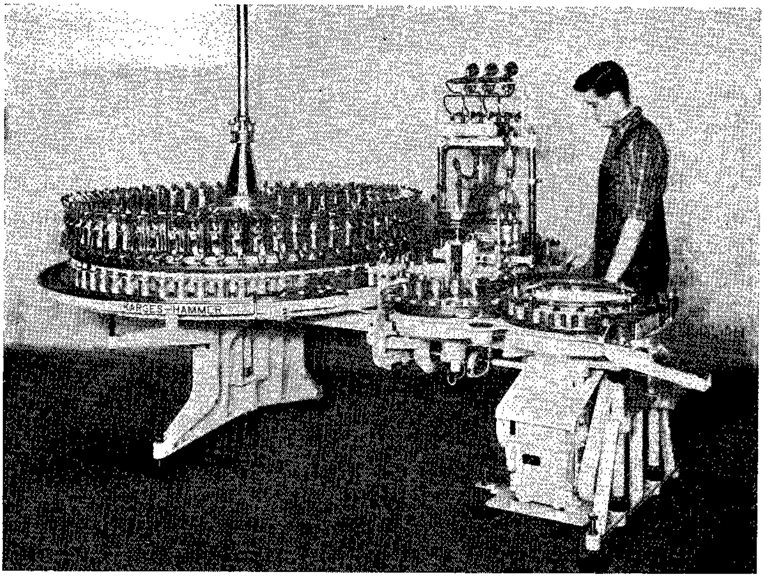
Packaging of Evaporated Milk

Most evaporated milk is packed in tins for domestic consumption; some milk is packed in glass bottles.

During sterilization there may be considerable differences in pressure between the interior and the exterior of the tin. Although in modern sterilizers these differences have been as much as possible eliminated, the tins should nevertheless be capable of withstanding changes in pressure and, above all, should be hermetically sealed.

A wide range of sizes is used in the world, the most current sizes being 14½ oz (411 g) or 16 oz (453 g). Generally the tins are of the closed type with a vent-hole, through which they can be filled, which is carried out by a fully automatic filler (see Fig. 5). The vent-hole is automatically soldered up, after which leaky tins, if any, are detected by immersion in hot water and re-soldered by hand.

FIG. 5
AUTOMATIC FILLING AND CLOSING OF TINS



Sterilization of Evaporated Milk

The object of sterilization is not only to destroy micro-organisms and enzymes but also to give the product a certain viscosity. The temperature to which the product is subjected to obtain the required viscosity is as a rule sufficient to destroy enzymes and bacteria. The heating should not be too intensive because discoloration and coagulation of the product may then occur. On an average the sterilization period should range from 15 to 20 minutes at temperatures of 115°C or somewhat higher. A usable combination is 15 minutes at 115°-116°C.

As well as the holding period—that is, the time during which the milk is at sterilization temperature—both the coming-up period and the cooling period affect the quality of the product. Usually, fixed times for the coming-up and the cooling period will also be chosen.

For sterilization both batch sterilizers and continuous sterilizers can be used. The batch sterilizers are especially suited for small factories: they can be used for tins of all sizes; in respect of filling and emptying they are labour-intensive.

The continuous sterilizers are suited only to larger factories, they are little labour-intensive, and they can be used for only a few types of tins.

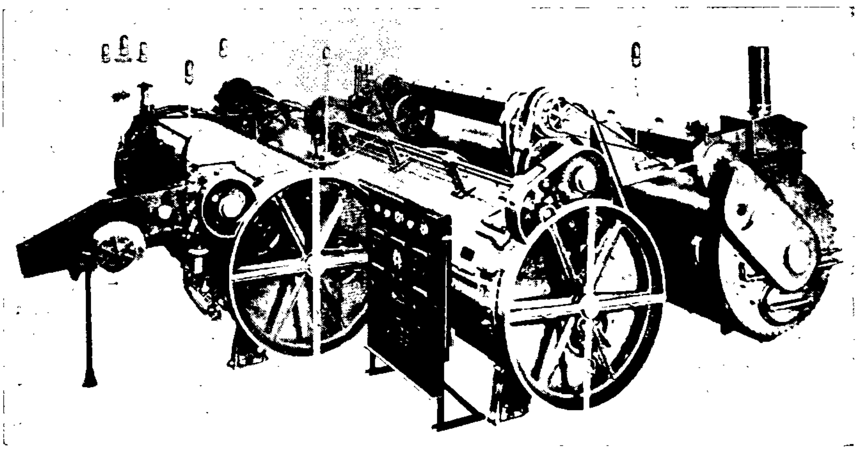
Batch sterilizers

The batch sterilizer consists of a large horizontal autoclave with a rotating frame. The tins are placed in crates which are loaded into the frame or put into it on drawers. In this sterilizer the coming-up, holding and cooling processes all take place. To achieve an even heating and cooling, the frame rotates round its longitudinal axis and the steam is introduced over the whole length of the autoclave by a tube with holes. For cooling purposes a long tube with holes is made at the top of the autoclave by which water can be sprayed. During the coming-up and the holding period the autoclave may be partly filled with hot water so that all tins are immersed once during each rotation. The number of revolutions of the rotating frame can be regulated. The rotation during the sterilization process serves not only to shorten the coming-up period, but also to subject the contents of all tins to an equal and even heat treatment.

Continuous sterilizers

A set for continuous sterilization may consist of three sections (see Fig. 6), namely, a pre-heater, a sterilizer and a cooler, the tins being moved automatically from section to section through pressure holding valves. Each section consists of a horizontal cylindrical drum in which a rotating reel

FIG. 6
CONTINUOUS STERILIZATION SET
(PRE-HEATER, STERILIZER AND COOLER)



moves the tins spirally from the entrance to the discharge end. Each tin has its own compartment so that the period of treatment is equal for all tins. After sterilization all tins may be automatically examined for leaks and underweight.

HTST-Sterilization

The natural properties of the milk are better retained with high sterilization temperatures applied during a short time than with low sterilization temperatures applied during a longer time. This knowledge has led to the application of high-temperature-short-time (HTST) sterilization, instead of the conventional practice of sterilization at about 115°C for 20 minutes.

The heat stability, i. e., the stability during the sterilization process, of the concentrated milk is better with HTST sterilization than with conventional sterilization—even to such extent that the finished product is insufficiently viscous and is thin in body and, in consequence, shows an increased tendency to fat separation. On the other hand, the shelf stability is relatively small, that is to say, gelation will occur after a short time. Advantages of the HTST sterilization are tendency towards a reduced cooked flavour and less browning.

Tarassuk (1959) describes two methods for HTST sterilization of milk, namely:

(1) in the tins at temperatures of 127°-132°C from 2 minutes to about 40 seconds;

(2) in a continuous-flow sterilizer for only a few seconds at 145°C or higher, with subsequent aseptic canning.

For increasing the viscosity of the finished product and reducing age-thickening, several methods have been proposed by which generally the sterilization period is lengthened or a supplementary temperature treatment is given before or after sterilization, for instance in the coming-up or cooling period.

Gammack & Weckel (1957) propose to keep the tins at 113°C for 10 minutes after HTST sterilization at about 127°C.

Hegarty (1958) sterilizes concentrated milk in a heat exchanger at 135°-150°C for 3 seconds, after which cooling is interrupted at 85°-92°C for so long as has been found necessary from a test. The milk is then homogenized at 245-280 kg/cm^2, cooled to about 20°C, and aseptically canned.

Although HTST sterilization is sufficient to obtain a sterile product, supplementary heat treatment is necessary to ensure a sufficient shelf stability of the finished product, which means that presumably the fullest benefit cannot be completely derived from the advantages of HTST sterilization.

Bacteriological Defects of Evaporated Milk

Evaporated milk should be sterile. If this is not the case, deterioration will set in if the conditions of life are favourable for the bacteria present in the product. Generally deterioration can be prevented by keeping the evaporated milk at a low temperature.

According to Davis (1955) non-sterility will occur mainly when the heating is not intensive enough or when tins are leaky. It may result from the application of an insufficiently intensive time-temperature combination, or from deviations from the chosen sterilization programme—for instance, temporary decrease in the sterilization temperature during the holding period. A second cause may be an uneven distribution of heat in the sterilizer, owing to which not all tins undergo the same heat treatment. The danger of this increases when HTST sterilization is applied.

When non-sterility is due to insufficient temperature treatment, thermophilic and heat-resistant spore-forming bacteria especially will develop. The principal defects that may then appear are, according to Hammer & Babel (1957) who make a survey of the literature, bacterial coagulation, gas formation and flavour defects.

Bacterial coagulation

Bacterial coagulation may be of a sweet or sour character. In the former case deterioration is caused by sweet curdling, spore-forming bacteria, such as *B. subtilis*. The coagulum formed can be digested, in which case at worst a brownish liquid is formed. At the same time a disagreeable bitter taste will occur.

Sour coagulation is caused by acid-forming bacteria, such as *B. coagulans*. The milk coagulates owing to the increased acidity. The taste is somewhat sour, sometimes a little cheesy. To this group belong the flat-sour bacteria, that is to say bacteria which make the milk sour, but form no gas and, consequently, cause no bulging.

Gas formation

This defect is generally due to spore-forming anaerobic bacteria. Usually the formation of gas is accompanied by coagulation of the milk and the development of very disagreeable flavour.

Some strains of spore-formers causing spoilage, such as the acid-forming *B. coagulans* and the gas-forming *Plectridium foetidum*, may withstand 15 minutes' sterilization at 118°C. It is thus certainly wrong, in choosing fresh milk, to disregard the bacteriological quality in favour of placing entire reliance on sterilization. Moreover, the heating will have to be the more intensive according as the initial bacterial count is higher; the utmost hygiene should therefore be observed in the factory.

Bacteriological Deterioration Resulting from Leaky Tins

Deterioration may be caused by non-thermoresistant, non-spore-forming bacteria; as a rule a mixed flora is found. Deterioration may be due to coagulation and gas development.

During cooling suitable pressure relationships should be maintained to prevent bulging of cans. If seams become weakened contamination of the final product by the cooling water may occur, for the decreasing internal pressure associated with the cooling of the can contents would draw the water and its bacteria into the can.

Although evaporated milk may be considered a sterile product, and can be stored without refrigeration for long periods of time, once the can has been opened it is as perishable as fluid milk, and unless consumed immediately it should always be placed under refrigeration. Contaminating organisms will grow rapidly in such milk and cause spoilage to take place very quickly unless it is held at a low temperature.

Non-bacteriological Defects of Evaporated Milk

Viscosity and heat coagulation

The finished product should have a certain viscosity to give the consumer an impression of the richness of the product and to prevent fat separation during storage.

Evaporation increases the viscosity, but the heaviest increase is caused by sterilization. In fact, the increase of the viscosity results from some coagulation of proteins.

This coagulation should not assume such proportions as to form a rough or grainy product or even a curd which no longer allows of dilution with water. The measure in which the milk stands up to such irreversible coagulation is called heat stability. This heat stability depends on the properties of the milk as well as the manufacturing process. Milk with an increased acidity will have less heat stability. Neutralization with sodium bicarbonate is not recommendable, as this may cause brown discoloration. Also, milk with a higher albumen content, such as that produced in the early days after calving, is more susceptible to heat coagulation. Here the salt balance also affects the heat stability; faults so originating are found especially in spring and, in a smaller measure, in autumn. As a rule the balance is disturbed by an excess of calcium and magnesium in relation to phosphate and sodium citrate. The balance can be restored by adding disodium phosphate or sodium citrate. The optimum quantity can be determined by preparing pilot experimental batches. The stabilizers can be dissolved in the water with which the milk is standardized after condensing.

Condensing and especially pre-heating usually cause the salt balance to change in favour of the phosphate. Thus pre-heating may have a stabilizing effect when there is an excess of calcium.

The more the milk is concentrated the more the heat-stability will decrease. With solids contents over 30 % it becomes more and more difficult to prevent coagulation. Also homogenization under high pressure may increase the hazard of coagulation, especially with milk of a small heat-stability, in which case homogenization at high pressure (higher than 200 kg/cm^2) should be avoided.

Pre-heating may affect the heat-stability, which is greater when pre-heating is done at higher temperature, albeit for a shorter time (see page 323). However, the heat stability may not be so great that it reduces the viscosity.

As a rule evaporated milk tends to become thinner during storage. This process is accelerated by high storage temperatures. Sometimes the viscosity increases during prolonged storage owing to gel formation.

Other defects

Fat separation may occur when the homogenization of the milk has not been carried out efficiently and/or the product is not viscous enough, which, for example, is the case when age-thinning occurs.

Brown coloration may especially occur during sterilization as a result of intensive heating; in this respect prolonged heating at a relatively low temperature is more harmful than HTST sterilization. Further, during storage a progressive darkening occurs with increasing temperature and time.

In evaporated milk a deposit is sometimes formed consisting mainly of crystals of calcium citrate and, further, of mineral salts.

REFERENCES

Davis, J. G. (1955) *A dictionary of dairying*, London, L. Hill, p. 277

Evenhuis, N. (1957) *Ned. Melk- en Zuiveltijdschr.*, **11**, 184

Gammack, D. B. & Weckel, K. G. (1957) *J. Dairy Sci.*, **40**, 1570

Hammer, B. W. & Babel, F. J. (1957) *Dairy bacteriology*, 4th ed., New York, Wiley, p. 327

Hegarty, A. (1958) *Dairy Ind.*, **23**, 3, 197

Hunziker, O. F. (1949) *Condensed milk and milk powder*, La Grange, The Author, 103, South Seventh Avenue, Ill.

Scott, J. K. (1952) *N. Z. Engng*, **7**, 325

Tarassuk, N. P. (1959) *Ned. Melk- en Zuiveltijdschr.*, **13**, 55