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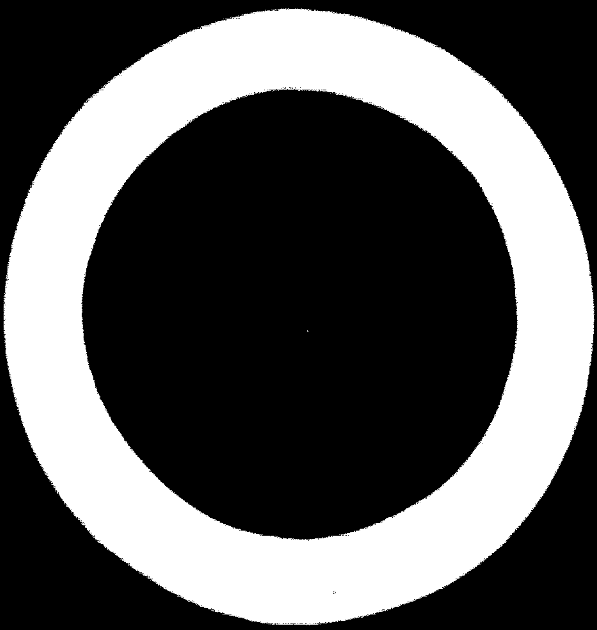
MODERN STERILIZATION METHODS FOR MILK PROCESSING

UNITED NATIONS



UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

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21 December 1970

UNIDO regrets the omission of the following acknowledgement, which is to be inserted at the end of the *Foreword* of this publication:

> The author acknowledges with appreciation the material presented on pages 11–15, 17–18 and 20–27, which has been reprinted from a series of articles entitled "Ultra-high-Temperature Processing Plants for the Production of Sterile Milk", written by Mr. H. Burton of the National Institute for Research in Dairying, University of Reading, England. The articles by Mr. Burton were originally published in Volumes 30 and 31 of the journal *Dairy Industries* in 1965 and 1966. Dairy Industries holds the copyright to this material.

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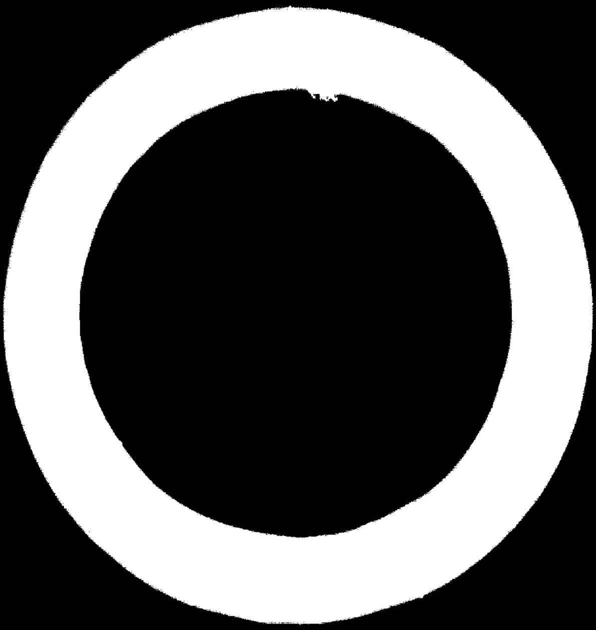

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FOOD INDUSTRY STUDIES No. 4

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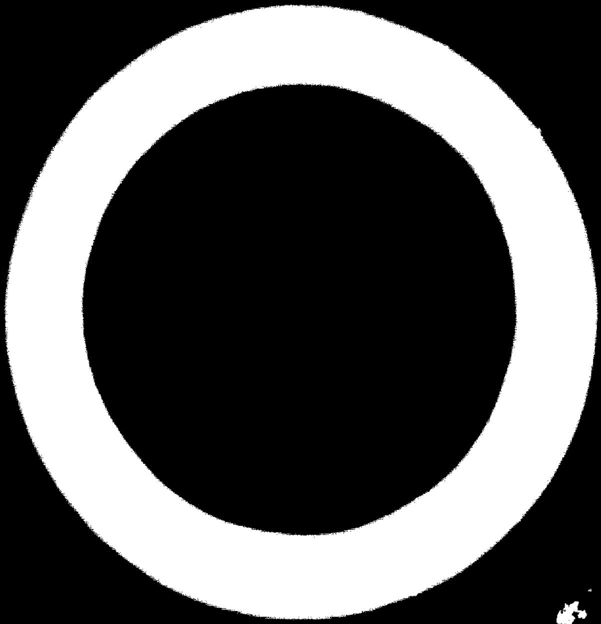
FOREWORD

This monograph is one of a series of studies designed for the use of the food-processing industries of developing countries. The approach used and the criteria followed are based on the concept that processes and techniques must be adopted that will produce goods that can compete in quality, price and reliability of supply with goods from countries whose industrialization began earlier. This concept is considered valid even when capital for investment and skilled labour may be in short supply and present markets for the products limited or even non-existent. No country, and especially no developing country, can afford to waste its resources by building industries whose products are too high in price and/or too low in quality to gain acceptability in the world market.

The objective of UNIDO in publishing this series of studies in the food-processing industry is therefore to help the developing countries to gain good technical insights into selected areas of food-processing and to avoid obsolescent procedures and processes. It is hoped that these studies will provide reliable and practical information for governmental authorities and for potential private and institutional investors.

The present monograph was prepared by Mr. Sune Holm of Alfa-Laval AB, Sweden in the capacity of consultant to UNIDO. The views and opinions are those of the consultant and do not necessarily reflect the views of the secretariat of UNIDO.



CONTENTS

Abbreviations

cm = centimetre
cm^3 = cubic centimetre
g = gram
gal = US gallon = 3.785 l
h = hour
HTST = high temperature short time
in = inch
in^2 = square inch
I.U. = international unit
kcal = kilogram calorie
kg = kilogram
kWh = kilowatthour
l = litre
lb = pound
m = metre
m^2 = square metre
m^3 = cubic metre
μg = microgram
øre = 0.01 SKr
SKr = Swedish crown = $US 0.194
ton = metric ton
UHT = ultra high temperature

INTRODUCTION

Sterilization of foods, to give them practically unlimited shelf life without cold storage, has recently become of topical interest. Because of sterilization, supermarkets became practicable, and distant places could be provided with safe, unspoiled foods. Even tropical countries can now be supplied with a large and increasing variety of processed foods.

Sterilization of food is by no means a new phenomenon. The development of the sterilization technique started during the first half of the nineteenth century in the form of heat sterilization in closed packages. Nicholas Appert (1752–1841) is regarded as the discoverer of the sterilization technique. Previously the only ways of keeping food were the natural ones such as salting, drying, fermenting, natural freezing and aseptic treatment. In 1860 Louis Pasteur successfully sterilized milk by heating it to 125°C at a pressure of 1.5 atm. Even today heat treatment is the most important method for sterilizing food so that it can be kept for long periods of time. Treating foods with ultra-violet, infra-red or radio-frequency rays, and gamma and beta irradiation have all been extensively tested, but so far no practical method has been found to replace heat treatment.

The technique of heat sterilization of milk has advanced rapidly over the years. Since Pasteur's time new forms of heat sterilization have been developed but now the following three systems are in most frequent use:

(a) *One-stage sterilization:* Warm bottles are filled with milk heated to about 80°C, capped and sterilized in an autoclave at 110–120°C for 10–20 minutes;

(b) *Two-stage sterilization:* The milk is heated to 130–140°C for a few seconds in a pre-sterilizer. After the bottles are filled the autoclave sterilization takes place at a somewhat lower temperature than one-stage sterilization;

(c) *Continuous sterilization (UHT):* The milk is heated, either by means of direct injection of steam or indirect heating, to 135–150°C for a few seconds, followed by cooling and aseptic filling of containers. There is no need for post-sterilization of the milk although pre-sterilization of the equipment is required.

The first two methods, and particularly the second, have been widely used. However, these processes result in milk that has a slightly brown colour, a strong cooked or caramelized taste and often considerable sedimentation. The third method kills bacteria before the cooked flavour and discolouration can set in, and the aseptic filling of the containers immediately after sterilization eliminates the need for further heat treatment; hence this method is largely free from the defects of the first two methods and is now regarded as superior to them.

Figure 1 shows the time-temperature curves for (A) brown discolouration, and (B) sterilization of milk. The figure shows that at 110°C the milk is sterile before it becomes discoloured. Autoclave sterilization requires heating the milk to 110–120°C for 10 to 20 minutes. This means that a sterile product is obtained that should be of normal colour. In practice it is necessary to pay attention to both heating and cooling times. For proper sterilization there must be a certain safety margin in time and this, of course, increases the possibilities of the heat-induced faults described above. This is why both one-stage and two-stage methods — which both require autoclave sterilization — result in brown discolouration of the product and a strong cooked flavour.

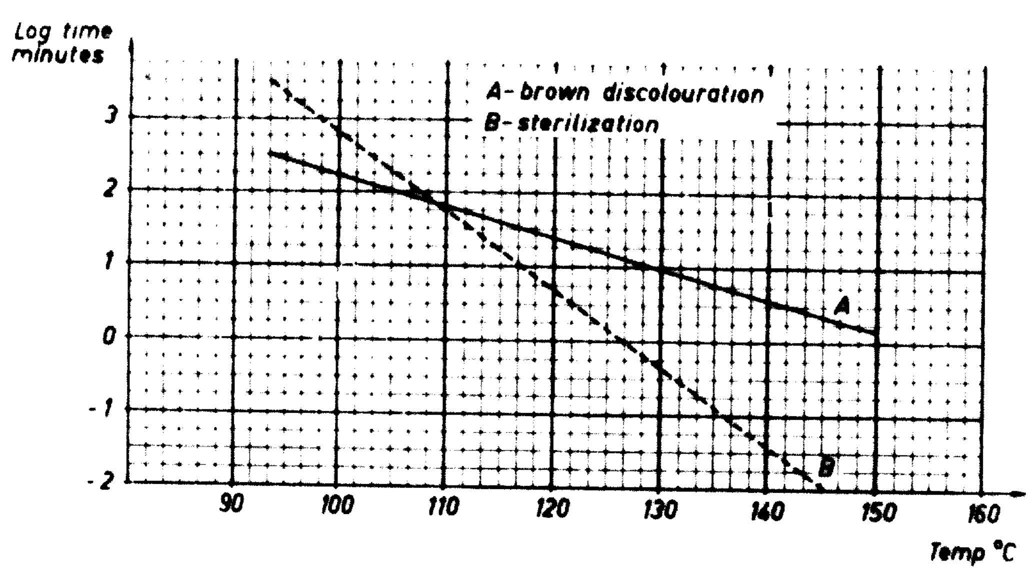


Figure 1. Time temperature curves

In studying the conditions for sterilization at even higher temperatures it has been found that the difference between the time required for sterilization and for brown discolouration increases. That is why it is more favourable to work with temperatures above 135°C. It is then possible with a wide margin to obtain sterile milk before the discolouration reaction sets in. This procedure is used today in modern plants for sterilizing milk.

Through experiment various scientists have determined the so-called temperature coefficient (Q10), which states the increase in reaction rate for a temperature increase of 10°C. Q10 for brown discolouration has been found to be approximately 2.6 ≈ 3 (Burton 1953) while Q10 for the killing of spores is said to be ≈ 10 (Rahn 1945, Clegg 1950) and recently as high as 20 to 30 (Franklin *et al.* 1958 and 1959). Thus, a temperature increase of 10°C results in a ten times more powerful killing effect of the spores but the speed of the reactions leading to brown discolouration increases only three times. For example, heating for 60 minutes at 110°C has the same sterilization effect as heating to [illegible] discolouration at 140°C is obtained [illegible] for [illegible] seconds.

Sterilization may be defined as the total destruction of all living micro-organisms and their spores. According to Swedish food regulations sterilized milk must be free from live micro-organisms. Another definition says that a sterile product must be in such a condition that changes caused by live micro-organisms do not occur during its storage.

The evidence that a micro-organism is alive is that it is able to reproduce, i.e. bacteria divide and spores grow. Such development requires a suitable environment (temperature, nutrition, water). Should the environment be less than suitable for certain micro-organisms, they will not reproduce but they can exist without being detected by normal methods. In this condition they are of no importance.

The food industry has introduced the terms "commercial sterilization" and "commercial sterility". These terms mean that a product is free from micro-organisms that can develop under the conditions normally present when the product is handled and stored. For example, thermophilic bacteria may be present but they would develop only at temperatures higher than those to which food is likely to be exposed. Unfortunately the meaning of commercial sterilization is not clearly defined. The lack of international acceptance of a sterilization standard can produce risky conditions as definitions and standards for sterilization vary greatly from place to place.

The term "free from" should also be defined. Even if one sample of a batch of milk is proved free from micro-organisms, it cannot be assumed that another sample from the same batch would be similarly free. If the requirement is that only one container out of 1,000 may be infected (i.e. that the safety margin must be 99.9 per cent), it is statistically possible to determine that 55,225 containers must be tested of which not more than 78 may be defective. It is not economically feasible to carry out such testing. Should the requirement be that only one container out of 100 is permitted to be infected (i.e. a certainty of 99 per cent), then 1,521 containers must be tested out of which not more than 22, an average of 1 in 70, may be defective.

Consequently the various definitions of sterilization and the various standards for producing a sterile product and checking the sterility of a product are causing difficulties and misunderstandings. Because of this, milk should be processed so that it has almost unlimited keeping quality from a practical microbiological viewpoint.

The International Dairy Federation considers that sterilized milk must remain stable and show no sign of bacterial development after incubation at two temperatures: 30° ± 1°C for fourteen days, and 55° ± 1°C for seven days respectively. The latter temperature can be omitted under conditions of temperate climates. The shelf life of UHT milk stored under normal conditions is from four to eight weeks or longer. Shelf life depends upon the ambient temperature among other factors.

Pasteurization and UHT treatment do not produce the same results. Pasteurization of milk produces a product that is hygienically without defect but which, as it is not germfree, must be stored in a cool place until consumed. The consumer must be supplied with pasteurized milk daily or every two or three days. In comparison UHT milk is completely sterile and therefore is not subject to bacteriological infection. If it is packed properly milk can be kept without refrigeration for several weeks, requiring fewer deliveries, which is of great importance to industrialized countries where the population is concentrated in large centres. Milk with long shelf life is particularly useful in tropical countries.

Sterilization plants are now in operation all over the world. They process mainly milk, but also other products. At first there was considerable consumer resistance to the cooked flavour of the milk, and business activity was slow. The trend was gradually reversed, however, as people grew used to the new flavour, and plants have continued in full operation and have even been able to broaden their product range. With the constant advances in technology, and given the wide acceptance and more extensive distribution of milk products throughout the world, it may be possible in the future to sterilize liquid dairy products without affecting the flavour.

GENERAL VIEWPOINTS ON MODERN HEATING SYSTEMS

As has been pointed out, the time-temperature curves of figure 1 show that heat treatment must take place at high temperatures and with short holding times to obtain optimum results. Plants fulfilling these requirements have been in operation for several years. These plants all have the same purpose to prolong the shelf life of milk with a minimum change in other characteristics.

Heating can be effected by direct steam injection or by conduction through heat-transfer surfaces, either plates or tubular. The various systems have different heat treatment efficiencies.

Indirect heating in a plate heat exchanger takes place by heat transfer from a heating agent to the liquid to be heated. The heating agent is hot water or steam. The heat passes through a plate or a tube wall, usually made of stainless steel. The flow must be turbulent. The heat quantity transferred is $Q = k \cdot F \cdot D_{tm}$ where k is the heat transfer coefficient, F the surface and D_{tm} the logarithmic mean temperature difference. The heat transfer coefficient depends on the flow rate and viscosity of the liquid and on the thickness and thermal conductivity of the plate. The transfer of great quantities of heat in a short time requires large surfaces, great temperature differences and high flow rates.

A heat transfer coefficient of 3,000 4,000 kcal/h $\cdot$ m^2 $\cdot$ °C is regarded as acceptable for heat exchangers with a heat transfer surface of stainless steel. Where steam injection is concerned, a heat transfer coefficient is not involved. However, the direct contact results in a film coefficient of heat transfer normally about 100,000 120,000 kcal/h $\cdot$ m^2 $\cdot$ °C. Rapid temperature increases are obtained by means of injection.

Figure 2 shows the temperature-time graphs for four different sterilizing plants. Graph 1 shows direct heating; graphs 2, 3 and 4 represent sterilizers with indirect heating.

The diagram shows the different holding times for the different methods. Steam injection is the gentlest heat treatment. The total heating time for temperatures over 75°C is consequently longer for all indirect heating than for steam injection.

The choice of equipment affects the final product. For example, it is necessary to choose the most gentle method of heating if a minimum of cooked flavour is desired. However, such a choice may be unimportant if a certain degree of cooked flavour is preferred or can be accepted, or if the milk is used in a flavoured product in which the added flavour dominates.

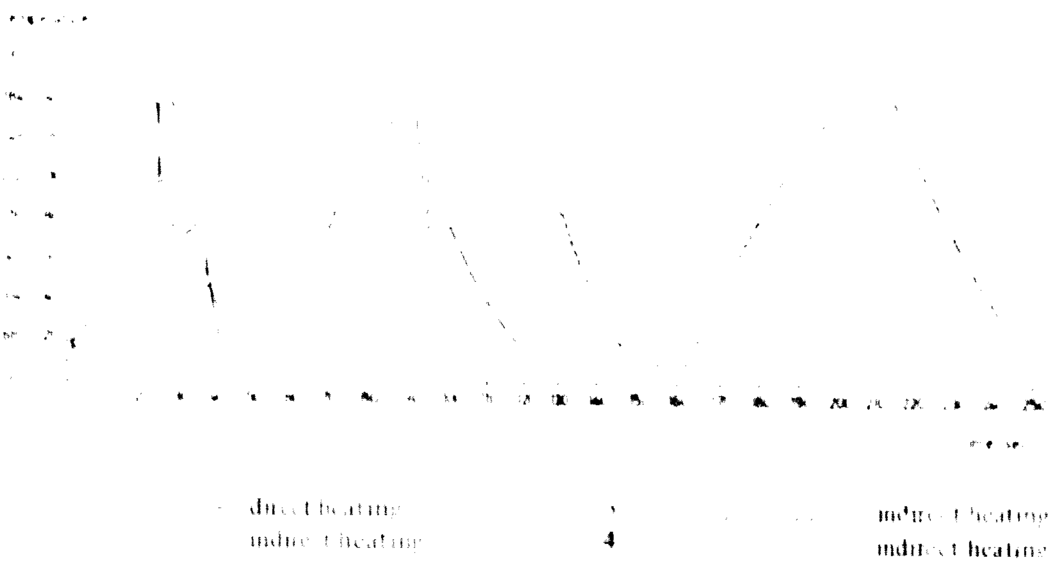


Figure [illegible] Temperature time diagram Alfa Laval

Graph 2 is from a plant using very powerful heat treatment, consequently the product will have a distinct cooked flavour. This results from the length of the holding time represented by the straight broken line. This holding time of about 85 °C acts as a stabilizer. Stabilization is desirable as it prolongs the operating time.

The direct heating method is preferable when flavour and operating times are important. An indirect heating plant can also be made to operate with short holding times. This can be carried out by special platages but often this leads to limited operating times. Some plants can be operated to only about two hours at a time. This is not practical and not necessary because intermediate cleaning is possible without its affecting the running operation of the plant. Interruption of production can be avoided only by introducing a buffer between the sterilizer and filling plant, a so-called aseptic tank.

The operating time for a sterilizer with direct heating can be about fifteen hours if the raw material is of good quality. The thermal stability must not be reduced for example by an excessively low pH or an unfavourable salt balance. A high quality of raw material is usually defined as high protein stability against alcohol. To be suitable for sterilization, milk should not flocculate at an alcohol concentration of below 75 per cent. The operating times in indirect heating sterilizers may sometimes be more limited, but it is normally possible to calculate with times corresponding to one shift.

A direct heating plant permits greater flexibility. For example, it is more suitable when used for products with different viscosities. The time-temperature graphs also show that the direct heating method permits the greatest flexibility in capacity. Capacity changes normally mean changed holding times, but as holding time for the direct method is already very short, the capacities can be changed without notable effect on the flavour of the final product. From a bacteriological point of view it is not possible to increase the capacity above the maximum calculated, as the holding time may then become too short.

Aspects of steam injection

The water balance must be maintained when the direct heating method is used. The same amount of water as was injected must be boiled off. This is easily done by adjusting automatically the pre-heating temperatures and the temperatures after the vacuum chamber. The water balance is normally checked by means of the dry matter content.

Steam to be injected directly into food must be of the highest quality. It must be clean and free from chemicals. The cleaning of steam may be effected by several methods. These are classified according to the final demands on the steam and the quality of the steam to be cleaned. The cleaning of steam is normally a relatively simple procedure.

Three different steam-purifying systems are illustrated in figure 3. The simplest is a centrifugal filter (figure 3A) that removes solid particles, water droplets and any chemicals dissolved in the water. This method is satisfactory only if the chemicals are not in a gaseous state during the filtering process. Better cleaning efficiency is obtained with an activated carbon filter in series with the centrifugal filter (figure 3B). A steam generator (figure 3C) must be used if neither of these two systems is satisfactory. It is really a boiler heated by steam. Boiler and pipes are made of stainless steel and therefore circulation cleaning with acid can take place. This eliminates the use of chemicals to prevent boiler scale. Ordinary city water is normally used. The steam generator requires a higher steam pressure from the main boiler. The pressure drop of the generator should be calculated for a pressure drop of about 4 atm in order to keep the price within reason. This means that, if the sterilizer requires a certain pressure from the boiler, this pressure should be increased by about 4 atm when using a steam generator. The efficiency of an activated carbon filter satisfies rigorous demands.

To sum up, a filter for cleaning steam for steam injection should satisfy the following demands: *(a)* separation of water droplets; *(b)* solid particles (scale, rust, boiler scale, etc.); *(c)* separation of oil; and *(d)* separation of salts.

The first two items have been fulfilled according to alternative A of figure 3. Separation of oil requires a filter with activated surfaces such as activated carbon. A steam generator can be used to separate salts, since an efficient filter is difficult to find.

Requirements regarding the feed-water for the steam generator must be set relatively high. Softened fresh water (< 0.5 German hardness degree) should be used. Condensed water is acceptable if the equipment does not contaminate the water while producing it. Condensed water containing oil, for example, cannot be tolerated. The feed-water pump should be of the centrifugal type, since piston pumps may leak oil into the feed-water.

Direct steam injection has also a legal aspect. The laws of certain countries do not permit any substance to be added to milk. Whether the methods involving the addition of water violate these regulations has been discussed frequently.

In Sweden investigations have determined that this method does not contravene the laws on additives. A similar decision has been made in most of the other countries with the same laws. The general opinion has been that the regulations have been intended only as a guard against adulteration and do not apply in this case.

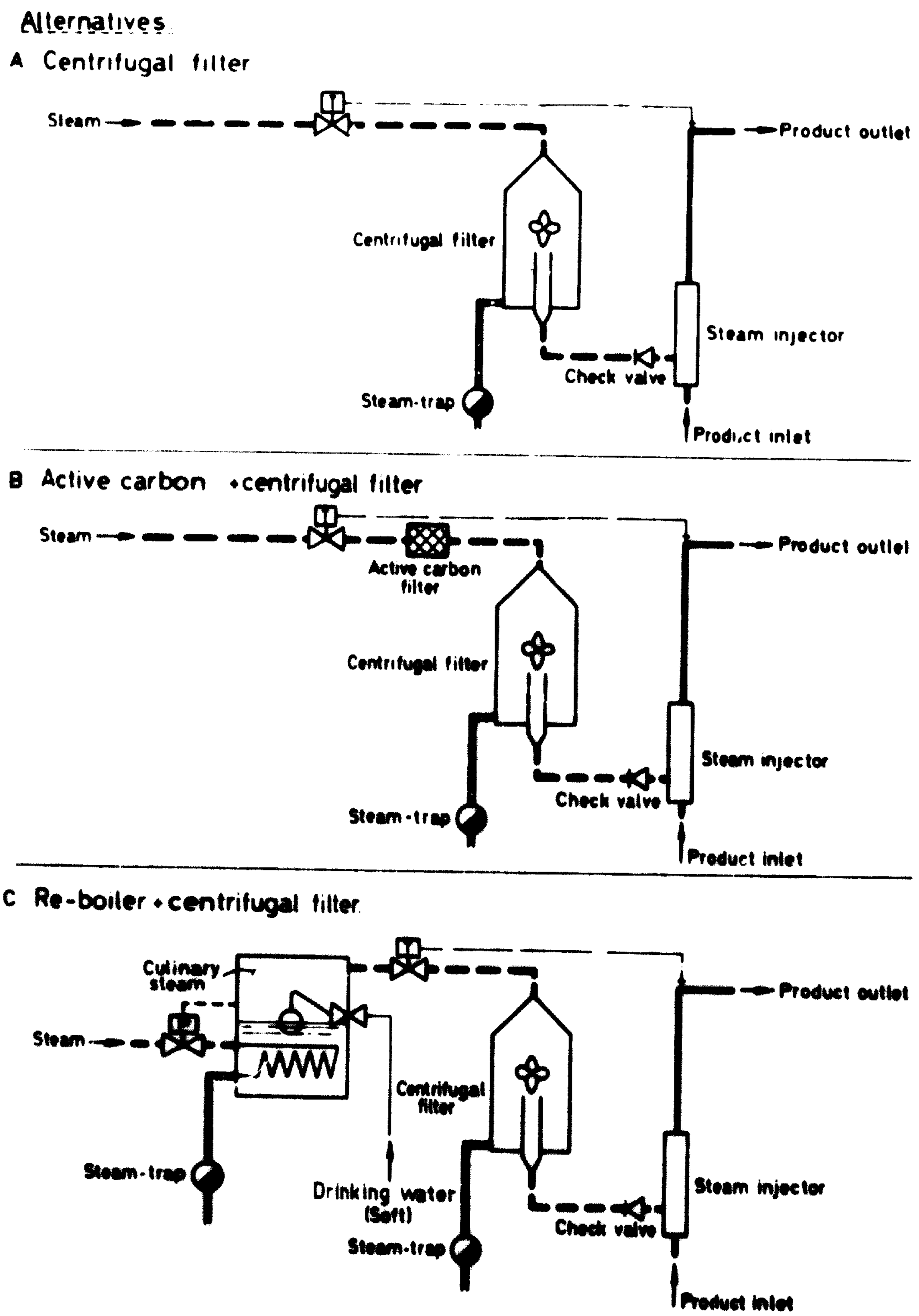


Figure 3. Steam-purifying systems

DIFFERENT STERILIZING UNITS

During the last few years a number of types of sterilizing equipment units fulfilling modern requirements have appeared on the market. They are classified below according to the different systems of sterilization:

Direct heating

(a) Alfa-Laval, VTIS
(b) Alpura (APV), Uperizer
(c) Breil and Martel, Thermovac
(d) Cherry-Burrell, I
(e) Creamery Package
(f) Laguilharre
(g) Paasch and Silkeborg, Palarisator

Indirect heating

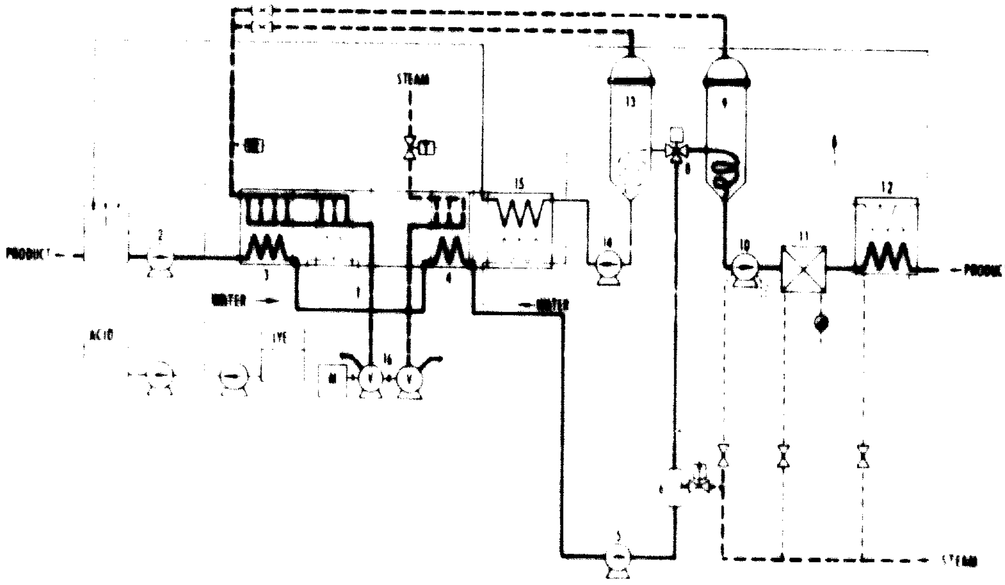
(a) Ahlborn
(b) Alfa-Laval
(c) APV Ultramatic
(d) Cherry-Burrell, II (Spiratherm)
(e) Creamery Package
(f) Sordi
(g) Stork (Sterideal)

DESCRIPTION OF EQUIPMENT

Direct heating systems

Alfa-Laval, VTIS

Figure 4 presents a flow diagram for the Alfa-Laval vacu-therm instant sterilizer (VTIS). The milk in the VTIS plant flows to a balance tank (1) from where it is pumped by a centrifugal pump (2) to two plate heat exchangers (3, 4) where it is



1	**Balance tank**	9	**Aseptic vacuum chamber**
2	**Centrifugal pump**	10	**Aseptic centrifugal pump**
3	**Preheater, condenser**	11	**Aseptic homogenizer**
4	**Preheater**	12	**Aseptic plate cooler**
5	**High-pressure pump**	13	**Vacuum chamber**
6	**Steam injector**	14	**Centrifugal pump**
7	**Holding tube**	15	**Diversion-flow cooler**
8	**Flow-diversion valve**	16	**Vacuum pump**

Figure 4. Flow diagram for Alfa-Laval vacu-therm instant sterilizer

heated by means of regeneration with steam from the vacuum chamber ( ) [illegible] by vacuum steam to 78°C. The regenerative section consequently acts as a condenser. The milk is then pumped by the high-pressure pump (5) through the steam injector (6) where steam of 8 atm heats it to about 140°C during a fraction of a second. Throttling discs at the outlets from the flow-diversion valve keep the pressure at approximately 4 atm, thereby preventing it from boiling. In the holding tube ( ) the milk is kept at 140°C for about 4 seconds and then continues through the flow-diversion valve (8) to an aseptic vacuum chamber (9). Here the vacuum is maintained at a level corresponding to a temperature of 76–77°C. In the vacuum chamber the temperature of the milk drops instantaneously to 76 or 77°C which is 1–2°C above the temperature before the steam injection. The temperature in the vacuum chamber must be slightly higher than before the steam injection, as the enthalpy of the injected steam and of the vapour are not identical. The milk which is now sterile, is pumped by an aseptic centrifugal pump (10) to an aseptic homogenizer (11) and then to an aseptic plate cooler (12) where the milk is cooled to about 20°C.

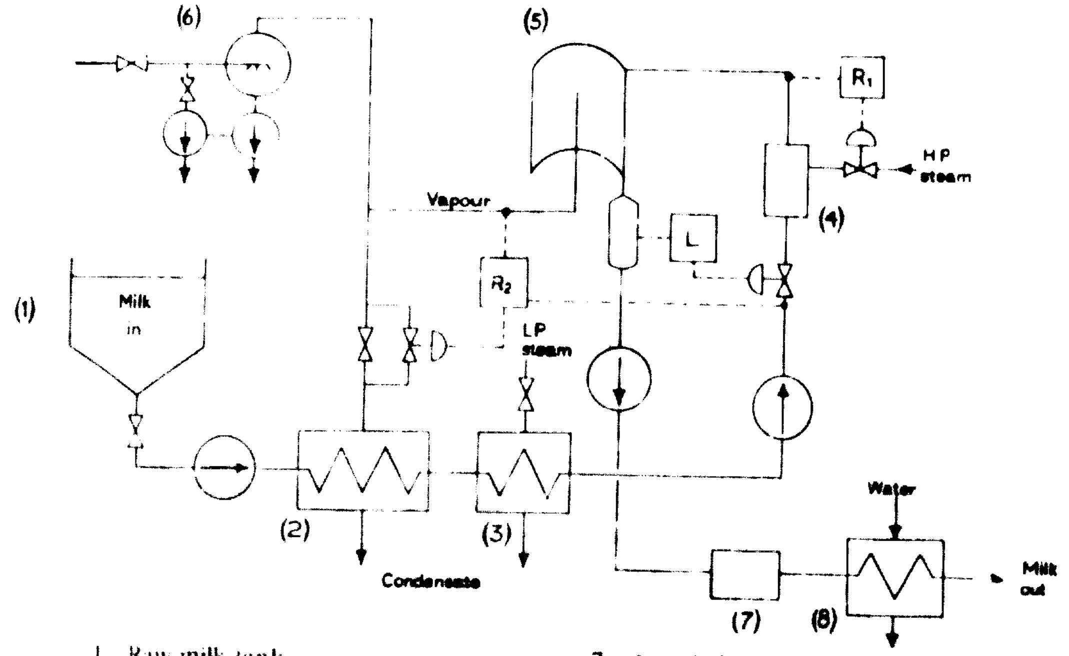
The flow-diversion valve (8) will automatically send the milk through another vacuum chamber (13) and a cooler (15) back to the balance tank.

The unit is also equipped with a complete CIP (chemical in-place) system for automated cleaning. This also includes the plant sterilization, which must be carried out prior to production and is done by steam under pressure, 130°C for 30 minutes.

APV, Uperizer

A flow diagram for the APV Uperizer is shown in figure 5. The milk is pumped from the raw milk tank (1) through two preheating stages (2) and (3), and its temperature is raised to 75–80°C. It is then pumped through the steam-injection head (4) to which steam at about 140 lb/in^2 is supplied through a control valve. The steam, in condensing, gives up its latent heat to the milk and raises the milk temperature instantaneously to 150°C. The milk temperature is determined by a controller (R_1) that operates a valve in the high-pressure steam line. The mean holding time at this temperature, 2.4 sec, is determined by the volume of the holding tube and the throughput of the plant. After the holding tube, the milk is sprayed into the expansion chamber (5), in which a constant vacuum is maintained by the water condenser and ejection pumps (6). The milk is cooled by expansion in this chamber to a temperature approximately equal to that before steam injection. If the temperatures before and after heating are related correctly, with the final temperature about 2.5°C above the initial temperature, the amount of water added as steam is exactly compensated for by that removed during cooling. Each individual plant is calibrated so that the temperature difference is correct and no change in the dry matter content results.

The vapours from the expansion chamber are used as the heating medium in the first preheater. The temperature difference is controlled by a ratio controller (R_2) that senses the difference between the milk temperature before steam injection and the vapour temperature from the expansion chamber. The vapour temperature is constant, determined by the constant vacuum in the expansion chamber, so the ratio



1 Raw milk tank
2 Preheater
3 Preheater
4 Steam injection head
5 Expansion chamber
6 Water condenser and ejection pumps
7 Aseptic homogenizer
8 Tubular water cooler
R_1 Temperature controller
R_2 Ratio controller
L Level controller

Figure 5. Flow diagram, APV, Uperizer

controller maintains a constant milk temperature before steam injection by varying the amount of vapour passing to the preheater. The second preheater is supplied with a pre-set quantity of steam at atmospheric pressure.

A pool of treated milk is held in the bottom of the expansion chamber. This pool is maintained at a fixed depth by a level controller (L) that acts as a restricting valve in the milk line before the steam-injection head.

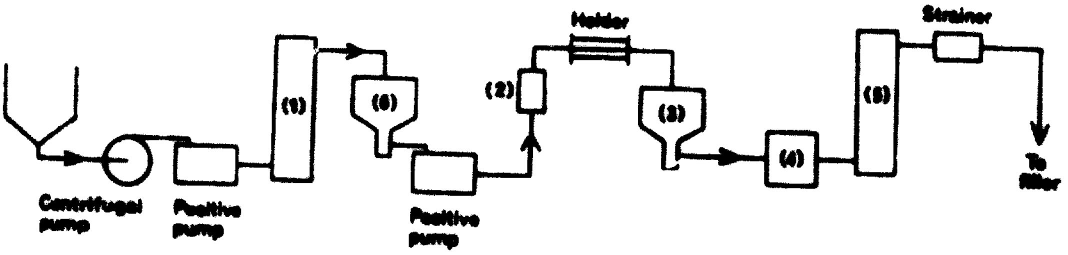
Milk is extracted from the expansion chamber by an aseptic pump and passes to an aseptic homogenizer (7) and a sterile tubular water cooler (8). The homogenizer is placed after the sterilizing process to remedy certain defects in texture that were found when homogenization preceded sterilization.

The operating temperature of 150°C gives a margin of safety for the production of milk that is sterile for all practical purposes. However, some safeguard is necessary in case the processing temperature should fall, for example, through loss of steam pressure. This safeguard is operated by the milk temperature. If it drops to 146°C an audible and visible alarm is given, but the sterilizer continues to operate on milk as usual. If the temperature falls still further, to 142°C, the raw milk inlet valve closes, and soft water is introduced instead of milk. Filling is automatically cut off after a suitable lapse of time to prevent non-sterile packs from being produced. When this second stage has started and water has replaced milk in the sterilizer, it is not possible to revert to milk flow without re-sterilizing the equipment.

An Uperizer can be cleaned by circulation. In most systems installed so far the control of the circulation cycle has been by manual operation of valves. However, plants with automatic control of the in-place cleaning cycle have also been designed. Equipment sterilizing is effected by circulation of water heated to 130°C.

Cherry-Burrell sterilizer

Figure 6 presents a flow diagram for Cherry-Burrell (direct) sterilizer. Milk is supplied by a centrifugal pump to a positive pump, which forces the milk through a plate or tubular preheater (1) to give a temperature of about 70°C. A positive pump is required to give the pressure necessary to pass the milk through the steam-injector head (2) which follows the preheater. The steam injector raises the temperature to 138–150°C according to requirements. For fluid milk, a temperature of about 145°C is recommended, with a mean holding time of four seconds. From the holding tube the milk passes into an aseptic Aro-Vac unit (3), which acts as an expansion cooler to a controlled temperature of about 70°C by control of the maintained vacuum. The cooled milk is extracted from the expansion chamber by an aseptic pump and is homogenized in an aseptic homogenizer (4). Tubular coolers (5) reduce its temperature to about 10°C for aseptic filling.



1	Tubular or plate preheater	4	Aseptic homogenizer
2	Steam-injector head	5	Tubular coolers
3	Expansion cooling chamber	6	Expansion de-aerating chamber

Figure 6. Flow diagram, Cherry-Burrell (direct)

It is normally recommended that an additional expansion chamber (6), acting as a de-aerator, should be included in the circuit immediately after the preheater (1). This de-aeration removes off-flavours and reduces the oxygen content of the milk, but its primary purpose is to reduce the amount of milk deposit formed in the steam-injection head.

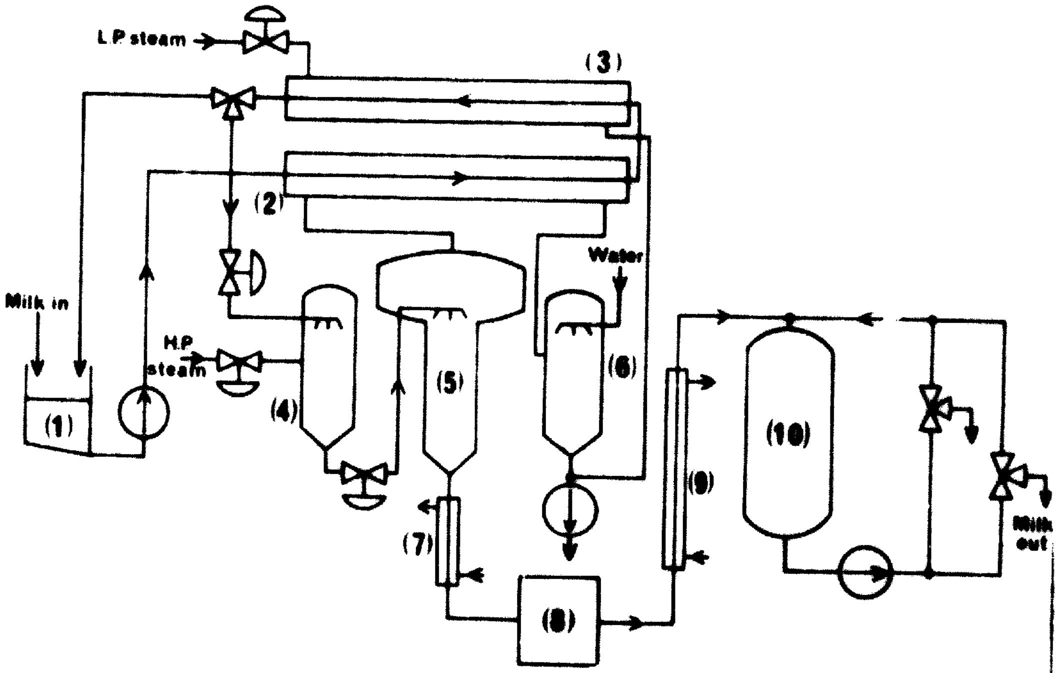
Automatic controls are normally required to maintain the processing temperature and the difference between the milk temperatures before steam injection and after expansion cooling in order to control solids content. In the United States the regulations of individual states determine the quality of steam required; it may be "culinary" steam obtained by treating normal processing steam, or steam produced from fresh water in a steam generator.

This type of direct heating equipment can deal with throughputs of 400–6,000 gal/h. The aseptic Aro-Vac is a development of the normal vacuum chamber used for de-aeration and off-flavour removal, but designed for sterile operation with steam sealing off all possible leakage points, such as sight glasses, inspection holes and connexions. If the vapours removed during cooling are to be used for preheating, the condenser is not required. Level controllers maintain a pool of the product at the bottom of the chamber by controlling either the product inlet rate or the outlet rate.

Paasch and Silkeborg Palarisator

A flow diagram of the Paasch and Silkeborg Palarisator is shown in figure 7. Milk is pumped from the balance tank (1) through the first tubular preheater (2) where it is heated by vapours passing from the expansion cooling vessel to the ejector condenser. In the second tubular preheater (3) the milk is heated by a low-pressure steam line to a controlled temperature of about 75°C and it is then injected into the heating chamber (4) after passing a three-way diversion valve. The steam pressure in the heating vessel is automatically controlled to give a temperature of 145°C. From the heating chamber the milk passes into the expansion cooling chamber (5). The temperature and pressure in the expansion chamber are controlled to give a milk temperature of a little over 75°C by varying the amount of water supplied to the condenser (6). The dry matter content of the processed milk is determined by the difference between the temperatures after the second preheater, controlled by the preheating steam supply, and after expansion cooling, controlled by the condenser water supply.

Air released from the milk in the heating chamber is extracted by a pilot line to the condenser, and then from the condenser by a vacuum pump.



1 Balance tank
2 First tubular preheater
3 Second tubular preheater
4 Heating chamber
5 Expansion cooling chamber
6 Condenser
7 Tubular water cooler
8 Aseptic homogenizer
9 Chilled water coolers
10 Sterile balance tank

Figure 7. Flow diagram, Paasch and Silkeborg Palarisator

The milk is pumped from the expansion chamber by an aseptic pump, and passes through a small tubular water cooler (7) to an aseptic homogenizer (8). The homogenizer pumps the milk through chilled water coolers (9) into a sterile balance tank (10). The air above the milk in the balance tank is kept sterile by a bacterial filter.

There is always some uncertainty as to the holding time in a plant of this kind because of the time it takes the milk to pass through the heating chamber and the presence of a pool of milk of undetermined volume at the bottom of the heating chamber. This uncertainty is minimized in the Palarisator by the use of level controllers. The homogenizer (8) operates as a pump, extracting a certain quantity of milk from the expansion chamber (5) according to the needs of the packing system. The expansion chamber is kept filled by means of a level controller, which actuates a pneumatic valve at the inlet of the heating chamber (4). The heating chamber is fitted with a second level controller, which actuates a pneumatic valve between the heating and expansion chambers. The effect of these controllers is to maintain a constant volume in both chambers, irrespective of the rate of milk flow.

If the sterilizing temperature falls 3°C below the set operating temperatures a visual alarm is given but processing continues. However, if the temperature falls 5°C below the set level an audible alarm is given, and both the pump extracting milk from the expansion chamber and the homogenizer stop so that no unsterile milk reaches the balance tank. Milk already in the tank can be filled safely, but the equipment must be cleaned and re-sterilized before being started again with milk. It is recommended that the Palarisator should be cleaned by circulating a cleaning agent through the whole equipment.

Sterilization of the equipment from the heating chamber forward to the balance tank, with the pipes to the filling machine, is by steam under pressure to give a temperature of at least 120°C for a minimum of 30 minutes.

Aspects of steam-injection equipment

Three types of steam-injection equipment are illustrated by:

figure 8 Steam-injection head, Alfa-Laval VTIS;
figure 9 Steam-injection head, Cherry-Burrell; and
figure 10 Product injection head, Palarisator.

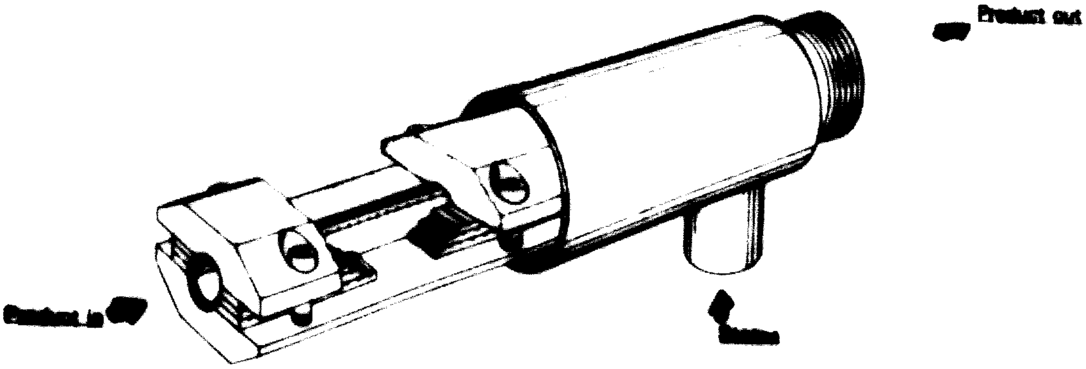


Figure 8. Steam-injection head, Alfa-Laval

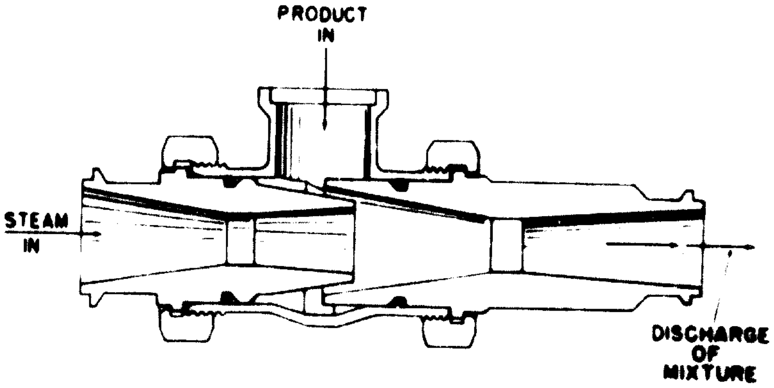


Figure 9. Steam-injection head, Cherry-Burrell

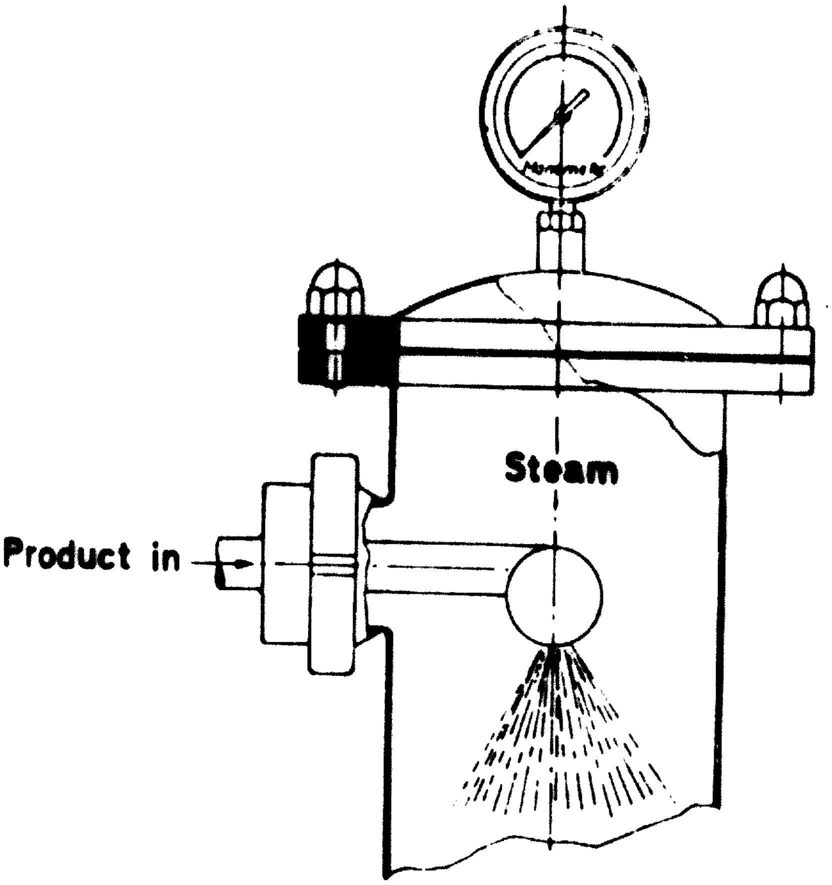


Figure 10. Product injection head, Palarisator

The three above-mentioned types of sterilization equipment all heat the product by mixing steam with it. The method of mixing varies. The two types first described (VTIS and Cherry-Burrell) inject steam under pressure through a nozzle into the milk stream. The third type, Palarisator, sprays the milk into a vessel containing steam of required pressure and temperature.

Instantaneous temperature increase is obtained in all three types of equipment. The figures show that the nozzles have been designed in different ways. The

Alfa-Laval nozzle consists of a set of "tubes". There is a large number of holes (less than 1 mm) between the tubes and the milk passes through the centre of the nozzle.

The Cherry-Burrell nozzle is of the ejector type. The milk passes through a slit where it is mixed with steam. The nozzle must fulfil the following requirements: *(a)* small drop in steam pressure, although sufficient for rapid and complete condensation; *(b)* minimum risk for burning-on to avoid reductions in the operating time; and *(c)* minimum noise level.

Rapid condensation is important in order to prevent steam and the product from becoming mixed in the holding tube which would involve the risk that the temperature reading would show the steam temperature and not just the product temperature. Consequently it is easy to be misled into believing that the product temperature is higher than it really is.

The present-day risks for burning-on are not considered great. Operating times of ten to fifteen hours can be obtained without difficulty. The quality of the raw milk is of exceptional importance and will be discussed later. The noise level is within the limits generally acceptable.

Indirect heating systems

The following sterilizers with indirect heating are described below: Ahlborn, Alfa-Laval, APV and Sordi, plates; and Cherry-Burrell and Stork, tubes (spirals).

Ahlborn indirect heating sterilizer

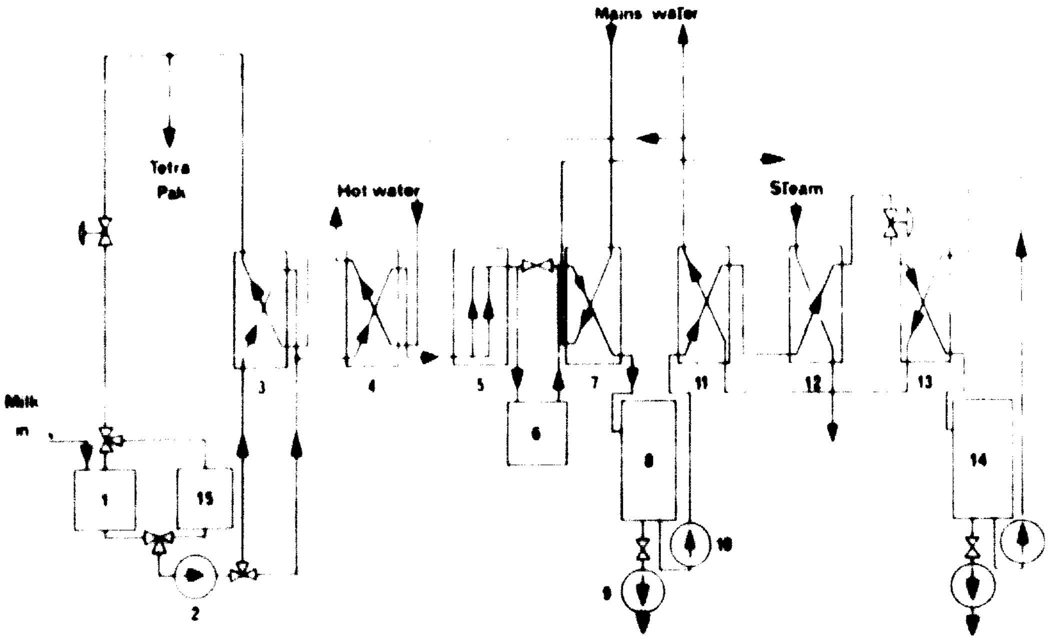
The Ahlborn sterilizer is an indirectly heated, plate-type equipment including two stages of de-aeration in the process (figure 11).

The milk is pumped from the raw milk tank (1) through a regenerative section (3) and a hot-water-heating section (4) to give a controlled temperature of 72°C. The milk is held at this temperature for 80 seconds in a plate-holding section (5) which is incorporated in the plate pack. The pre-holding treatment is intended to stabilize the milk against deposit formation. After the holding time the milk is homogenized. The homogenizer (6) does not have to be of the aseptic type, as the sterilization process comes later.

The homogenizer is followed by a de-aerator. This consists of a main water cooler (7), which discharges into a vacuum chamber (8) connected to a vacuum pump (9). At this stage the dissolved gas in the milk is removed together with some of the volatile sulphydryl-containing compounds produced during the 80-second holding at 72°C. The de-aeration takes place without any removal of water.

Milk is pumped from the vacuum chamber through a hot-water-heating section (11) and then through a steam-heated section (12) to give a final processing temperature of 139°C. A steam pressure of about 40 lb/in^2 is required in the final heating section. The milk immediately passes from the steam heating section to a second de-aeration stage, identical with that used earlier and consisting of a cooler (13) and a vacuum chamber (14). This de-aeration stage removes further volatile sulphydryl-containing compounds produced during the final heating to the full sterilizing temperature. It is said to give an excellent flavour to the milk. The temperature of the milk is reduced to 72°C in this stage.

The cooling sections (7, 13) associated with the de-aerators, and the hot-water-heating section (11), share a common water circuit, so that an indirect



1	Raw milk tank	9	Vacuum pump
2	Pump	10	Pump
3	Regenerative section	11	Hot-water-heating section
4	Heating section	12	Steam-heating section
5	Plate-holding section	13	Cooler
6	Homogenizer	14	Vacuum chamber
7	Main water cooler	15	Closed vessel
8	Vacuum chamber		

Figure 11. Flow diagram. Ahlborn indirect heating sterilizer

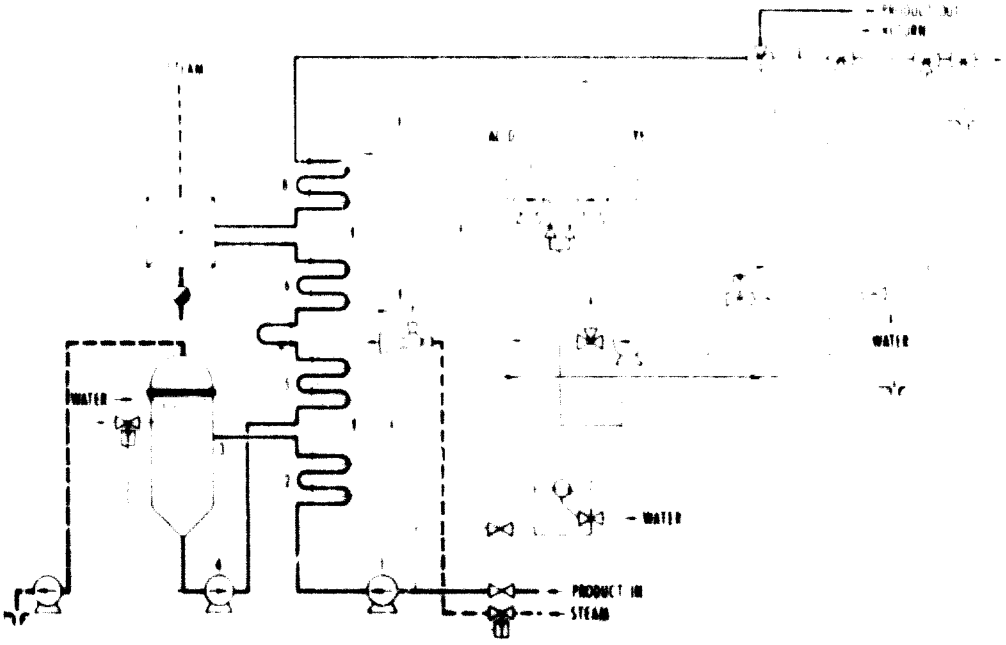
regenerative effect is obtained. The milk is finally cooled to a filling temperature of about 20°C by the incoming raw milk in the first regenerative section (3).

The temperature of the milk in the pre-holding section is controlled by a temperature-sensing element in the milk line that controls the temperature of the heating water. The sterilization temperature is controlled by a similar element in the milk line that controls the pressure of the steam for heating. The temperature to which the milk is reduced in the second de-aeration stage is automatically maintained at 72°C by control of the water flow through the indirect regeneration circuit.

The equipment is sterilized by the circulation of water under pressure. The vacuum pumps for the two de-aeration units are isolated. The regenerative section (3) and the homogenizer (6) are by-passed. The raw milk tank is isolated, and the circulation is completed through a closed vessel (15). With the water cooling circuit out of action, the whole equipment reaches the sterilizing temperature of 120°C which is maintained for 30 minutes. When sterilization is complete, the cooling and regenerative sections are brought into action, and the controller for the final processing temperature raises the temperature to 139°C. Normal circulation can then be established completely, and filling can begin. Circulation cleaning is used, with the help of spray balls built into the vacuum chambers (8, 14). No manual cleaning is necessary.

Alfa-Laval indirect heating sterilizer

Figure 12 presents a flow diagram for an indirect heating sterilizer. This system is one example of Alfa-Laval's several types of equipment in operation.



1	Centrifugal pump	4	Centrifugal pump	7	Aseptic homogenizer
2	Preheater	5	Final heater	8	Aseptic final cooler
3	De-aerating chamber	6	Aseptic cooler	9	Flow-diversion valve

Figure 12. Flow diagram, Alfa-Laval indirect sterilizer

The milk is pumped by a pump (1) to a preheater (2) where it is preheated to approximately 70°C and then flows to a de-aerating chamber (3) where de-aeration takes place. This can be considerable, as built-in condensers make possible boiling without any loss of product. By a pump (4) the milk is pumped from the vacuum chamber to the final heater (5) where it is heated to about 138°C. After being held at this temperature for approximately four seconds the milk is cooled down to about 75°C in an aseptic cooler (6) and then homogenized in an aseptic homogenizer (7). It is finally cooled to about 20°C in an aseptic final cooler (8), passes through a flow-diversion valve (9) and is finally filled.

Heating is done with water according to a particular circulation system. This means that heat regeneration always occurs between water and product and never between product and product. A product will therefore never stand still in any part of the equipment during either forward or return flow.

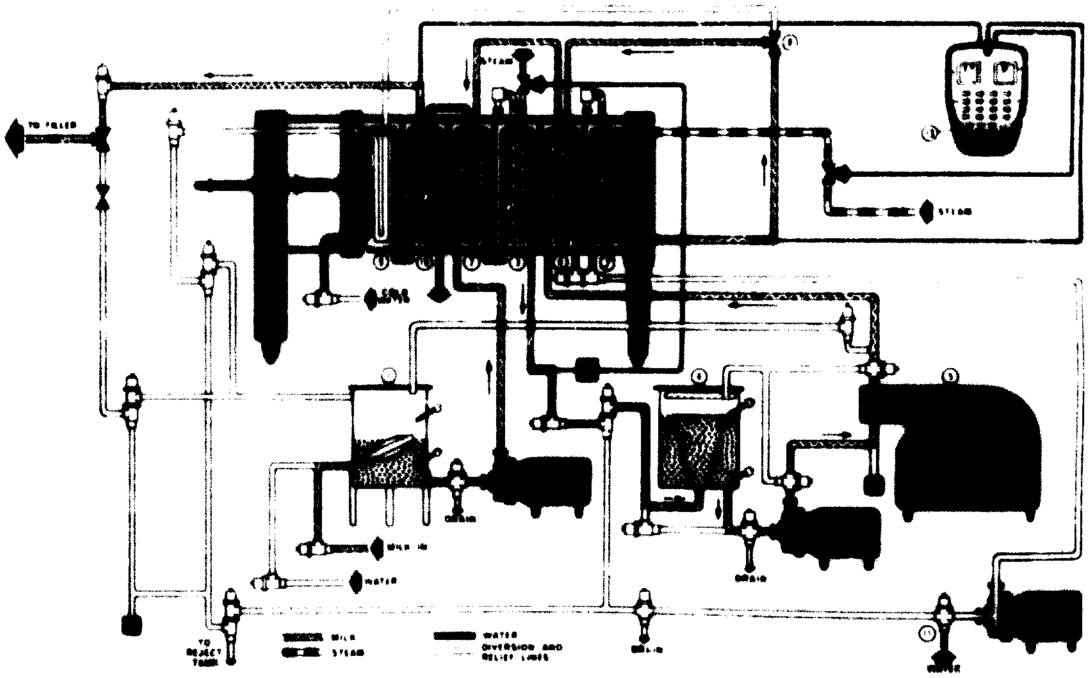
The plant is fully automatic with respect to equipment sterilization, production and cleaning. It also has an automatic supervising equipment-sterilization guard.

De-aeration takes place at 70°C and can, as was mentioned, be considerable because of flashing, which can be permitted as the built-in condensers prevent any loss of product. Any off-flavours in the raw product will then be removed. Aeration also takes place and this increases the operating time. Heat stabilization should be used if very long operating times are required; 83°C is a normal stabilizing temperature.

The equipment is built for maximum flexibility. New components can easily be added and are easily adapted as the plant is already prepared for automation. This means that the make-up of the process, to a great extent, is optional. The equipment described has no crash cooling which can, however, be easily installed if the quality of the product requires it. The automation also includes so-called intermediate cleaning, which can be carried out in a short time (about 40 minutes). Asepsis can be maintained during the cleaning process, thus permitting uninterrupted operation of the plant for long periods.

APV, Ultramatic sterilizer

A flow diagram of the APV, Ultramatic sterilizer is presented in figure 13. The incoming milk is pumped from the balance tank (1) through a regenerative section (2) and a low-pressure steam heating section (3). The steam heating section is automatically controlled by a pneumatically operated control system to give a milk outlet temperature of 85 C. The milk then enters a holding vessel (4) where it is held for a mean time of six minutes. The purpose of this holding period is to reduce the amount of milk solids deposited in the later high-temperature sections of the heat exchanger.



1	Balance tank	7	Final heating section
2	First regenerative section	8	Flow-diversion valve
3	Low-pressure steam-heated section	9	Water-cooling section
4	Holding vessel	10	Water-cooling section
5	Homogenizer	11	Water fill
6	Second regenerative section	12	Automatic control box

Figure 13. Flow diagram, APV, Ultramatic sterilizer

From the holding vessel the milk is pumped to the homogenizer (5). As the homogenizer is placed before the sterilizing section of the heat exchanger, it does not necessarily have to be designed for aseptic operation. Whether, in an indirect sterilizer, the homogenizer needs to be placed downstream from the sterilizer is still debated. Since an aseptic homogenizer is more expensive than the standard type, the APV Company installs the homogenizer upstream from the sterilizer wherever it is acceptable.

Milk passes from the homogenizer to a second regenerative section (6) and from there to the final heating section (7), heated by steam at about 50 lb/in². The steam supply is automatically controlled by a pneumatically operated system from a temperature-sensitive element in the hot milk, to give a normal milk temperature of 135°C. The element also determines the operation of the flow-diversion controller, which actuates the air-operated flow-diversion valve (8) if the milk temperature falls significantly below 135°C. Diverted milk flows through a water-cooling section (9) back to the balance tank.

In forward flow the milk passes through the two regenerative sections (6) and (2), and a water-cooling section (10) before leaving the plant at 10–15°C for filling. In a plant of this kind 80 to 90 per cent of the heat requirement is obtained by regeneration.

Although this is the standard system it can be modified if necessary. The importance of rapid heating and cooling in minimizing the cooked flavour of sterile milk has been emphasized. In particular, the denaturation of soluble proteins in the retarder vessel may cause a cooked flavour. When aseptically filled sterile milk competes with pasteurized milk and the best flavour possible is sought, it may be desirable to eliminate the holding vessel and reduce the amount of heat transfer by regeneration.

However, elimination of the holding vessel restricts the operating time, particularly with certain milk supplies, and this introduces commercial problems of plant operation.

The automatic controls built into the Ultramatic equipment are very comprehensive. The operator commences the process by pushing the sterilizing button. The equipment is automatically filled with water (11), which is circulated and heated to 145°C without cooling in a closed circuit, which includes the final heating section (7), the regenerative sections (6, 2) and water cooling section (10), the pipe to the filling machine, and the filling valve. At the same time the aseptic Tetra Pak machine (figure 18) is sterilized by its own system.

When the pre-set sterilizing time has elapsed, and if a signal has been received that the sterilizing cycle of the filling machine is complete, milk is automatically admitted to the equipment, and the controls take over the regulation of the temperature. During this time the homogenizing valves are automatically loaded. When the full processing temperature is reached, the equipment changes to forward flow from diverted flow, a small amount of milk is allowed to leave the equipment, and filling begins.

At the end of the run the operator pushes the shut-down button. The equipment is automatically emptied of milk, flushed with water, stopped and drained. If, for any reason, the supply of milk fails, this sequence will be followed and the machinery will shut down.

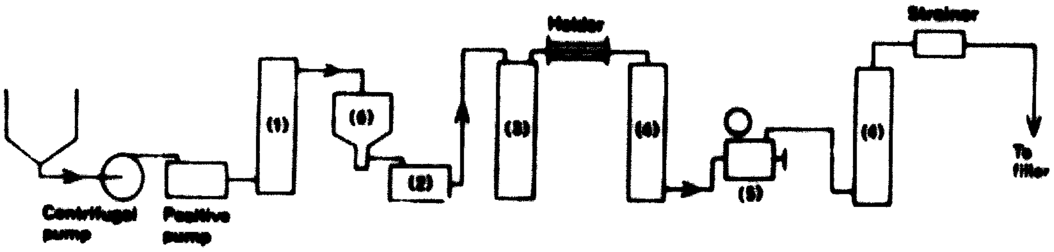
Cleaning normally involves circulation of a single detergent solution. When the cleaning button is pressed, the equipment is recharged with water, which is automatically heated to the correct cleaning temperature. An audible or visible alarm then instructs the operator to add detergent to the circulating water, although this also can be automatic if required. The hot detergent is circulated for a pre-set time. The equipment is then flushed with water, shut down and drained as at the end of a processing run.

The milk, water and detergent circuits are controlled by air-operated Zephyr valves that operate micro-switches to interlock them with the automatic control circuits. The control buttons, together with indicator lights, and hot and cold milk recorders, are mounted on a small, pedestal-supported console. The main control equipment, comprising programme controllers, timers, contactors, etc., is contained in a separate cabinet that can be mounted in any convenient place in the dairy.

Cherry-Burrell indirect heating sterilizer

Tubular heat exchangers (Spiratherm) are used for heating at temperatures above 70°C and for cooling the sterile product, as they have no gaskets and can withstand high pressures. The heat exchangers consist of spiral tubes arranged in cylindrical heating chambers. (See figure 14 for flow diagram.)

Hot water, cold water or steam may be used as the heat-transfer medium. If water is used, the cylinder is fitted with a series of baffles to direct the water flow and improve heat-transfer coefficients. For heating by steam, mean product flow velocities of 18 to 22 feet per second are used to improve heat transfer and reduce the amount of deposit formed. In the lower temperature heating sections, or the cooling sections, lower velocities of eight to twelve feet per second are adequate. The product tubes in the heat exchangers will withstand pressures up to 4,000 lb/in^2 and the heating medium shells will withstand up to 150 lb/in^2.



1 Plate or tubular preheater
2 High-pressure pump
3 Tubular heater
4 Tubular coolers
5 Aseptic homogenizing valve
6 De-aerator

Figure 14. Flow diagram, Cherry-Burrell (indirect)

The product is pumped through a plate or tubular preheater (1) to give a temperature of about 70°C. It then passes through a high-pressure pump (2), which is the pump section of a homogenizer. This provides the pressure necessary to force the product through the subsequent tubular heating sections and to homogenize the milk later if this is necessary. Tubular heater (3) with steam as the heating medium raises the product temperature rapidly to 138 150°C, and the sterilizing temperature is maintained in an air-insulated tubular holder for up to eight seconds according to requirements. The product is then cooled in tubular coolers (4) to about 10°C for aseptic filling. If homogenizing is needed, an aseptic homogenizing valve (5) is included in the cooling line where the temperature is about 70°C.

The product pressure is always maintained higher than the pressure of the heat-transfer medium in the final spiral cooler by a restriction at the sterile outlet to produce back pressure. An aseptic strainer is fitted immediately before the filler to remove any burned-on or undissolved particles.

As with the direct heating system considered above, it is recommended that a de-aerator (6) be fitted after the preheater and before the high-pressure pump. This will remove any off-flavours that are not removed in the indirect heating system during flash cooling after sterilization. De-aeration usually allows a longer processing run by reducing the amount of deposit formation in the later, high-temperature stages of the process.

In the assembly of the larger sterilizers from the component units all welded construction is employed wherever possible to reduce the risk of contamination. If connexions have to be made in the sterile line between the processing plant and the filler, aseptic connectors jacketed with high-pressure steam are used. Similarly, any valves used in sterile lines will contain high-pressure steam glands.

Sterilization of the equipment before operation is preferably carried out by circulation of water under pressure and at high temperature. A water temperature of 150°C, with a pressure of 60 lb/in^2 is recommended.

Any degree of automation can be built into the sterilizing systems described to give temperature control and recording, warning of incorrect operation and so forth. However, the amount of automation will depend on circumstances, and particularly on the throughput of the plant; too much automatic control is not considered justified economically in the small units.

Sordi, Steriplate sterilizer

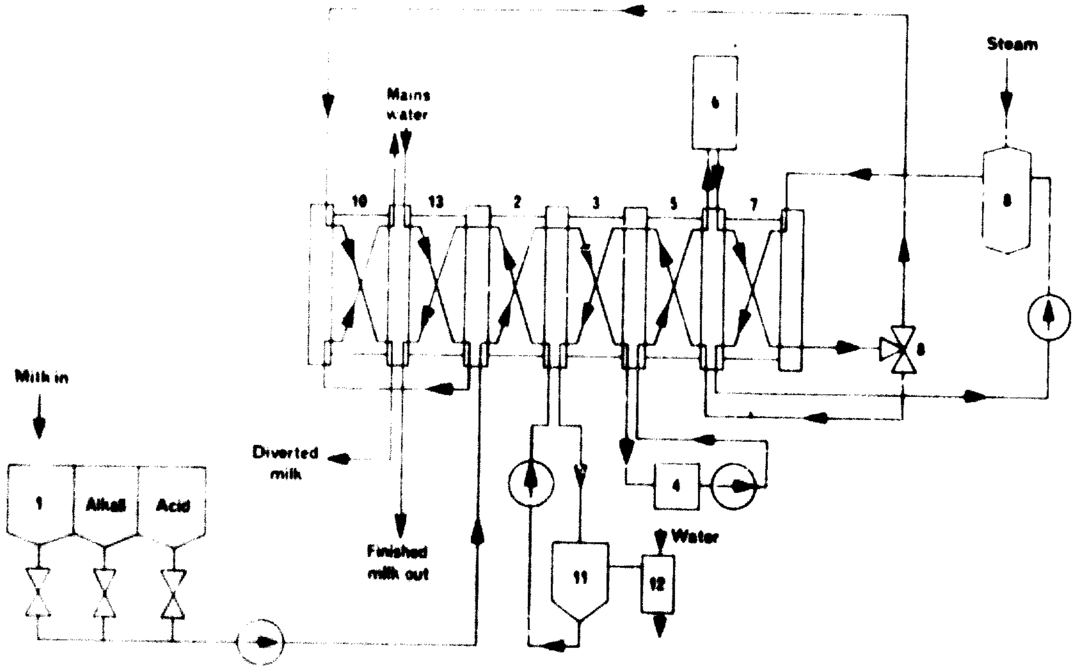
The Sordi sterilizer (figure 15) is another plate-type, indirectly heated sterilizer, with one stage of de-aeration after sterilization. The sterilizer is assembled as a compact unit, complete with its control system on a common base plate.

Raw milk is pumped from the raw-milk tank (1) through two regenerative sections (2, 3) to give a temperature of 75°C. At this temperature it is homogenized (4), and it may also be centrifugally clarified. The use of a clarifier is supposed to reduce considerably the deposit formation in the high-temperature sections. The clarifier comes before the homogenizer, which in its turn feeds the high-pressure pump, which supplies the succeeding stages.

The milk then returns to the plate heat exchanger, and a third regenerative section (5) raises the temperature of the milk to 108°C. A tubular holding section (6) allows the milk to be retained at this temperature for about 33 seconds. This holding section helps to reduce the deposit formation in the final heating section.

After the holding section, the milk again returns to the plate heat exchanger, and a final heating section (7) raises the milk temperature to 135°C. The heating medium is hot water at a temperature of about 139°C. The water is heated by steam in a heat exchanger (8) and is pressurized with compressed air at 90 lb/in^2 to prevent boiling. The temperature of the hot water is controlled by a temperature-sensitive element in the hot milk line.

A pneumatically operated flow-diversion valve (9) actuated by a temperature recorder/controller is fitted at the outlet of the final heater. If the milk is not at the required temperature, it is diverted through a water cooling section (10) and returned to a separate tank for returned milk. If the temperature is satisfactory, the milk is passed to the regenerative sections (5, 3). After two stages of regenerative cooling the milk temperature is 70°C, and the milk leaves the plate heat exchanger and passes to a vacuum de-aerator (11) in which a pressure of about 4 lb/in^2 is maintained by a water ejector (12). No water is removed from the milk during de-aeration.



1 Raw-milk tank
2 First regenerative section
3 Second regenerative section
4 Homogenizer
5 Third regenerative section
6 Tubular holding section
7 Final heating section
8 Heat exchanger
9 Flow diversion valve
10 Water-cooling section
11 Vacuum de-aerator
12 Water ejector
13 Water-cooling section

Figure 15 Flow diagram, Sordi, Steriplate

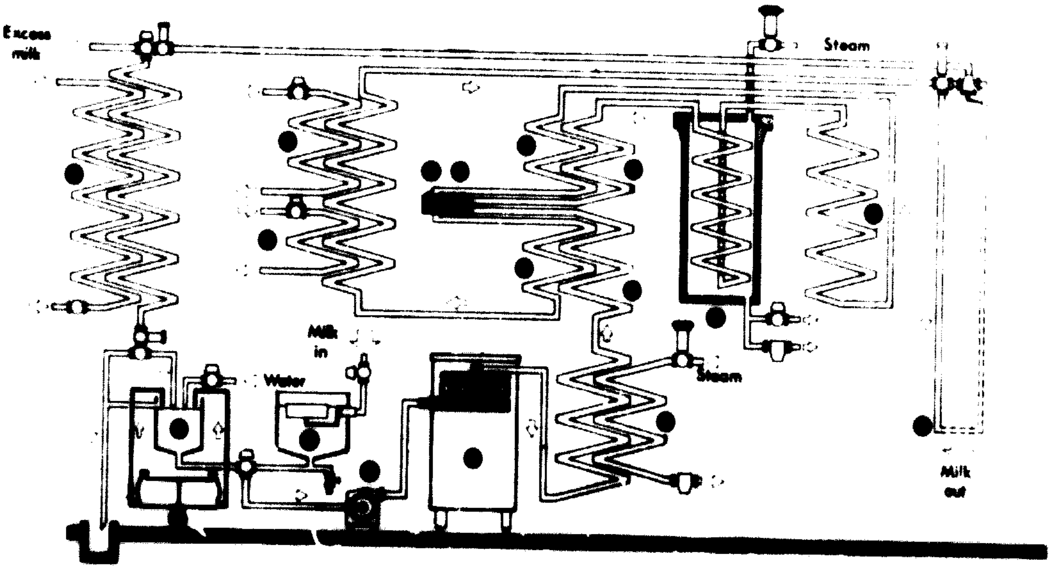
The milk is extracted from the vacuum vessel by an aseptic pump, and is pumped through a final regenerative section (2) and a mains water cooling stage (13) to give a filling temperature of 18°C. With a total of three stages of regeneration, the combined regenerative effect is about 75 per cent.

The processes of cleaning and sterilization are automatically time-controlled by a series of fourteen electronic timers. These timers operate pneumatic valves. After an initial water rinse, cleaning is effected by the circulation of alkaline solution for 40 minutes at a temperature of 80–90°C, followed by rinsing water at the same temperature running to waste, then acid for 25 minutes, also at 80–90°C, and a final hot water rinse. The alkaline and acid cleaning solutions are kept in tanks mounted with the raw milk balance tank.

Equipment sterilization is carried out by the circulation of hot water at the full processing temperature of 135°C with the water cooling sections inoperative. The sterilization circuit does not include the raw milk tank; therefore the circuit can be operated under pressure at full temperature. The cleaning and sterilizing circuits include both the forward flow and the diverted flow lines.

Stork, Sterideal sterilizer

Figure 16 shows a flow diagram for the Stork, Sterideal sterilizer. Milk enters the equipment at the float-controlled balance tank (1) and is pumped by a centrifugal pump (2) to a five-cylinder positive displacement pump (3). This is the pumping section of a homogenizer; in a normal homogenizer the pumping section delivers directly to the homogenizing valves, whereas in this case the valves are separate from the pumping section in the milk line. However, the valves are still mechanically mounted on the body of the homogenizer, or pump; they are continuously lapped and derive their oil-loading pressure in the normal way.



1 Balance tank
2 Centrifugal pump
3 Five-cylinder positive displacement pump
4 Circuit sterilizer
5 Regenerator, first heating section
6 First homogenizing valve
7 Regenerator, second heating section
8 Tubular heating section
9 Holding section
10 Regenerator, first cooling section
11 Regenerator, second cooling section
12 Second homogenizing valve
13 Mains-water cooler
14 Chilled-water cooler
15 Filling machine
16 Rinsing tank
17 Detergent feed tank
18 Auxiliary cooler

Figure 16. Flow diagram, Stork, Sterideal

The five-cylinder pump was developed especially for use with tubular sterilizers because the greater number of cylinders and the low piston speed reduce the fluctuations in the output pressure. With fewer than five cylinders, it is necessary to use air bottles to absorb the pressure fluctuations which might otherwise cause undesirable mechanical vibrations in the pipework. These air bottles are difficult to clean and sterilize and should be eliminated from an equipment intended for producing sterile milk.

The high-pressure pump (3) provides pressure to pass the milk through the remaining stages of the equipment, and to operate two homogenizing valves. First, however, milk passes from the pump through the circuit sterilizer (4), which has no function during normal operation. After the first part of the regenerator (5), when the milk is 65°C the milk leaves the regenerator and returns to the first homogenizing valve (6). The homogenizing pressure here is normally about 200 kg/cm^2 (3,000 lb/in^2), but it can be remote controlled at any value up to 250 kg/cm^2 (3,750 lb/in^2).

The second part of the regenerator (7) heats the milk to 120°C. The milk then passes to the final tubular heating section (8), where it is heated indirectly by steam to 135-150°C. The required temperature is maintained by a pneumatic control system operating on the steam inlet valve. A holding section (9) may or may not be included.

The cooling section of the regenerator is also divided into two sections (10, 11), with the second homogenizing valve (12) interposed where the milk temperature is 65°C. The maximum homogenizing pressure that can be used in this second stage is 50 kg/cm^2 (750 lb/in^2), but a minimum pressure of 5 kg/cm^2 (75 lb/in^2) is always applied during normal operation to prevent boiling of the milk at the operating temperature. The total pressure of the two homogenizing valves must not exceed 250 kg/cm^2 (3,750 lb/in^2).

Milk leaves the regenerator at about 30°C and then passes to mains and chilled water coolers (13, 14) before passing to the filling machine (15).

When the milk supply stops, the equipment is automatically rinsed with water supplied from the rinsing tank (16) through a three-way valve in the milk line. The steam supply to the final heating section, the water supplies to the coolers, and the homogenizing valve pressure are all removed at this time. On the other hand, steam is automatically supplied to the circuit sterilizer (4) so that the water temperature is slowly raised. After water has completely displaced milk and rinsing is complete, recirculation is established through the three-way valve above the rinsing tank. The water temperature is then steady at 80°C.

After the rinsing period alkaline detergent is introduced from the detergent feed tank (17) into the rinsing tank to give the necessary concentration, and is circulated. After an intermediate water rinse, nitric acid of suitable concentration follows, and finally a third water rinse. All the solutions circulated are at the steady temperature of 80°C and the circulation periods are determined by the programme timer. The machinery then automatically shuts down.

To sterilize the equipment, water heated to 140°C by the circuit sterilizer (4) is circulated through it. The sterilizing temperature is controlled by a pneumatic system operated on the steam supply to the circuit sterilizer. This temperature is maintained through the regenerative sections, the homogenizing valves, steam heating section and milk pipe lines as far as the auxiliary cooler (18), and the circulating water temperature is reduced to 60°C until the circuit sterilizer is reached again. At the same time, a throttle valve at the outlet of the auxiliary cooler is brought into action to provide back pressure to prevent boiling; in normal operation this is provided by the second homogenizing valve.

After the pre-set sterilizing time, steam is cut off from the circuit sterilizer but is applied, under automatic control, to the final steam heater. Water is cut off from the auxiliary cooler but is supplied to the mains- and chilled-water coolers. At the same time, the minimum homogenizing pressure of 5 kg/cm^2 (75 lb/in^2) is applied automatically to the second homogenizing valve. The equipment therefore settles down to circulate water under normal operating conditions.

As already mentioned, the milk sterilizing temperature is maintained by control of the steam supply pressure at the final steam heater (8). If for any reason the correct sterilizing temperature is not reached, the equipment automatically changes to the rinse position, as if the run had been completed. The full sequence of rinsing cleaning and sterilization must then be carried out before processing can begin again.

Stork has recently introduced a regulating system on the final heater that makes possible a variation of the steam supply corresponding to different capacities.

Summary of indirect heating sterilizers

The indirect heating sterilizers described above are similar in many ways but also differ in important respects. The choice of equipment depends on the demands on the final product. To obtain a minimum of cooked flavour, the platage of the plate heat exchangers should be calculated for short holding times. Heat stabilization can be introduced if long holding times are required, but this causes a cooked flavour.

General equipment for sterilizers

Aseptic homogenization is used in nearly all types of equipment (direct and indirect heating) to obtain an effective splitting of the fat globules. Homogenization by the high-temperature treatment has a splitting effect also on denaturated protein (sediment). Aseptic properties are normally maintained by means of a double steam seal for the pump pistons. The seals are made of teflon rings and the pistons are hard chromed in order to resist corrosion. The homogenizers are normally made for a working pressure of up to 300 kg/cm^2 (4,300 lb/in^2) in two stages. All sterilizers are made in standard sizes 2,000, 4,000 and 6,000 litres per hour. The multiple 2,000 corresponds to the capacities of a one-half litre aseptic filling machine.

The mounting of equipment varies considerably. There are compact units such as Alfa-Laval VTIS and Sordi Steriplate in which all components are assembled in a single unit on a main frame. The entire machinery is consequently assembled at the factory, where it can be tested before delivery and then shipped as a complete unit. Mounting in the dairy will then include only connexion of steam, electricity, water and air.

Other types of equipment are floor mounted, but some of them (e.g. Alfa-Laval indirect) are composed of complete blocks that are made ready at the factory and have only to be joined and connected at the dairy. From the point of view of mounting, the compact units are preferable. Transport problems are the only disadvantage.

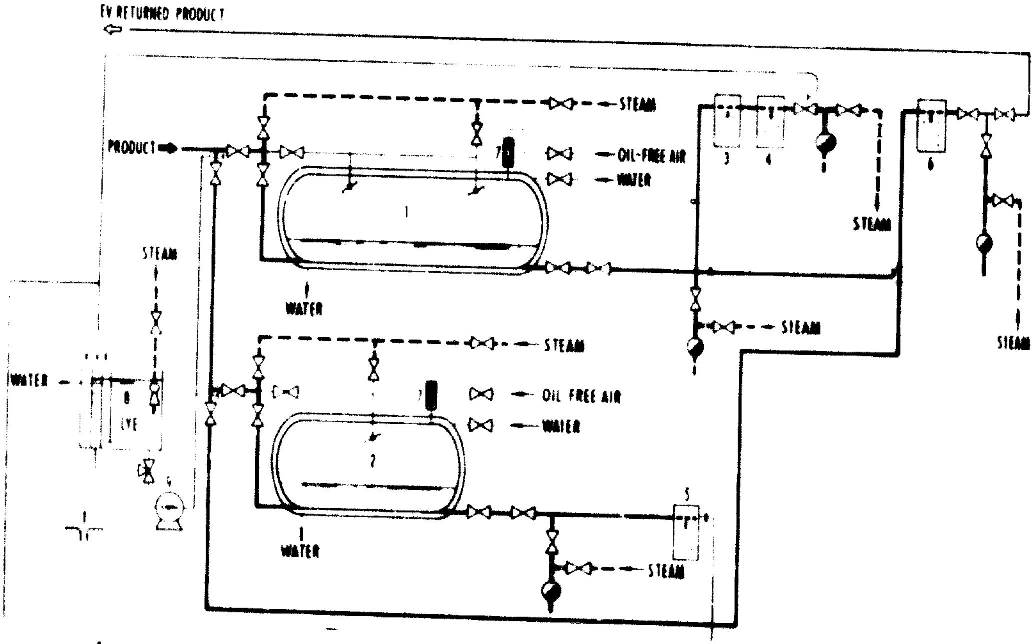
Flexible capacity is a novelty. The homogenizer has previously been the restriction, but it can now be provided with either pre-set speeds or with variable speed transmission. The capacities can then be varied according to changes in the filling department; however, changes in the holding time cause uneven product quality. This may be corrected by changes in the heating section (e.g. in the steam section). The Stork, Uperizer and Alfa-Laval sterilizers, among others, can be delivered with variable speed homogenizers. The variable speed systems may be hydraulically operated or operated by thyristors.

INTERMEDIATE ASEPTIC TANK

General description

An aseptic tank is increasingly regarded as a necessary and integral part of sterilization. Installation of such a tank is a complicated operation, since there must be a guarantee that it will operate under aseptic conditions. The construction of an aseptic tank must therefore be extremely exact. The tank must be pressure resistant in order to stand up to equipment sterilization (approx. 2.7 kg/cm^2 = 38 lb/in^2). It must be fitted with an aseptic air filter, which guarantees that oil-free air is sterilized. The air is used to force the milk out of the tank.

The valve programme on inlets and outlets is arranged so that there are always two seals with a steam seal in between when a sterile product is shut off against unsterile atmosphere. Figure 17 shows how an Alfa-Laval aseptic tank system with



1 Aseptic tank
2 Aseptic tank
3 Aseptic filling machine
4 Aseptic filling machine
5 Aseptic filling machine
6 Aseptic filling machine
7 Sterile air filter
8 Cleaning unit
9 Centrifugal pump

Figure 17 Alfa-Laval aseptic tank installation two aseptic tanks (1 and 2) is installed. They are each separately connected to aseptic filling machines (3, 4, 5 and 6). Each tank has a sterile air filter (7). This special installation is made for production of three different products from one sterilization plant. The tank installation makes it possible to fill three products simultaneously in different filling machines.

Justification for installing aseptic tank

The aseptic tank is used for the following purposes:

(a) Levelling out the operating times. Cleaning the sterilizer takes longer than cleaning the tank and filling the equipment: the filling time can therefore be extended.

(b) Storage when an interruption in the filling department occurs. The sterilizer continues to deliver a product of the same quality and with unchanged capacity to the tank while the defects in the filling department are corrected.

(c) Intermediate cleaning of the sterilizer, which has a higher capacity than the filling department. Filling can take place continuously also when the sterilizer is being cleaned.

(d) Sterilizing different products in succession when different filling machines are used for the different products.

(e) Long-term storage of a sterile product.

STERILIZED MILK CONTROL

Raw milk control

The most important demand on raw milk is stability during sterilization. From a chemical-physical point of view the stability of the milk protein must be such that it resists an alcohol concentration of about 75 per cent.

From a bacteriological point of view there must be no spores that resist the sterilization temperature. There is no known method for determining this rapidly. However, spores that can resist sterilization temperature are very rarely found in milk.

Sterilizing effect

Testing the effect of sterilization directly through storing containers from the commercial operation of a plant creates great difficulties, and the results are difficult to interpret, since infections irrelevant to the sterilization process may occur during filling. A special method is used therefore to test the sterilizing effect of a sterilization plant.

The sterilizing effect expressed as a logarithmic reduction is:

$$SE = \log \frac{\text{initial spore count}}{\text{final spore count}}$$

Large amounts of spores of some suitable type of bacteria are usually used for direct determination of the effect. Tests are made using a series of falling temperatures. Spores are more difficult to kill than living cells, and the great number used facilitates the determination of surviving spores at a certain temperature.

B. subtilis and *B. stearothermophilus* are used as test organisms. The former are the most common spore-formers, and the latter are extremely heat resistant. It takes 175 times longer at 120°C to kill 99 per cent of the spores in a *B. stearothermophilus* suspension than 99 per cent of the spores in a *B. subtilis* suspension.

Table 1 shows the results of a test with Alfa-Laval VTIS using milk as the sterilized medium and with spores of the two above-mentioned types as test organisms. The sterilizing temperature has been allowed to drop from 140°C to 120°C. The number of spores in the different tests has varied between 10,000 and

TABLE 1. EFFECT OF STERILIZATION EXPRESSED AS LOGARITHMIC REDUCTION OF SPORE COUNT

	B. subtilis			*B. stearothermophilus*		
Ster. temp. °C	*Initial spore count per* cm^3	*Final spore count per* cm^3	*Log. red.*	*Initial spore count per* cm^3	*Final spore count per* cm^3	*Log red.*
140	450,000	0.0004	9.0	10,000	0.0004	7.4
135		0.0004	9.0		0.0004	7.4
130		0.0007	8.8		0.45	4.3
125		0.45	6.0		2.5	3.6
135	4,000,000	0.0004	10.0	250,000	0.0004	9.0
130		0.0004	10.0		0.095	6.4
125		0.04	8.0		2.5	5.0
120		4.5	6.0		2.5	5.0
135	75,000,000	0.0004	11.0			
130		0.025	9.5			
125		4.5	7.2			
120		9.5	7.0			

75,000,000 per cm^3. The lowest spore count that could be determined was 0.0004 per cm^3 (approx. 1 spore per 2 litres). The results show spore-reduction figures of 9 and more for *B. subtilis* and 7 and more for *B. stearothermophilus*. These spore-reduction figures are very high and are quite safe.

There are not as many spores in ordinary milk as were used in the test and vegetative cells found in milk are much easier to kill. A determination of the required sterilizing effect for milk will show a spore reduction figure of at least 7, if possible 8, for the types of spores found in milk (principally *B. subtilis*). The sterilizing effects found consequently have a wide margin; all vegetative cells have also been killed.

Chemical changes and taste

Heating of milk brings about chemical changes of its components. Milk consists mainly of fat, protein, carbohydrates, salt and vitamins. Some enzymes are also found in milk. Salts and carbohydrates are molecularly dissolved in the aqueous phase while protein and fat are found in the form of colloidal solutions or emulsions.

The following reactions can happen within the sterilization zone, that is when heating milk to a maximum of 150°C for a relatively short time. The reactions that may occur where fat is concerned are decomposition of free fatty acids and primary and secondary oxidation. These are of minor importance at the time-temperature combinations in question. However, the protein may undergo decomposition during the above reactions with a result of ruptures of secondary bonds and changes of the molecular structure. To begin with the reactions show up as a change in the solubility and later in the sedimentation. Proteins can also react with carbohydrates, which means that aldehyde groups react with amino groups. This is called Maillard reactions. The non-enzymatic brown discolouration is also important for the carbohydrates. In principle this corresponds with the Maillard reactions (see figure 1).

Chemical changes are checked with suitable analyses. The protein denaturation can be followed by examining the amount of soluble nitrogen, the protein decomposition through determining non-protein nitrogen (NPN), the cystine decomposition through determination of SH-groups, enzyme decomposition through determining the enzyme activity, and Maillard reactions through determining remaining NH_2-groups, etc.

After treatment in a modern sterilization plant milk has a very faint cooked flavour and differs slightly from pasteurized milk. The taste of the milk from different plants varies a little and milk treated in plants using the direct heating method usually has a slightly less cooked flavour. The flavour comes from sulphur compounds freed from sulphurous amino acids. However, these compounds tend to prevent oxidation, and the associated harmful effects. It is possible to determine analytically that the sulphydryl groups disappear gradually during storage. The cooked flavour then also disappears. Optimum taste is normally obtained after two to three weeks depending on storage conditions.

Another taste deficiency sometimes is the so-called chalky taste. This may vary from plant to plant but it seems to be directly connected with the quality of the raw milk.

Nutritive value

During heating there may be changes in essential amino acids that affect the nutritive value, for example, decomposition of lysine. Sulphurous amino acids such as cysterin and metionin can decompose, producing changes in taste as well as in nutritive value.

Some investigations and experiments seem to show that it is mainly the vitamins that are affected by heat treatment. Nevertheless, the conclusion may be drawn that UHT-treated milk is equivalent in value to pasteurized milk. Most investigations indicate that UHT-treated milk is definitely superior to milk that has been sterilized in bottles with respect to vitamins and nutritive value.

A great number of investigations have been carried out regarding the effect of heat treatment on the nutritive value of milk. Interest has been directed mainly at pasteurization and sterilization of market milk. Earlier investigations were concerned only with autoclave sterilized milk as compared with HTST- (= approx. 72°C/15 seconds) treated milk and untreated milk. Later when UHT- (= 140–150°C/2–4 seconds) treated milk became available on the different markets interest was directed towards these products. When studying investigations of the nutritive value, autoclave-sterilized and UHT-treated milk must be considered separately, since autoclave sterilization is a much more violent form of heat treatment.

The results of the investigations vary considerably depending on the method of analysis. The term "nutritive value" has not been clearly defined. There are many factors that can influence the nutritive value of foods, such as protein content, mineral content and vitamin content, but the taste of food is also important. Another factor of importance is the keeping quality. Food that has begun to deteriorate before it has been consumed offers little nutritive value because of its unpalatable condition.

Several investigations and their findings regarding the effect of UHT treatment on milk are mentioned below:

The National Institute for Research in Dairying at Shinfield, Reading, England:

(a) In an article entitled "The Effect of Ultra-high-temperature Heat Treatment on the Content of Thiamine, Vitamin B_6 and B_{12} of Milk", which appeared in *Dairy Research* (1965) 32:13, the authors, M. E. Gregory and H. Burton, revealed the findings of an investigation that compared direct and indirect sterilizers.

The vitamin content was determined by means of bacteria. *Lactobacillus fermenti* were used for thiamine and *Saccharomyces carlsburgensis* and *Lactobacillus leichmanii* for vitamins B_6 and B_{12} respectively.

The investigation offers the following results: UHT sterilization has no effect on thiamine, but the losses of vitamins B_6 and B_{12} are somewhat higher than in pasteurization. However, these losses are much lower than for sterilization in bottles. The investigation also shows that indirect sterilization results in a greater loss of vitamin B_{12} than of vitamin B_6. The result is reversed in direct sterilization.

(b) S. K. Kon is of the opinion that proteins in milk have a high nutritive value. They are slightly deficient in sulphur-containing amino acids but because of their high lysine content, they compare very favourably to vegetable

proteins. Dr. Kon's findings are revealed in an article entitled "Amino Acid Make-up of the Milk Proteins in Relation to their Nutritive Value", published in 1962 in the *IDF Annual Bulletin*, part II, p. 131 (Båstad Seminar, 4–6 Sept. 1961).

Modern methods for manufacturing aseptic milk, dried milk and condensed milk have little effect on the value of the milk as a source of protein.

(c) An investigation carried out on milk sterilized in the Alfa-Laval VTIS produced the following results (unpublished):

Vitamins

Vitamin B_6	no losses
Vitamin B_{12}	no losses
Thiamine	no losses

Soluble proteins

α	lactalbumin	96% undenaturated
β	lactoglobulin	49% undenaturated
Turbidity		Corresponding to 45–50% raw milk

SH-groups (thiol groups)

Free	0%	
Bound	48%	Compared with untreated milk
Total	48%	

A loss of 20 per cent of vitamin B_6 occurred when the milk had been stored for three weeks. This was considered normal.

Article on Milk Hygiene published by Dr. Kon in 1962:

Sterilization in bottles destroys 50% of vitamin C, 30 to 40% of thiamine, 100% of vitamin B_{12} and part of vitamin B_6. The biological value of the proteins is reduced only by a few per cent.

UHT treatment has very little effect on the vitamins. The results are about the same as for pasteurized milk, with the exception of a slightly higher loss of vitamin B_{12}. According to experiments with rats, UHT treatment has no effect on the biological value of the protein.

Shillam and others have found that three-week-old calves raised on UHT-treated milk showed a significantly smaller increase in weight than calves raised on raw or pasteurized milk. Pol and Groot report that UHT treatment results in a certain loss of essential fatty acids.

FRICKER, A., "Ernährungsphysiologische Eigenschaften von uperisierter Milch, 1964" (Nutrient properties of uperized milk), *Kieler Milchwirtschaftliche Forschungsberichte* 16: 315–318 (1964).

The author reports on rats that were for five generations raised on uperized milk. He finds that UHT treatment does not destroy the nutritive value of the milk. Breeding of the animals was not affected at all. Microscopical and histological investigations of the organs gave no reason to suspect this. An extension of the holding time from 0.75 to 2.4 seconds did not reduce the biological value of the milk protein.

WAGNER, K. H., "Technische Verfahren der Milchkonservierung und ihr Einfluss auf den biologischen Wert der Milch" (Milk conservation processes and their effect on the biological value of the milk). *Fette – Seifen – Anstrichmittel*, [illegible] Weilburg Lahn.

The author compares fresh milk with UHT treated milk and pasteurized milk. He found that the growth of rats taking UHT milk was slightly below that of rats taking fresh milk but above that of rats taking pasteurized milk. He shows the following results regarding the effect of uperization on vitamins.

	Fresh milk	*UHT milk*
β carotin	14	11 μg
vitamin A	112	92 I.U.
vitamin E	320	295 μg
vitamin B_1	16	13 μg
vitamin B_2	93	77 μg
nicotinic acid	114	112 μg

BERNHARD, K., L. GACHEEDLER and A. SARASIN, "Die biologische Wertigkeit der ultrapasteurisierten Milch" (The biological value of UHT pasteurized milk). *Bulletin der Schweizerischen Akademie der Medizinischen Wissenschaft*, Vol. 9 (1953) 312 – 324 (Basel University).

The growth of rats raised on normal food with the addition of UHT milk was extraordinary and was not surpassed by that of the control group, which was given pasteurized milk. Autoclaved milk resulted in reduced growth.

There was no difference in the vitamin C content of UHT, pasteurized and autoclaved milk. Autoclaved milk contained only 65.5 per cent while UHT milk contained 90.6 per cent of the vitamin C content of the pasteurized milk. The content of vitamin B_1 in UHT milk and autoclaved milk was 85.5 per cent and 71 per cent respectively of that of the pasteurized milk. The lactoflavin was not appreciably affected by UHT or pasteurization.

The authors are of the opinion that UHT milk has the same biological value as pasteurized milk and surpasses that of the autoclaved milk with respect to vitamins C and B_1 because better growth of the rats was a result of its use.

Experiments carried out on rats at the Medical-Chemical Institution at Uppsala University, Sweden by Prof. G. Ågren.

The growth of rats raised on the following diets was examined. *(a)* metionin and casein; *(b)* UHT-treated and frozen dried milk; *(c)* pasteurized and frozen dried milk; and *(d)* whole milk, frozen dried.

The increase in weight of the four groups was compared after a three-week period and the following results obtained for each group: *(a)* 114-gram increase; *(b)* 68-gram increase; *(c)* 81-gram increase; and *(d)* 74-gram increase. Of more scientific interest than the weight gain over a period of time are the following data:

TABLE 2. DATA COLLECTED FROM EXPERIMENTS ON RATS AT UPPSALA UNIVERSITY

Diet group	*Body nitrogen gain per 3 weeks (g)*	*Nitrogen consumption per 3 weeks (g)*	*NER*[a]	*PER*[b]	*PPV*[c]	*Protein content in original material (g/100 g)*
(a)	3.23	4.55	25.0	4.00	71.0	10.3
(b)	1.91	2.97	22.9	3.66	64.3	24.6
(c)	2.24	3.48	23.3	3.72	64.3	25.5
(d)	2.11	3.32	22.3	3.57	63.6	25.8

[a] NER – Nitrogen efficiency ratio $= \dfrac{\text{weight gain}}{\text{nitrogen consumed}}$

[b] PER – Protein efficiency ratio $= \dfrac{\text{weight gain}}{\text{protein consumed}}$

[c] PPV – Productive protein value $= \dfrac{\text{N – content of experimental rats – N – content of weanling rats 24 days old}}{\text{N consumed during experimental period}}$

Note: The PPV value, which can be compared with more usual NPU (Net protein utilization) in some countries, is an often-used nutrition value. As can be seen from the table a certain insignificant reduction could be found.

Processing costs

Sterilization costs are very reasonable. The list below presents a comparison between the costs for treatment in an Alfa-Laval VTIS (direct heating method) and in an Alfa-Laval indirect heating sterilizer. The result shows that the processing costs are lower for an indirect heating sterilizer.

Assumptions

Depreciation period	10 years
Rate of interest	8 per cent
Maintenance	2 per cent
Working days per year	250
Working hours per day	8
Annual production	2,700,000 litres
Steam costs	SKr/ton
Electricity costs	SKr/kWh
Fresh water costs	SKr/m^3
Costs of detergent	SKr/kg
Labour costs	SKr/man-hour

Market prices

1800 l VTIS (standard)	about	350,000 SKr
1800 l Alfa-Laval indirect sterilizer	about	300,000 SKr

Alternative I 1800 l/h Alfa-Laval VTIS (direct heating)
Annual production = 2,700,000 litres
Alternative II 1800 l/h indirect sterilizer (Alfa-Laval)
Annual production = 2,700,000 litres

TABLE 3. COMPARISON OF ANNUAL COSTS: VTIS AND ALFA-LAVAL INDIRECT STERILIZER

	Annual costs (SKr)	
	VTIS (direct)	*Alfa-Laval ind. ster.*
Fixed annual costs		
1. Depreciation + rate of interest + maintenance = 16% X 350,000 SKr	56,000	48,000
2. Costs for plant sterilization and cleaning:		
(a) Labour costs, weekly: 52 weeks X 2 h/week X 9.50 SKr/h	988	988
(b) Labour costs, daily: 250 days X 2 h/day X 9.50 SKr/h	4,750	4,750
(c) Cost of detergent: 1,900 kg X 1 SKr	1,900	1,900
(d) Heat for cleaning and sterilization: 250 days X 17 SKr/ton X 1.5 h/day	638	638
(e) Electricity for cleaning: 250 days X 2 h/day X 0.07 SKr/kWh	875	875
(f) Water for cleaning and sterilization: 250 days X 1 h/day X 0.60 SKr/m³	450	675
Fixed costs, total	65,601	57,826
Variable annual costs		
1. Wages: 250 days X 6 h/day X ½ man X 9.50 SKr/h	7,125	7,125
2. Costs for steam: 250 days X 6 h/day X 17 SKr/ton	7,905	1,913
3. Costs for electricity: 250 days X 6 h/day X 0.07 SKr/kWh	4,725	4,725
4. Costs for water: 250 days X 6 h/day X 0.60 SKr/m³	5,040	900
Variable costs, total	24,795	14,663
TOTAL COSTS	90,396	72,489
Total costs, øre/litre of product	3.35	2.69

The costs for aseptic filling, which are high particularly when the direct heating method is employed must be added to the processing costs. The total cost increase as compared with pasteurized milk can be regarded as 25 to 30 per cent. In spite of this it is economically justifiable in view of the money that can be saved because of cheaper distribution, cheaper storage, reduced product losses and increased convenience for the consumer.

Chapter Six

VARIETY OF PRODUCTS

Different products have been produced in the above-mentioned sterilization plants. In principle it is possible to treat mechanically all liquid products, although the effect on the characteristics of the different final products must be observed. This requires certain development work for the adaptation as indicated in the following products.

Whole milk and skim milk

The bacteriological keeping quality is unlimited within the compass of what the packing plant can guarantee. This is not the case chemically-physically. Gel formation may occur after a few months. The time depends directly on the storage conditions, mainly the temperature.

The gel formation is probably partly the result of reactivation of proteolytic enzymes, but other factors are certainly involved also. These are at present being investigated. However, it has been shown empirically that it is possible to partly eliminate this gel formation and obtain a keeping quality of three to six months.

At times sedimentation problems may arise. They are caused by denatured protein. Correct homogenizing pressure and temperature can greatly help to overcome this. Whole milk is normally homogenized at 250–300 kg/cm^2 in two stages and skim milk at 175–200 kg/cm^2.

Recombined milk

The ingredients are mainly the following: *(a)* skim milk powder; whole milk powder; *(b)* unsalted, uncultured butter; butter oil; vegetable fat; *(c)* stabilizer (sometimes flavour and colour).

The mixing of the ingredients is normally carried out in the following way: *(a)* milk powder, fat and stabilizer (flavour and colour) are mixed in hot water (temperature well over the melting point of the fat); *(b)* the mixture is homogenized at 63°C and 150–200 kg/cm^2; and *(c)* finally the product is cooled down to about 10°C. The product is then normally sterilized and homogenized at 150–300 kg/cm^2.

Experience has shown that recombined milk is very suitable for sterilization; very long running times have been registered. The burning-on on the heating surfaces is usually less than with ordinary milk and easy to clean off.

Puddings and similar products

Various puddings and custards have been sterilized with good results. The demand on the viscosity of the final product can vary, but a jelly-like, highly viscous product is most common. Stabilizer and emulsifier are added to obtain this consistency. Development work has been directed largely towards adapting flavour and consistency to the requirements of the customer. Future goals will probably be an increased assortment of flavours and cheaper ingredients. The puddings are made in the conventional way and with very little homogenization.

Chocolate milk and other flavoured milk

There are no great problems with these products. It is important that the flavours are not heat sensitive or volatile – particularly the latter if vacuum cooling is used. If in spite of this different flavours are to be used, they must be added after the milk has been processed. This is carried out by means of an aseptic system.

The treatment prior to sterilization may vary according to customers' requirements. The homogenizing pressure is 50–200 kg/cm^2. Long operating times have sometimes been registered with chocolate milk, for chocolate particles seem to have a cleansing effect on the heating surfaces. Other examples of flavoured milk are strawberry milk and orange milk.

Concentrated milk

Concentrated milk with a dry matter content of up to 30 per cent has been treated. There are no special problems regarding the operation of the plant. The previously mentioned gel formation is more accentuated in concentrated products. Pre-heat treatment is commonly used to prevent this. It may in some cases mean heating the product to approximately 85°C for 30 minutes.

Ice cream mix

Sterilized ice cream mix is a first-class product. Certain adaptations of stabilizing and emulsifying agents have been necessary. The homogenizing pressure may vary between 180 and 250 kg/cm^2.

Whipping cream

Making good sterilized whipping cream is very difficult, and the problems connected with this have not yet been solved. Sometimes it is possible to make an acceptable whipping cream, but at other times the cream is impossible to whip even if the same temperatures and pressure have been used.

Tests have shown that the whippability will be better if the cream is not homogenized, but after ten to fourteen days the body of the product is very uneven and the product has an unpleasant appearance. If, on the other hand, the product is homogenized, even at very low pressure (about 40 kg/cm^2), the product will have a better consistency but usually a reduced whippability. The same effect has been noticed with pasteurized whipping cream.

It seems to be necessary to add a stabilizer to maintain the whippability. A suitable stabilizer is, for example, glycerol, monosterate. In Norway an application for a patent for a method using agents not alien to milk has been filed. A mixture of skim milk powder and buttermilk powder is added. The content of surface-active substances in the buttermilk is the reason for the good characteristics of the final product. Storage conditions also affect whippability. Cool storage for a certain length of time before whipping is important.

Coffee cream

Sterilization of cream with a fat content from 12 to 25 per cent is not technologically difficult. It is nearly always possible to obtain a product with a desired viscosity and body by altering the homogenization.

Problems with coffee cream are for example "feathering" and "free fat formation" when the cream is poured into hot coffee. This might be caused by wrong homogenization and can be eliminated if the homo-pressure is lowered or if stabilizers are added. A change of only one to two degrees could drastically affect the chances of achieving the best results.

Chapter Seven

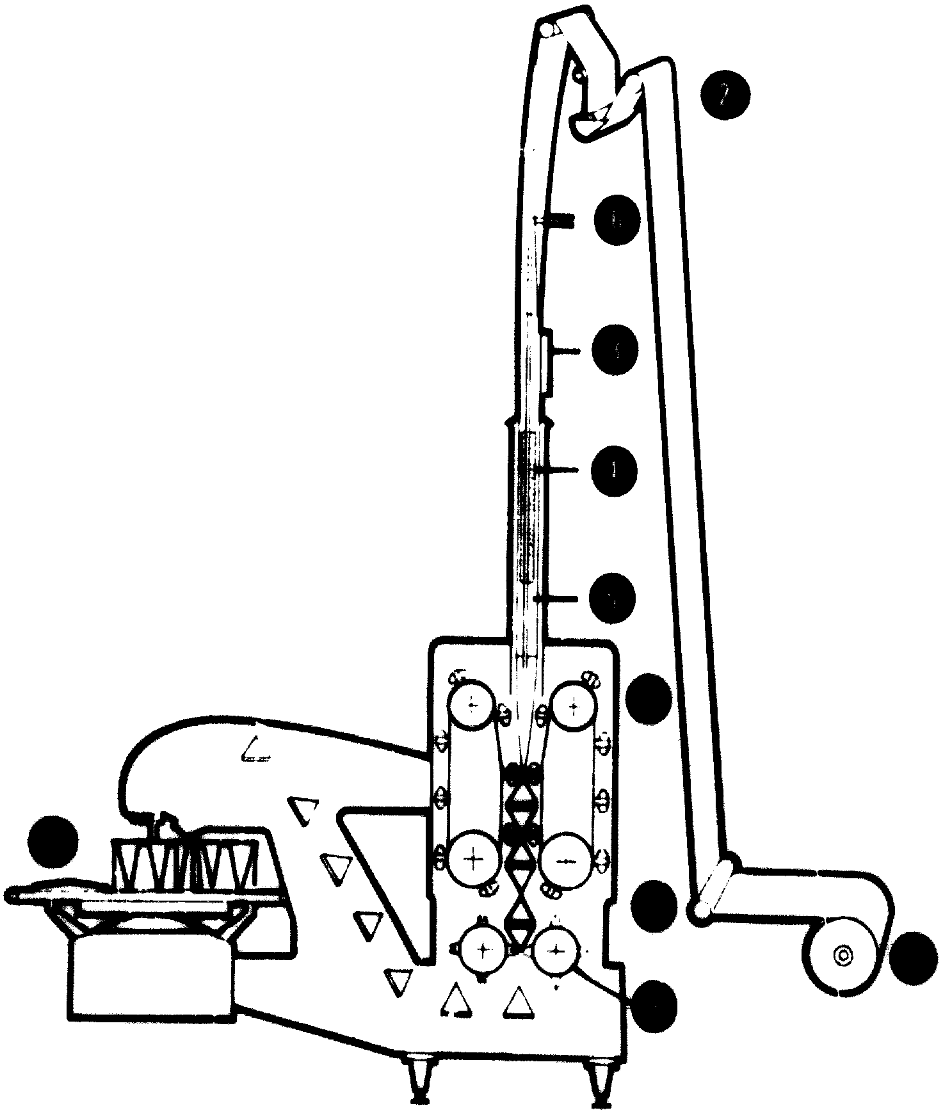
ASEPTIC FILLING

For continuous sterilization each sterilizing plant must be combined with an aseptic filling plant so that the sterile liquid will enter containers without risk of infection. Many firms have tried over a long period to modify ordinary filling machines, but it has been very difficult to obtain reliable results.

Pre-sterilization by means of superheated steam has been tried. Filling has then been carried out aseptically. This system is used by James Dole in the United States. The method is expensive and is therefore best suited for special products such as condensed milk and ice cream mix.

Filling glass bottles under aseptic conditions has been under development for a long time but breakage has been a problem. Some prototypes of this method are now ready for aseptic filling. A cheap aseptic container would certainly arouse interest in continuous sterilization and aseptic filling. Tetra Pak was the first aseptic filling machine (see figure 18) and it fulfils the required price demands. Other types of paper containers will be introduced shortly. However, it has been established that the Tetra principle is highly suitable for aseptic filling.

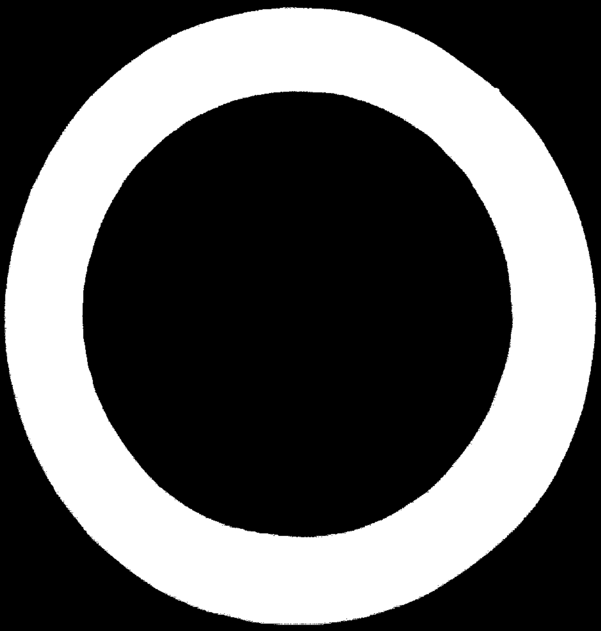
The packing material is polythene-lined kraft, which has a very high hygienic standard. It is possible to obtain 90 per cent sterile containers without any special measures, but this is not sufficient. The paper must be sterilized immediately before the container is filled. This is done by chemical-thermal sterilization. The paper passes through a hydrogen peroxide bath. The hydrogen peroxide is reduced when the paper passes a heating element with a temperature of 400°C. The holding time is approximately five seconds, and during this time the hydrogen peroxide decomposes into oxygen and steam, which are removed. The container is then filled with sterile milk and sealed in the conventional manner.



1 Roll of laminated paper
2 Hydrogen peroxide bath
3 Initial thermal welding of edges of paper
4 Heating element for the reduction of hydrogen peroxide
5 Sterilized milk chamber

6 Inflow of sterilized milk
7 } Formation and closing of Tetra Pak
8 }
9 Separation of Tetra Paks by cutting
10 Finished Tetra Pak

Figure 18. Flow diagram Tetra Pak aseptic filling machine



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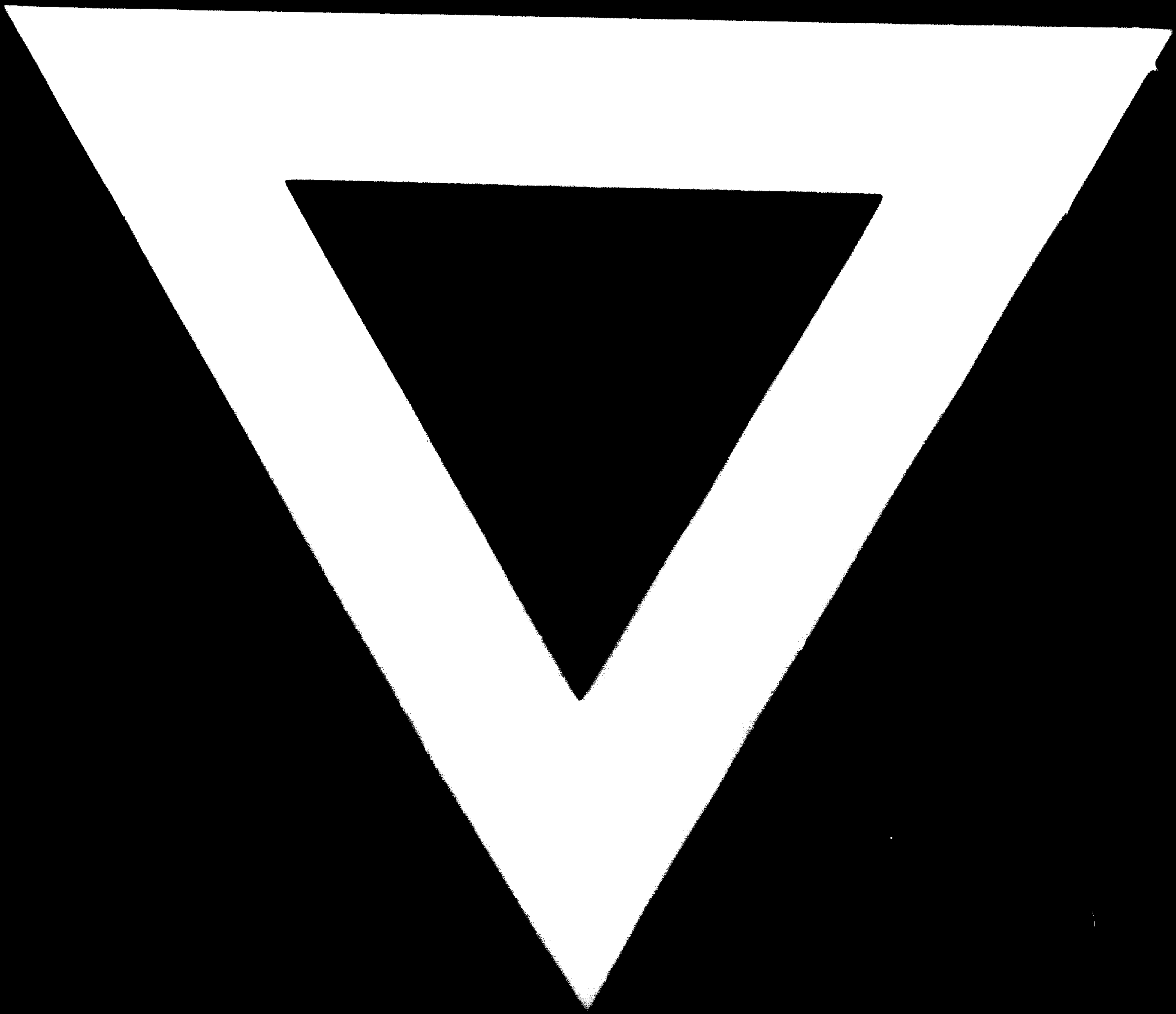

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