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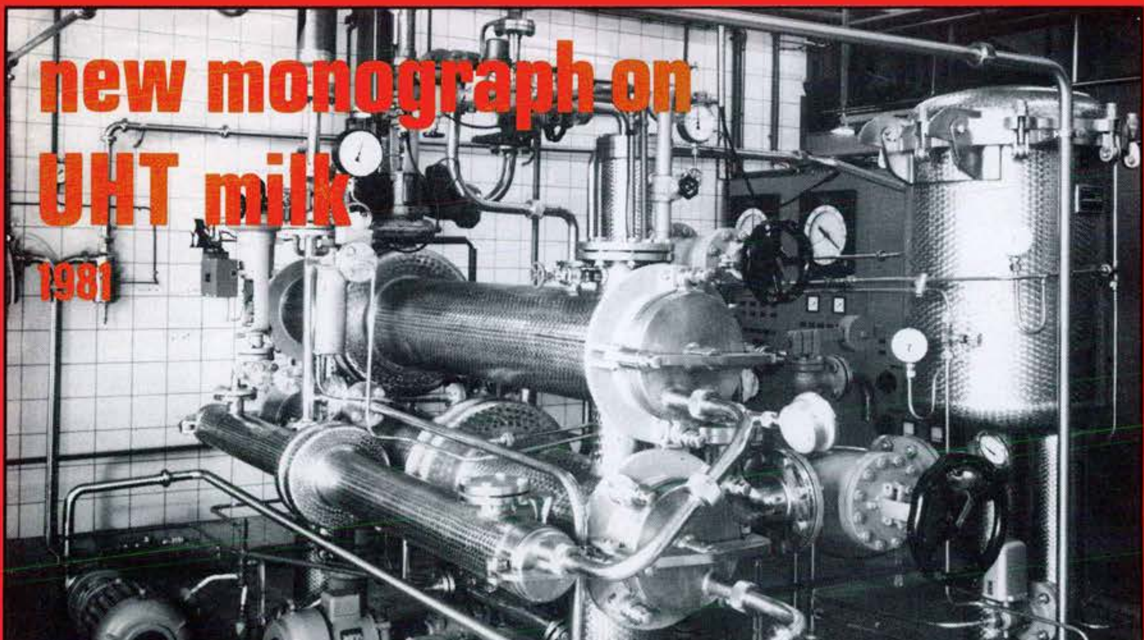

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NEW MONOGRAPH on U H T MILK 1981

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contents

FOREWORD

by Dr T.R. Ashton

With the compilation and publication of IDF Document 68 (Monograph on UHT Milk) and Document 89 (UHT treatment of milk-based products) in 1972 and 1976 respectively, the responsibilities of the Group of Experts (Group B2* of Commission B) had diminished to such an extent that it seemed wise to merge its interests with the newly formed Group B21** which had been charged with a study on the subject of "Methods for improving the keeping quality of heat-treated milk".

Arising from a meeting held in Brussels in November 1978, the members of Group B21 undertook "the task of revising and updating the monograph on UHT milk, provided the authors of the individual chapters of the original monograph were prepared to produce a new version of their chapters and provided also new authors could be found for some of the chapters": – changes consequent upon retirement, change of duties and responsibilities, decease, etc.

Invitations for contributions sent out to "old" and "new" authors of chapters were met not only with assent but with quick response so much so it was considered that publication of a further edition should be possible early in 1981.

This second edition of the Monograph on UHT milk, is based on a lay-out similar to that of the 1972 version.

A few chapters are in fact identical: e.g. chapter 2, section a) by Prof. Dr H. Hostettler (on appearance, flavour and texture) was taken over in entirety from the 1972 monograph, but a section b) was added to report on developments since 1972. But most chapters are new, to the extent that they were either rewritten in the light of present day experience and conditions or introduced *de novo*: e.g. chapter 8 by Mr C.H. Brissenden on "UHT processing and packaging plant: basic requirements, services and maintenance", or chapter 9 by Mr D.I. Shew on "Technical aspects of quality insurance.

Marketing aspects have been dealt with in an appendix (not in chapter form as in the 1972 version) which describes the market for UHT milk in the Federal Republic of Germany (author: Dr M. Drews). The Group considered that it was not yet in a position to report in a comprehensive way on the markets for UHT milk in the individual countries, hence this limitation to the very significant developments which occurred in Germany since the early 1970's. Group B21 expects to be able to report in more detail on these aspects in a future issue of the monograph.

The 1972 Monograph on UHT milk has been out of print for several years, testifying to the good work done by Group B21. As Chairman of the Group, I feel sure that this new edition which reflects the up to date situation of 1980 (when the new chapters were finalized) will enjoy equal success. The Group also hopes that readers will not hesitate to communicate to the IDF General Secretariat in Brussels, their remarks, comments and criticism on the lay-out and contents of this new monograph. This should enable Group B21 to plan a future edition in the best possible way.

To the contributors of this 1981 Monograph on UHT milk, I would like to pay a warm tribute for their indefatigable help. For his immense patience and help over the last 14 years whilst the first and second editions of this monograph have been in course of preparation, my sincere thanks and those who have been associated with the work are extended to the Secretary General of IDF, Mr Staal.

T.R. Ashton, July 1981

* *The Group of Experts (Group B2 of Commission B) responsible for the overall planning of the first edition of the monograph on UHT milk (Document 68, 1972) were:*

T.R. Ashton (GB), Chairman, J. Drogt (NL), H. Hostettler (CH), A. Lembke (DE), A. Lovio (FI), R. Negri (IT), A.C. O'Sullivan (IE), J. Pien (FR), P. Rønkilde-Poulsen (DK), E.G. Samuelsson (DK), D.I. Shew (AU).

** *The Group of Experts (Group B21 of Commission B) responsible for the planning of the revised edition of the Monograph on UHT milk were:–*

T.R. Ashton (GB), Chairman, A. Sargant (CA), P. Rønkilde-Poulsen (DK), J. Auclair (FR), Shri M.R. Srinivasan (IN), H.G. Kessler (DE), M.G. Van den Berg (NL), D.J. Shew (AU), D.B. Stüssi (CH), R. Negri (IT), J. Drogt (NL), J. Haukka (FI), M. Lavoie (CA), J.H. Downes (ZA), M. Teuber (DE), O. Cerf (FR), M. Naudts (BE), H. Wainess (US). Invaluable assistance in the compilation of this new work was also received from the following experts: A.J.D. Romney (GB), P. Solberg (NO), M. Busse (DE), B. Blanc (CH), G. Odet (FR), and others.

COVER: One of the first SULZER uperisation plants installed in 1962 in Verbandsmolkerei Bern, Switzerland. Reproduced with kind permission of SULZER Bros Ltd, Winterthur (Switzerland) and of Verbandsmolkerei Bern.

CHAPTER 1

MICROBIOLOGICAL ASPECTS

by Prof. Dr M. Teuber (Kiel) & Prof. Dr M. Busse (Weihenstephan)

The purpose of the ultra-high temperature (UHT) treatment of milk is to produce a sterilized milk which must:

1. keep without deterioration i.e. remain stable and of good commercial value for a sufficient period to satisfy commercial requirements,
2. be free of microorganisms and toxins harmful to the health of consumers,

   and
3. be free of any microorganisms liable to proliferate during storage (Pien, 1965).

On this basis, the term "sterilized milk" means that the final product has not to be absolutely sterile. It may contain living microorganisms that are inhibited under the prevailing storage conditions. It has therefore been denominated a sterile milk in a commercial sense (Lembke, 1972).

To achieve the listed goals, it is necessary to define the microbiological quality of the raw milk to be used for the UHT treatment and the physical conditions of the UHT process which must be compatible with the microbiological status of the raw milk as well as with the desired organoleptic and keeping qualities of the produced UHT milk. In addition, aseptic packaging of the product and a proper microbiological control of the whole process are of equal importance (Cerf, 1980).

MICROORGANISMS IN MILK AND THEIR RESPONSE TO HEAT TREATMENT

The microorganisms occurring in milk can be classified according to their resistance to moist heat into the following sorts:

Class I. The microorganisms killed by conventional pasteurization e.g. the high-temperature-short-time (HTST) process with typical time-temperature combinations around 71-72°C and 15 to 30 s. This treatment eliminates most vegetative cells of bacteria like *Staphylococcus aureus*, hemolytic streptococci, the gram-negative enteric bacteria (*Escherichia coli, Salmonella* species), *Pseudomonas* species, *Brucella abortus, Mycobacterium tuberculosis*, and all yeasts and moulds.

Class II. The microorganisms resistant to HTST treatment but sensitive to UHT treatment e.g. a time-temperature combination of 1 to 4 s at 135 to 150°C.

The HTST treatment is tolerated by some thermoduric vegetative bacteria like enterococci, some micrococci, microbacteria, thermophilic lactobacilli (*Lactobacillus bulgaricus, L. lactis*), *Streptococcus thermophilus*. In addition, the thermoduric spore cells of aerobic and anaerobic endospore-forming bacilli (*Bacillus* and *Clostridium* species) survive HTST treatment. Dormant spores may even be activated by this treatment to germinate and produce heat-sensitive vegetative cells.

Class III. Microorganisms resistant to UHT treatment.

Especially spores of the obligate thermophilic soil bacterium *Bacillus stearothermophilus* are known to withstand UHT-treatment of milk. But also some spores of mesophilic bacilli and clostridia may survive UHT treatment, if the milk is heavily contaminated (see below).

KINETICS OF THE HEAT INDUCED DEATH OF MICROORGANISMS

The molecular mechanism underlying the thermal death of microorganisms is not at all clear in every detail, but it is believed to be due to thermal denaturation of the secondary and tertiary structure of macromolecular cellular organizations (DNA, proteins, membranes, etc.). For the purpose of this chapter, it suffices to recognize that the kinetics of thermal inactivation follow more or less a first order kinetic

$$\frac{-dN}{dt} = k' . N.$$

It means that the decline of the viable count (dN) of bacteria in a given time interval (dt) is proportional to the initial concentration of living cells (N), k' being a temperature dependent reaction constant.

Integration of this equation within the limits N_o (viable count at the beginning) and N (viable count after a heat treatment of the time t) yields

$$\frac{N}{N_o} = e^{-k't}$$ demonstrating the exponential nature of thermal death rates of microorganisms.

Figure 1 shows the time-dependent inactivation of spores of *Bacillus stearothermophilus, B. subtilis* and *B. cereus* at 140°C (Miller & Kandler, 1967). From this graph, it is possible to determine the time necessary to kill 90% of the cells at a given temperature. This time is the so-called decimal reduction time (D). D is temperature-dependent and decreasing with increasing heating temperature (see table 1). However, it has been demonstrated that the reduction of spore viability is much higher in experimental and industrial UHT plants than in the glass capillary tubes used in the laboratory to measure heat inactivation (Hermier et al., 1975; Burton et al., 1977). This may be due to a heat shock if spores are injected into live steam (Hermier et al., 1975). Therefore, extrapolation of any thermal death rates to other temperatures, equipments and microorganisms are still difficult and to be treated with great caution.

To employ heat as a bactericidal agent for the treatment of milk is only practicable if the nutritive and organoleptic values of milk remain acceptable.

Fortunately, there are sufficient time-temperature combinations available which allow an efficient inactivation of microorganisms without a gross impairement of the nutritional and sensoric properties of milk. This is due to the fact that inactivation of microorganisms has a higher Q_{10}-value (Q_{10} = 8-30) than for example the heat coagulation of casein. The term Q_{10} describes the increase in reaction rate corresponding to an increase of the reaction temperature of 10°C. Figure 2 gives the temperature-time-diagram of the heat-treatment of milk (Kessler 1976). It clearly demonstrates that the time-temperature combinations used for the heat-treatment of milk are located in areas combining optimal conditions for the inactivation of microorganisms with the lowest possible influence on the physical and chemical properties of the milk.

MICROBIOLOGICAL PROBLEMS IN UHT–TREATMENT

1. Problems caused by the microbiological condition of the raw milk.

From the discussion of the effect of heat on the inactivation of microorganisms, microbiological problems can be envisaged if the raw milk contains numbers of mesophilic and thermophilic thermoduric spore cells exceeding the sterilizing effectiveness of the UHT plant. The sterilizing effect is defined as

$$\log_{10}\left(\frac{\text{initial spore count}}{\text{surviving spore count}}\right).$$

This term and method has been introduced by Galesloot (1956) to determine under practical conditions the sterilizing efficiency of a UHT process. For mesophilic *Bacillus* spores, sterilizing effects of 6 to 11 have been reported depending on holding time and temperature (Burton, 1969). According to Horak (1980), sterilization efficiency of industrial UHT plants is much higher. For *B. stearothermophilus*, a value of 2 was obtained if UHT milk containing spores was diluted with diluents other than UHT milk and plated on a suitable nutrient agar. However, since outgrowth of this species is inhibited in UHT-milk itself, an apparent sterilizing effect of about 8 may be more realistic. Assuming one heat resistant spore per milliliter of raw milk, a sterilizing effect of 6 would yield 1 unsterile container in 1000 one-liter-packs, constituting an acceptable commercial risk of 0.1% (Wasserfall, 1973). Great care has to be taken if UHT milk produced in countries with moderate climate is to be exported to countries with a tropical climate. The minimum growth temperature of *B. stearothermophilus* is 40 to 45°C (Bergey, 1974), a range normally not observed during storage of UHT milk in moderate climates.

2. Problems due to microbial products

In contrast to in-container-sterilized milk, UHT milk may develop more often upon storage bitter off-flavour and also gelation and coagulation of milk proteins without a concomitant growth of spoilage microorganisms (Ashton, 1966). Although it is not easy to prove the enzymic nature of these defects in every instance, several laboratories have provided convincing evidence that especially psychrotrophic bacteria including pseudomonads and spore-forming bacilli do produce proteases and lipases at storage temperatures as low as 4°C (Speck & Adams, 1976; Snoeren et al., 1979). Some of these enzymes are extremely heat resistant and withstand to a large extent the UHT-process. D values of 90 s at 15°C have been determined for some *Pseudomonas* proteases in milk (Adams et al., 1975). Enough enzymes were produced at 5°C by as few as $10^3 - 10^4$ *Pseudomonas* MC 60 cells per ml to cause a significant loss of native milk proteins and a bitter flavour. (*)

If aseptically drawn milk was contaminated with milk stored for 120 h at 4°C to yield a microbial count of $2 \cdot 10^6$ colony forming units per ml, direct heating for 4 s at 142°C produced an UHT-milk which coagulated within 18 - 21 days storage at 28°C. Under the same conditions the aseptic milk showed coagulation after 91 - 94 days probably due to native milk protease not completely inactivated by direct heating (Snoeren et al., 1979). The last mentioned experiments show very clearly that the time of coagulation depends very much on the bacteriological quality of the milk. Therefore it is not advisable to use milk stored for a prolonged time at low temperature for the production of UHT-milk.

(*) See also report F–Doc 85 on heat resistant proteinases submitted to IDF Commission F in 1981.

Aseptic filling

Aseptic filling of the UHT-milk is of utmost importance since contamination with only one viable bacterium able to reproduce in milk will inevitably spoil the product during storage within a few days (Langefeld & Bolle, 1979). A common process for the sterilization of the packaging material is the use of H_2O_2 in the case of paper board bricks. For details, see chapter 7 of this monograph.

Sterility control

Unsterility of UHT milk is mainly a problem of packaging the sterile product. Practical experience has shown that spoilage of UHT milk is usually caused by microorganisms of heat sensitivity classes I or II. This does not apply, of course, to thermophilic spore formers which, however, are of minor importance, in temperature zones.

Apparently, a certain risk of contamination is connected with sterilization of packaging material, especially at the time when rolls of paper are changed. Worn out gaskets in the sterile part of the equipment may harbour microorganisms and protect them against sterilization treatment. Other sources of unsterility are condensed water at the filling pipes and faulty sealings of packages. Thus sterility control should start with a very stringent surveillance of maintenance and proper operation of equipment.

An important question in the sterility control of UHT milk is the number of packages to be tested. According to Wasserfall (1973) 300 random samples should be drawn from a series of 6000 to 8000 packages. Allowing a risk of 5%, one infected package within the 300 samples can be accepted to indicate that not more than 0.1% of the lot is contaminated. Because of this large number of samples this method, however, does not seem to be practical. Bockelmann (1974) recommends a sampling of 50 to 100 units daily per line. With modern equipments giving outputs of 4000 units per h this sums up to about 0.1 to 0.2% of the whole production.

The technique of sterility testing consists in an incubation of packages for a suitable period. Temperature should be between 25 and 30°C. For detection of thermophilic spore formers 55°C is appropriate. Appearance, taste, pH-values, and blowing of packages are recorded. Packages showing any defect are microbiologically analysed by streaking a sample on plate count agar. Plates are incubated at least for 2 days at 30°C. If thermophilic spore-formers are suspected, incubation is made at 55°C. Streaking is essential to establish the microbiological nature of the defect. In addition, microorganisms grown on the plates should be differenciated, since valuable information with regard to the source of infection may be obtained in this way. No complicated techniques or specific knowledge of taxonomy are required for flora analysis. Usually colony morphology, microscopic examination and oxidase test or catalase test will be sufficient.

Care should be taken to avoid gross contamination of the sample during sensoric testing and pH measurement. Contaminations introduced by pH electrodes can easyly be in the order of 10^4 organisms/ml.

The question how long samples should be incubated to detect a reasonable proportion of infected packages is not settled. In practice, incubation periods of 3 to 5 days are applied. Langefeld & Bolle (1979) have determined the minimum and maximum incubation periods necessary to detect spoilage organisms by streaking under conditions where only one viable organism had contaminated the sample. From their results with 28 different strains of microorganisms commonly encountered in spoiled UHT products they suggest an optimum preincubation period of 7 to 9 days followed by a 4 day incubation of inoculated plates (see table 2). No information, however, seems to be available on the percentage of contaminated units which remains undetected if shorter periods of incubation are used.

Interpretation of results

Contamination rates are estimated from the results of sensoric testing and pH measurements. Further, the type of the contaminating microflora is to some extent related to the source of infection. Evidently, this applies to thermophilic spore formers grown on streak plates incubated at 55°C. They indicate insufficient heating of the product. On the other hand, heat sensitive bacteria are indicative for recontamination. No distinction can be made in the case mesophilic spore formers are found. These organisms may have survived heat treatment or may be due to recontamination.

In cases of recontaminations caused by defective gaskets or condensed water at the filling pipe, all contaminated packages contain a rather uniform microflora. Usually only one microorganism species is found as a pure culture. Less frequently 2 or even more kinds of bacteria are found in the milk. In this case all packages contain the contaminants in about the same ratio.

Quite different results are obtained when unefficient disinfection of packaging materials, faulty sealing of packages or corroded plates of heat exchangers are involved. Such defects result in a most variable contamination flora which differs from package to package.

Table 1. Decimal reduction time (D in seconds) of spore suspensions in water and milk (Miller & Kandler, 1967)

Temperature (°C)	*B. stearothermophilus*		*B. subtilis*		*B. cereus*	
	water	milk	water	milk	water	milk
105	2857.0	2856.0	27.8	28.6	12.05	11.24
120	38.6	–	4.54	–	4.18	–
130	8.77	7.35	3.06	2.70	2.63	2.27
140	3.85	–	2.14	–	1.28	–
150	2.44	1.59	1.09	1.15	0.97	0.71
160	1.37	–	0.46	–	0.66	–

Table 2. Necessary minimum and allowed maximum pre-incubation of UHT-milk with minimum incubation period of the inoculated agar plate broth at 30°C (Langeveld & Bolle, 1979). Conditions had been chosen so as to detect contamination of 1 living cell per container.

	Necessary minimum pre-incubation (days)	Allowed maximum pre-incubation (days)	Minimum incubation PCM plate (days)
Aerobic sporeforming bacteria			
a) from faulty aseptic UHT products			
Bacillus sp. 8208	7	> 15	1
B. cereus DV2	> 8	> 15	1
b) from culture collection			
B. coagulans 5743H	> 8	7	2
Bacillus sp. 693	6	8	2
B. subtilis Va Z 1	> 3	> 15	1
B. licheniformis 4651H	6	> 15	1
B. circulans Delft 3	⩾ 3	> 15	2
Aerobic non-sporeforming bacteria			
a) from faulty aseptic UHT products			
coryneform No 3	> 8	> 15	1
coryneform No 16	⩾ 3	9	2
coryneform No 13	4	> 15	2
Micrococcus sp.	6	> 15	2
Gram-negative coccus	⩾ 3	> 15	1
rod	⩾ 3	> 15	1
b) from culture collection			
b1) Gram-negative bacteria			
Pseudomonas fluorescens P442	⩾ 3	> 15	1
Alcaligenes sp. 312C	⩾ 3	> 15	1
Flavobacterium sp. R100	⩾ 3	> 15	2
Enterobacter aerogenes 11	⩾ 3	> 15	1
b2) lactic acid bacteria			
Streptococcus cremoris AM	6	4	3
S. lactis 2701	⩾ 3	> 15	1
S. faecalis B 3	⩾ 3	> 15	1
S. thermophilus Ops.	4	> 15	4
Leuconostoc citrovorum Ur b	5	9	3
Lactobacillus bulgaricus Wb	⩾ 3	8	4
b3) Micrococcaceae			
Micrococcus sp. C19	⩾ 3	> 15	1
S. aureus Nm 7	⩾ 3	> 15	1
Moulds from culture collection			
Penicillium candidum Pec	–		–
Aspergillus versicolor Meppel 2	6	> 15	3
Yeasts from culture collection			
Candida pseudotropicalis			

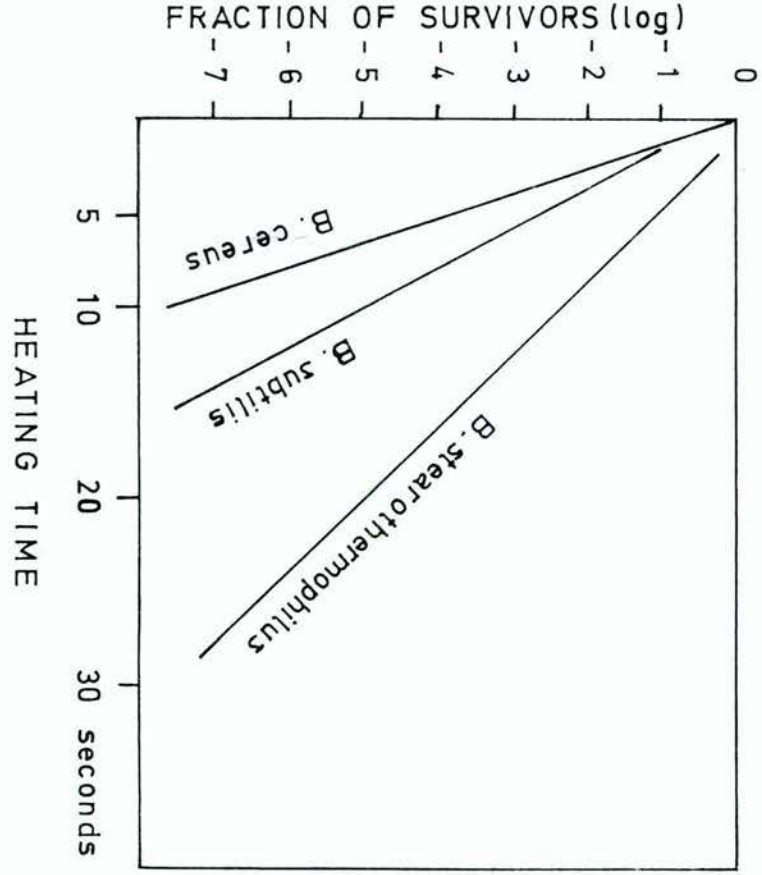

Fig. 1. Time-dependent inactivation of spores of *Bacillus stearothermophilus, Bacillus subtilis* and *Bacillus cereus* at 140°C as determined with the capillary method (Miller & Kandler, 1967).

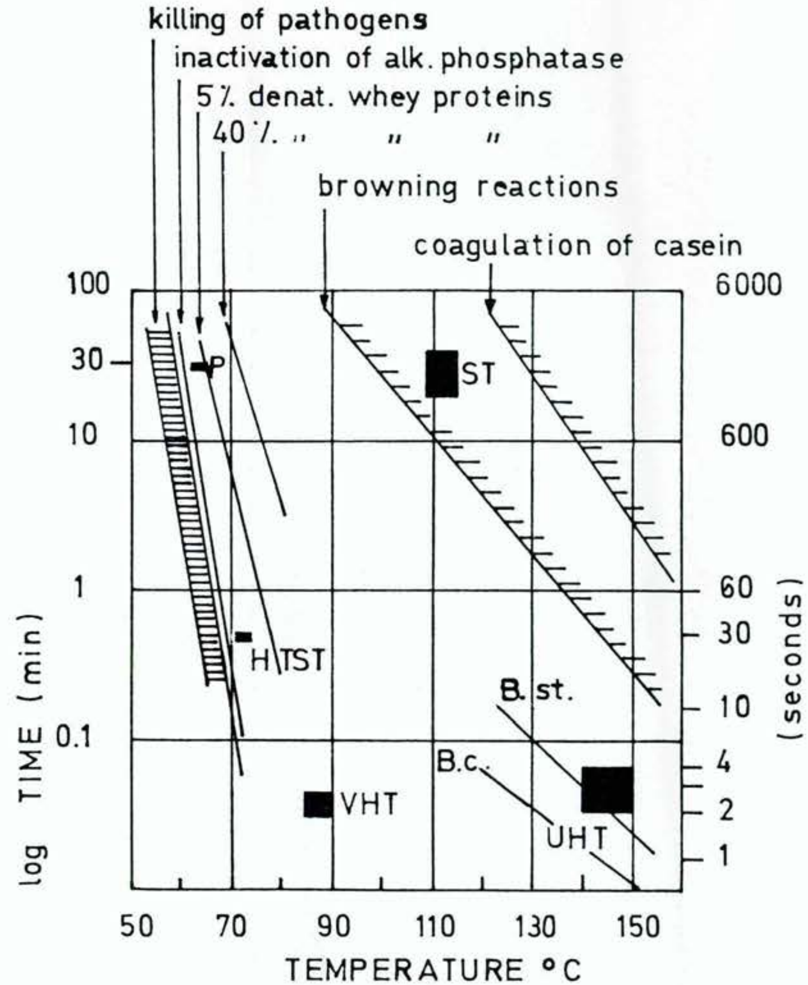

Fig. 2. Time-temperature diagram of the heating of milk (modified from Kessler, 1975).

P:	long-time pasteurization
HTST:	high-temperature-short time pasteurization
VHT:	very-high-temperature pasteurization
UHT:	ultra-high-temperature treatment
ST:	sterilization
B. st.:	decimal reduction of *Bacillus stearothermophilus* in milk (Miller & Kandler, 1967)
B. c.:	decimal reduction of *Bacillus cereus* in milk (Miller & Kandler, 1967).

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CHAPTER 2a

APPEARANCE, FLAVOUR AND TEXTURE ASPECTS: DEVELOPMENTS UNTIL 1972

by Prof. Dr H. Hostettler (Switzerland)

I. COLOUR AND APPEARANCE

An essential feature of UHT-sterilization is the small change in colour and appearance of the treated milk (Williams et al. 1955).

According to experiments by Burton (1954, 1955, 1959) light reflection in the wave length range 400 - 550 nm is considerably higher from UHT-processed milk (Uperization ®, Stork and APV processes) than from milk sterilized in bottles. Apart from the size distribution of the fat globules, the appearance of the milk is connected with the distribution of the milk proteins. Experiments carried out by Hostettler et al. (1965a, 1965b) with the ultra-centrifuge and electron microscope to determine the effect of UHT-sterilization (Uperization ®) on the distribution of milk proteins showed that changes take place with regard to both the whey proteins and the casein particles. A portion of the whey proteins is precipitated on the casein particles. A protein/protein interaction occurs between casein and the whey proteins which results in an increase of the relative concentration of the proteins travelling in free electrophoresis (Tiselius) with the α - casein at the expense of the whey proteins – primarily the β - lactoglobulin (Hostettler et al. 1958).

The differences found in the distribution of proteins in UHT-sterilized and autoclaved milk and the suppression of a decisive browning reaction when milk is treated by the UHT-process explain the difference in appearance (light scattering) of the two types of milk. Jordan (1968) points out that at temperatures above 130°C the death rate of microorganisms is considerably greater than the browning effect, so that no visible browning is detected when the milk is treated by the UHT-process. Due to precipitation of the whey proteins, the colour of the UHT-heated milk can even be lighter compared with that of raw or pasteurized milk.

UHT-sterilization reduces the browning reaction to a minimum (Zadow, 1970). The extent of browning depends largely on the process used. Determination of the ferricyanide reducing (FR) substances and the hydroxymethylfurfural (HMF) content are used to follow the browning reaction. Skimmilk exposed to direct and indirect UHT-sterilization at 145°C/3 s gave higher values of FR and HMF for milk heated by the indirect process than for milk heated by the direct process. On storage at 2°C the values for FR and HMF decreased. This decrease was more rapid in milk samples heated by the direct process than in those heated by the indirect process. The main decrease in the FR- and HMF-values occurred in the first few days after processing, in which period a rapid change in the flavour of UHT-products takes place. Three days after processing, UHT-milk treated by the direct process showed only slightly reducing properties and a small amount of early intermediate browning products. UHT-milk heated by the indirect process examined after 3 days of processing had retained a significant part of the highly reducing properties and a higher percentage of intermediate browning products.

Concentrated milk also does not show any change in colour (browning) when treated by the UHT-process in comparison with the pasteurized products (Seehafer, 1969). The colour stability during processing is an advantage which cannot be achieved during heating in the autoclave. Uperized milk concentrated to a ratio of 3 : 1 is considerably whiter than autoclaved milk.

A striking difference in colour between uperized and autoclaved milk shows up under ultra-violet light. Pasteurized and uperized milk show yellow fluorescence, while autoclaved milk shows blue fluorescence.

II ODOUR AND FLAVOUR

a. Raw Milk

The question of flavour is of the greatest importance for milk and milk products as it is for all foodstuffs. There is no market for a food substance which has not a pleasing flavour. Fresh milk is a most unstable food and even before it is received for processing it is exposed to numerous factors which have a great effect on changes in odour and flavour.

According to the classification given by Davis (1966) the flavour properties of milk can be separated into 2 classes:

- normal or natural and desirable flavour properties
- faulty flavour properties, not typical for the products and mostly undesirable.

Of the latter, the odour and flavour defects produced during and after milking which can be determined when the milk is received for processing are of the greatest importance for the processing of the milk and the quality of the products made.

Such defects could be for example:

- excessive cow flavour caused by disordered endogenous energy metabolism (Ketosis)
- feed odour and flavour caused by feeding of strongly smelling feeds such as silage, turnips, cabbage or by weeds such as leek, camomile and other pasture weeds
- rancidity due to enzymatic hydrolysis of milk fat by lipase.

Milk can also become defective by absorption of bad odours from the air in the byre during milking. The transfer of undesirable volatile odour and flavour substances into the milk can also take place via the cow's lung; in this case, the odour substance can appear in the milk within only a few minutes. Onion smell absorbed via the lung appears in the milk within 15 minutes. (Dougherty, 1962). Via the rumen the transfer takes more than 30 minutes. Numerous odour and flavour components of the milk were identified by gas chromatography and mass spectrometry and large differences were found between milks of different origin. (Patton, Forss & Day, 1956; Jensen, Lassiter & Huffman, 1958; Tharp & Patton, 1960; Cole, Harper & Hankinson, 1961; Bassette & Whitenah, 1961; Jennings, Viljhalmsson & Dunkley, 1962; Kintner & Day, 1965 and others).

According to Wynn, Brunner & Trout (1962) different ratios of volatile odour and flavour components were found in individual milks after feeding materials such as lucerne-silage and the green of onions and turnips; these rations were specific for the respective material fed. In bulk milks acetaldehyde, methyl sulphide, acetone and other non-identified carbonyl compounds were found. Using a vacuum heating plant it was possible to remove 85% of these substances from the milk. Milk with a feed flavour was graded one or two points up after vacuum treatment.

Numerous publications deal with the formation of an oxidation flavour in milk; this flavour defect was found to be dependent on feed conditions (Dunkley, Smith & Ronning, 1960) as well as on the stage of lactation and cattle breed, on whether morning or evening milk was tested and on the summer or winter feed (Kuzdzal-Savoie & Mocquot, 1958).

Normal milk has a slightly sweet flavour. It also has a characteristic cow and byre odour which is more pronounced in the winter months. The dimethyl sulphide–$(CH_3)_2S$– particularly is responsible for this (Patton, Forss & Day, 1956). The level for it to bring about an irritable effect lies in the region of 12 ppb. It is found in the cow's breath and the sulphone derivative $(CH_3)SO_2$ has been detected in the cow's blood. Further flavour substances found in milk are acetaldehyde, C_3 – to C_6 -methyl ketones (Jennings, Viljhalmsson & Dunkley, 1962), primary amines (Cole, Harper & Hankinson, 1961) and free fatty acids (Kintner & Day, 1965). As a preliminary stage to the dimethyl sulphide Samuelsson (1962) recognised methionine. Making use of intravenous injection of marked methionine, he subsequently isolated a radioactive dimethyl sulphide fraction. After normal feeds of hay and corn, acetone and butanon were found in winter milk (Bassette & Whitenah, 1961).

Bergman, Bertelsen, Berglöf & Larsen (1962) found greatly increased flavour defects on storing milk for 48 h at 0 - 4°C. Dimethyl sulphide is also formed in milk in the cold from the δ - methyl sulphonium salt of methionine (Maier, 1970).

Since, depending on the process of UHT-heating used, undesirable odour and flavour properties can to a certain degree be transferred to the heated and packaged milk, only normal raw milk of satisfactory flavour should be used for producing UHT-milk.

b. Packing material

In the packaging of the milk, great care must be taken that the packaging material used has no odours of its own, since milk and milk products readily absorb such odour substances. At the "Odour of Packaging" conference arranged by the Institute of Packaging jointly with the packaging industry in 1960, the causes of foreign odours in packaged food stuffs were discussed. Information on the inherent odour of plastic foils frequently used for packaging of milk and milk products is of particular interest to the dairy industry. (Bader-Becker, 1961). Thus for instance polyester foils (polyethylene terephthalate) may have a paper-like odour of terephthalic acid; polyethylene foil an odour of oxidized oil and of wax derived from the stabilizer and lubricants; polypropylene foil a burnt and phenolic odour derived from the stabilizer. The packaging material to be used must also be satisfactory from a hygienic point of view and no prohibited plasticizer is allowed in any of the plastic materials employed. To protect any packaged milk which is to be stored for longer periods against the effects of light and foreign odours, the packaging material used must be impervious to light and impermeable to gases.

c. UHT-heated milk

It has been said by several authors that uperized milk is comparable to pasteurized milk (Burri, quoted by W. Regez, 1962; Tentoni, 1954 and Laniesse, 1956). Mocquot & Hermier (1955) came to the same conclusion for milk treated by the Laguilharre process. Kiermeier (1965) points out that the critical consumer finds the flavour of UHT-heated milk slightly different from that of pasteurized milk. The reason for this is that at the higher heating temperatures the aroma substances of the milk – including the undesirable byre and feed odours – are removed to a greater extent, so that one consumer finds the flavour to be flatter while another finds it is purer. On the other hand the cooked flavour of these milks and milk products is normally stronger although it can fluctuate from "mild" to "pronounced"; this does not only depend on the sensitivity of the palate but on a variety of other factors.

The direct UHT-processes, in which the injected steam for heating the product is removed again under vacuum after the UHT-treatment, are the most efficient processes for the removal of undesirable byre and feed odours. The milk undergoes a very powerful steam distillation, whereby the volatile odour and flavour substances are carried away with the steam.

Various reports have been published on the removal of undesirable odour and flavour substances from milk by vacuum steam distillation (Scott, 1956; Roberts, 1959; Anderson et al, 1961; Graves et al., 1962) which show that the efficiency of the process depends largely on the intensity of heating and the quantity of steam passed through. Thus Graves et al. (1962) worked at relatively low temperatures (67.5 to 95°C) using steam injection and obtained a very limited efficiency in the removal of garlic, silage, feed and boiled flavours.

The UHT-steam injection processes operating at temperatures of 140 - 150°C produce far more extreme conditions. In the uperization®process some 13 kg steam are required to heat 100 kg milk from about 80 to 150°C. In the steam removal process under vacuum following the UHT-heating, a vigorous boiling takes place with the result that the volatile odour and flavour components in the milk are carried away with the evolved vapours. At the same time the process also brings about extensive deaeration, so that any oxygen present in the milk is almost completely removed (Haerry, 1953). Changes occurring during storage in the aseptically filled UHT-milk are retarded. (Fuchs, 1953; Fuchs & Stein, 1960), Hostettler, 1968; Porter & Thompson, 1968; Lechner & Kiermeier, 1969). Practical experience in the direct heating process (steam injection and subsequent steam removal by flashing into an expansion vessel, namely:

- almost complete removal of undesirable byre and feed odours
- reduction of cooked flavour by removal of volatile SH-compounds
- reduction and retardation of the changes in the milk after filling

are achieved in certain indirect processes; here a flashing stage is arranged in the heating procedure in which the water withdrawn in the form of steam is condensed and subsequently added back to the milk. Deaeration is thus carried out without concentration of the milk.

The quality of the steam is of the greatest importance in its effect on the flavour of milk sterilized by the UHT-steam injection process and in principle should be produced only from water of potable quality. It must be odourless and tasteless. Additions to the boiler feed water which could create a health hazard or have an undesirable odour effect on the steam generated are not permissible. The quality of the steam must correspond to all further requirements as stated in legal prescriptions.

Numerous publications deal in detail with the changes in the flavour of milk during storage brought about by UHT-heating. Burton (1959) points out that UHT-milk immediately after UHT-treatment has a hydrogen sulphide odour and a cooked flavour which disappears within 24 h.

Wälzholz et al. (1962) point out that uperized milk freshly filled into cartons (Tetra Pak) has a cooked flavour which, however, can no longer be detected after 24 h storage. Walser (quoted by Regez, 1962) found a higher resistance to the formation of oxidized flavours in uperized milk than in pasteurized milk. Based on experiments carried out by Gould (1939), Josephson (1939), Greenbank (1940) and Stewart (1951), this was traced to the formation of reducing substances.

The sulphhydril (–SH) groups formed during heating must largely be held responsible for this effect. Extensive experiments were carried out by Kiermeier et al. (1961 a, b, c) on the formation of SH–groups, the factors affecting it and also on their behaviour during storage of the milk and milk products (Kiermeier et al, 1962). Dill et al. (1962) investigated the effect of direct steam heating in an Aro–Vac plant on the formation of heat activated sulphur compounds in skimmilk over a range of temperatures from 88 to 149°C.

They showed that on vacuum-cooling the amount of titratable sulphur compounds falls. This drop was considerably greater on vacuum-cooling than on cooling in a plate cooler. From this difference found in the two cooling systems it was concluded that part of the activated sulphur compounds are transformed into a volatile form. Blankenagel et al. (1963) showed in experiments carried out in a plate heater at temperatures in the range from 82.2 to 140.5°C and a holding time of 3.5 s, that the first effect of an increase in temperature was a denaturation of the serum proteins which was followed by the formation of SH–groups and finally by the appearance of a cooked flavour. Keeping the holding time constant both the formation of SH–groups and the intensity of the cooked flavour reached a maximum at 130°C; at higher temperatures both were produced to a smaller degree. The main source of the SH–groups is the β - lactoglobulin which was found to have undergone complete denaturation at 130°C. Skimmilk UHT-sterilized at 140.5°C and stored at room temperature for one week contained no more SH–groups; stored at 4.5°C small amounts of these reducing groups were still found in the milk after 3 weeks. Lyster (1964) distinguishes between free and masked SH–groups and shows that in UHT-sterilized milk immediately after heating almost all the SH–groups are free. During cold storage (4°C/98 h) the total content (masked and free) of SH–groups is reduced only to a small extent; during storage at room temperature, however, it diminishes very quickly within 48 h. Ashton (1965) made extensive and detailed studies on the changes in flavour of UHT-sterilized milk (APV, VTIS–Alfa Laval). The first one to 2 days after processing, the flavour is unsatisfactory, improves quickly on storage at 4 - 21°C and approached that of pasteurized milk. The optimum is reached after 5 - 12 days, then gradually falls off while a flat, chalky flavour is developed. Higher storage temperatures (27 - 38°C) and longer periods of storage speeded up these changes. The use of aluminium-coated packaging material slows down these processes, blackened paper has but little effect. After UHT-heating the content of free SH–groups fluctuates within wide limits which also depend on the season. A quick drop is observed in the first 3 h after processing followed by a slower decline.

In a further publication Ashton (1969) deals in detail with the changes in flavour taking place in UHT-treated milk. These changes are closely connected with the time/temperature conditions or the intensity of heat treatment to which the milk is subjected.

The flavour developed in milk treated by the UHT-process is classified as follows:

(i) a caramel or cooked flavour, similar to that developed in the commercially in-bottle sterilized milk

(ii) a strong sulphydryl or "cabbage" odour similar to that of boiled milk and which remains detectable after the milk has been cooled.

In freshly treated UHT-milk the sulphhydryl or cabbage smell masks the caramelized effect.

The following table has been drawn up to show the changes in flavour which occur:

A Primary phase	(a)	Initial heating flavour accompanied by a strong sulphhydryl or cabbage smell
	(b)	Weaker sulphhydryl or cabbage odour with residual cooked flavour
	(c)	Residual cooked flavour with normal acceptable agreeable flavour.
B Secondary phase	(d)	Normal acceptable to agreeable to flat acceptable flavour
	(e)	Flat acceptable to starting oxidized flavour
	(f)	Incipient oxidized flavour (or rancidity) to pronounced rancidity.

Later in the last phase, initial gelation progressing to distinct gelation can be observed. This process is of physico-chemical nature and has no connection with the changes in flavour.

The different phases in the changes of flavour are discussed in detail and special attention is given to the effect of the oxygen present in the milk. In closed indirect systems the percentage of oxygen dissolved in the milk falls only little during heating, and after heating is still present in quantities of 10 ppm. The initial heating flavour and the strong sulphydryl or cabbage odour then disappear quickly within 1 to 3 days, the primary phase A in the Ashton table is quickly passed through to reach phases (c) and (d). In the direct heating systems flash-cooling under vacuum leads to almost complete removal of the oxygen present (Haerry, 1953).

By this expansion part of the free sulphhydryls are also carried away, odour and flavour reach the condition prevailing in phase (B) and show then a residual cooked flavour similar to that of the milk heated and deaerated by the indirect process. Passage through the subsequent phases of the changes in flavour is very much slower in the absence of oxygen.

The fall in SH–groups present is speeded up by exposure to light and storage temperature (Kiermeier & Hamed, 1961, 1962). According to the same authors (1962) milk fat seems to hinder the decrease of SH–groups in the milk exposed to light, since in whole milk the fall in SH–groups was somewhat lower than in skimmilk. Kiermeier & Ranfft (1970) suggest that the difference in the stability of the sulphydryl groups as a function of the heating temperature, the holding time and the storage temperature is due to an up till now unknown enzyme, the sulphydryloxidase, which oxidizes the sulphhydryl groups. This enzyme acts specifically on both any added substrate containing SH–groups and also on SH–groups linked to protein compounds.

Jordan (1968) confirms that the flavour of milk due to sulphhydryl groups disappears within a few days as a result of oxidation processes. In the direct heating process by steam injection oxidation takes place at a slower rate due to the removal of oxygen. By passing oxygen through the product, oxidation of the reducing substances is speeded up; AB Tetra Pak (1963) took out a patent to have this process protected.

The effect of the oxygen content on the flavour of UHT-milk during storage was thoroughly investigated by Zadow (1970). Milks with different oxygen contents and heated by both the direct and the indirect UHT-processes were compared.

After storage for short periods the milk with a high oxygen content was given preference. After storage for longer periods the milk with a low oxygen content was found to be better. Samples with a high oxygen content led to remarks such as "oxidized" or "slightly rancid".

The development of a stale flavour after storage of UHT-heated milk for 2 months at 22°C is attributed by Kirk, Hedrik & Stein (1967) to the storage temperature.

Besides discussing the effects of the type of heating process used, temperature/time relation, oxygen content, odour and flavour defects of the milk before heating, exposure to light, storage temperature, type of packaging and packaging material on the changes in flavour taking place in the milk, numerous additional effects due to the properties of the raw milk must be mentioned. With regard to the release of sulphydryl groups during heating variations must be expected, since the properties and the composition of the milk varies from animal to animal, from breed to breed and also depends on the type of feed. On heating individual milk samples Riel & Tanh (1970) found great variations in the sulphydryl content from one milk sample to the next. They showed that summer milk is more resistant to a loss of sulphydryl groups by heat than winter milk. They concluded from their work that each milk has a threshold value and a resistance to denaturation. Burton (1959) pointed out that the SH–content of heated milk is dependent on the treatment of the milk before heating.

The result of the changes in flavour taking place in the second phase of Ashton's table is also largely affected by environmental conditions, such as storage temperature, exposure to light and oxygen. Packaging in tin cans gives complete protection against light and oxygen. Only UHT-milk packaged in this way can be called a preserve. Uperized milk filled into tins was marketed for the first time in Switzerland in 1953 (Hostettler, 1961; Hostettler, Fuchs, Löliger & Regez, 1961; Regez, 1962). When a heating process adapted to the keeping quality requirements with regard to thickening and gelation was used, a keeping quality of 12 months was achieved. With milk packaged in cartons, the most effective protection against light is paper lined with aluminium; within a short period this was generally used as a packaging material already shortly after the introduction of aseptic filling of uperized milk into tetrahedral cartons. The comparative experiments carried out by Flückiger (1970) dealing with the effect of the packaging material on the quality of UHT-milk confirmed that the paper lined with aluminium is superior to a carton paper provided with a black inside layer. The insufficient protection against light of the latter material has also been recognized by Ashton (1965). This foil also is too permeable to oxygen (Flückiger, 1970), so that within a few days after filling the milk is saturated with oxygen, while in a pack made from foil lined with aluminium the originally low oxygen content of the uperized milk is maintained. But even in this foil a slow penetration of oxygen, for instance through the seams, cannot be ruled out. The change in flavour takes place very slowly here; nevertheless, depending on the storage temperature, phase (f) in the Ashton table will be reached sooner or later.

For UHT-milk filled into glass bottles the question of protection against light is of major concern; so it is when plastic bottles are used. In the latter case the additional problem arises of protecting the milk against infiltrating oxygen.

Several investigators dealt with further odour and flavour substances which can be found in fresh and stored UHT-milk. Making use of GL- and TL-chromatography, numerous substances were found and identified.

According to Tharp & Patton (1960) δ - dodelactone and δ - dodecalactone are partly responsible for flavour defects in heated and stored milk products, such as the development of a coconut-like flavour. Scanlan et al. (1968) dealt with volatile odour and flavour components developed in the UHT-processes. Milk heated to 146°C for 4 s by the indirect process was distilled under vacuum immediately after heating. The raw milk used in the experiment was treated in the same way. The numerous substances separated and identified in the experiment, were formed directly by the heating process; they are listed in the author's article.

Patel et al. (1962) identified numerous flavour components which had formed during storage in concentrated milk standardized to a total solids content of 36.6% and heated in a tubular heater to 146°C for 3.5 s. Storage at increased temperatures led to considerable increase in the formation of volatile odour and flavour substances.

Some of these substances could be detected only after storage, not in the freshly heated product. Substances listed in connection with changes in flavour are ethanol, dimethylsulphide, acetone, 2-pentone, pentylacetate. Arnold et al. (1966) identified numerous components of the stale flavour of sterile concentrated milk. Seehaver (1969) considers that the improvement in flavour of UHT-sterilized and aseptically filled concentrated milk is substantial compared with milk sterilized in the autoclave.

III TEXTURE AND STRUCTURE

a. Sediment formation

Texture and structure of UHT-heated milk are closely connected with its taste. During UHT-heating coagulae in the submicroscopic to microscopic region can be formed; during storage this can lead to separations, such as ground deposits and the collection of a fatty-sandy mass at the tip of the tetrahedral carton. In connection with this a deviation from normal milk, perceived by the tasting sense of the tongue and palate as "chalky" to "sandy", is found when taste tests are carried out.

According to reports published in the literature, milk fat homogenization is related to sediment formation (Humbert, 1956; Jackson & Brunner, 1959). Fox, Holsinger, Caha & Pallansch (1960) have described a fat/protein complex which is formed under the influence of homogenization. They found that the formation of the complex is enhanced by an increase in the homogenization pressure, of the fat content and of the solids content. An increase in calcium concentration also has a promoting effect.

The formation of this fat/protein complex goes hand in hand with an increase of viscosity and a reducing heat stability. Deyscher, Webb & Holm already in 1929 dealt with the problem of the effect of homogenization on the heat stability of milk; they found that at pressures above 200 atm the heat stability declined substantially. An increase in the content of fat free dry matter and a non-satisfactory raw milk have a deteriorating effect.

A decline of the heat stability by homogenization was also found by Demott (1955). Wilson et al. (1960) showed that the quantity of sediment in milk after UHT-processing increased with the intensity of the heating process. They used the centrifuge for determining the quantity of sediment. During storage the quantity of sediment fell off. Samuelsson, Gynning & Olsson (1962) investigated the effect of the steam injection process on the formation of sediment. They found that the alcohol test was a good method to determine the sensitivity in the formation of sediment. A test result of 85% or less was always connected with much sediment, while 95% gave little sediment. The process conditions had some effect, but the quantity of sediment could be controlled by addition of citrate and bicarbonate. Thome, Samuelsson & Holm (1964) showed that the quantity of sediment increased with an increase of the heating temperature and holding time in the region 140 - 150°C and 2 - 4 s respectively. Samuelsson & Holm (1966) found furthermore that less sediment was formed in the direct UHT-process than in the indirect process. Corradini, Dellaglio & Bottazzi (1967) arrived at a contrary result, namely that less sediment was formed in the indirect process than in the direct process. The same result is reported by the United States Steel Corp. (1965).

Sediment formation in the uperization process was thoroughly investigated by Hostettler & Imhof (1963). They confirmed the formation of a fat/protein complex due to homogenization as described by Fox et al. (1960) and were able to take electron microscopic pictures of the aggregates formed. They found that the formation of such aggregates by the attachment of milk proteins (casein and whey protein) to the newly formed surface of the fat globules depends on the homogenization pressure, the fat content and the content of dry matter. A considerable formation of these aggregates can occur in whole milk, even if low homogenization pressures are used.

This can be clearly seen in the clarifixation of whole milk in the clarifixator described by Storgards (1962). (Fig. 1).

The effect of the formation of these aggregates became apparent during storage of UHT-milk in the form of a greatly increased quantity of sediment which was deposited on the bottom of the carton. With the formation of these aggregates the viscosity measured in the Oswald viscosimeter had also risen. As had been found already by Fox et al. (1962) the conglomerates show a varying behaviour in the centrifuge depending on the fat/protein ratio: one part sinks to the bottom, another part rises to the top, while a further part remains in suspension. The formation of the fat/protein agglomerates described is caused by the destabilising effect of homogenization on milk and milk concentrates as shown by other authors (Deysher et al., 1929; Demott, 1955).

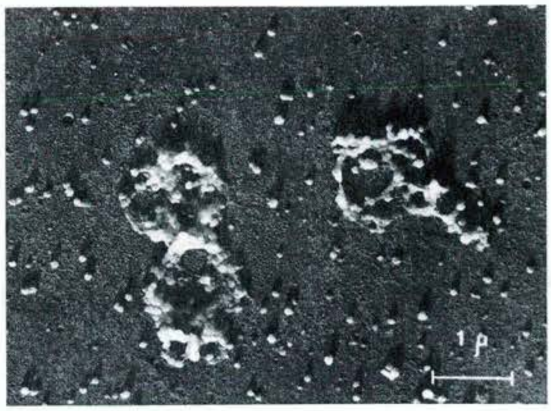

Figure 1

Casein/fat aggregation during clarifixation of whole milk

During subsequent UHT-heating the agglomerates are condensed to compact particles under the effect of heat shock. As soon as that exceed a certain size, their impression on the tongue and palate is that of chalkiness. If, however, homogenization is carried out after UHT-heating, then these conglomerates are not formed at all or to a much smaller extend. In this case the distribution of the casein particles in uperized milk differs little from that in pasteurized milk.

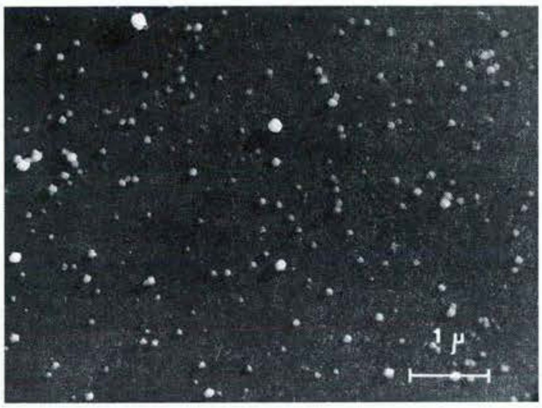

Figure 2

Casein particles in raw milk

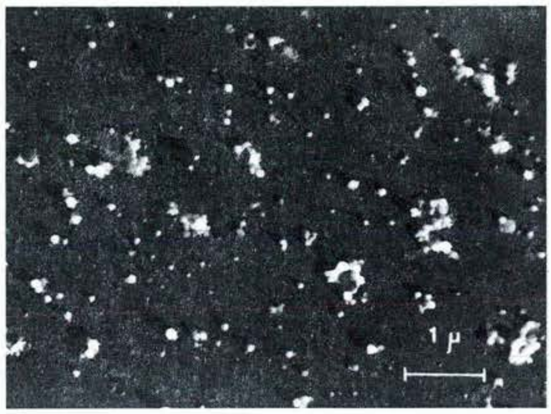

Figure 3

Pasteurized, homogenized whole milk

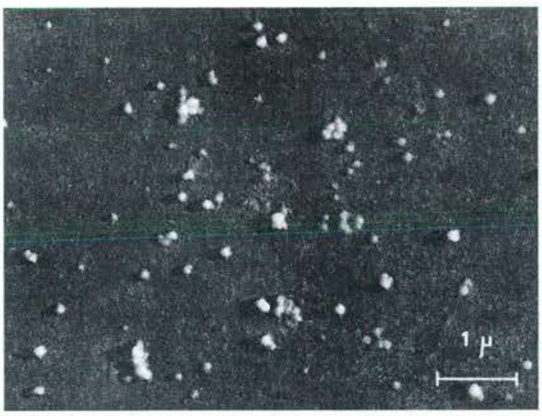

Figure 4

Uperization before homogenization

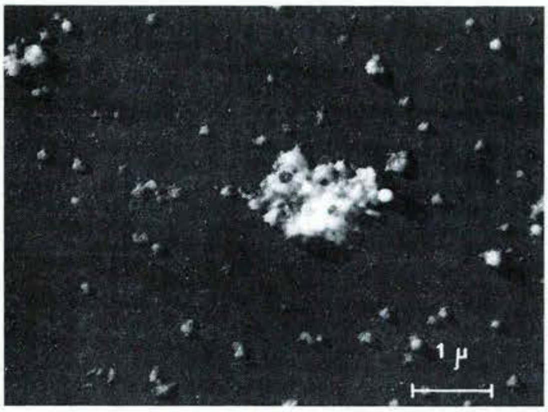

Figure 5

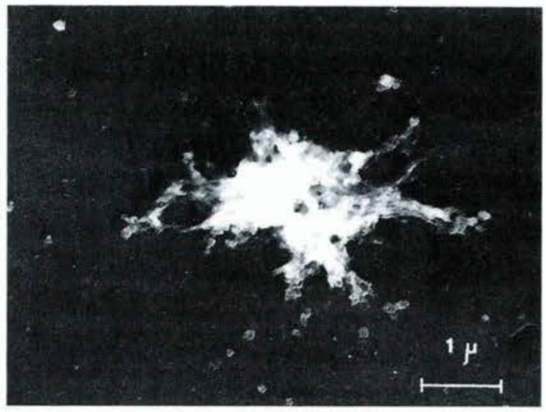

Figure 6

Uperization after homogenization

Practical experience confirms that by downstream homogenization in the Uperization-process the defect of chalkiness can change. This arrangement is more costly, however, since it requires the use of a sterile operating homogenizer. Jordan (1968) found in confirmation of these investigations, that the destabilisation of milk constituents and the agglomeration of fat/protein in UHT-milk products can be prevented if the homogenizer is arranged downstream in the UHT-system. For UHT-ice cream mix this arrangement has the advantage that the addition of stabilizers can be reduced.

b. Distribution of the milk proteins

Detailed investigations about the effect of heat on the distribution of milk proteins were carried out with skimmilk (Hostettler, Stein & Imhof, 1965). It was shown that during pasteurization (85°C), uperization (150°C/2.4 s) and sterilization (117°C/15 min) the quantity of protein fractions precipitated at pH 4.6 increased with increase in temperature and holding time of the heat treatment process (Table 1).

The increase in the protein fraction precipitated at pH 4.6 occurs because part of the heat labile whey proteins are deposited on the casein particles and are brought down with them when they are precipitated in the acid product (pH 4.6). A considerably larger portion of the milk proteins remains in the milk serum during pasteurization and uperization than during sterilization in the autoclave as pointed out by Burton already in 1959. He found that considerable differences can be obtained depending on the quality and degree of maturity of the raw milk. Based on these investigations it can be concluded, that with regard to the distribution of the milk proteins, uperized milk is more akin to pasteurized milk than to milk sterilized in the autoclave.

This can also be seen in the electron microscopic pictures (Fig. 7 - 10) which show the distribution of the casein particles.

Electron microscopic pictures of skimmilk

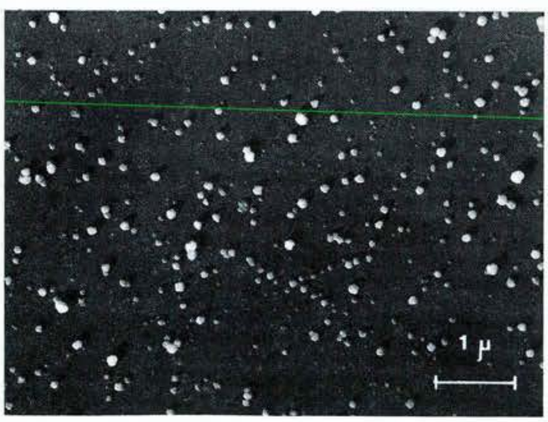

Figure 7

Raw milk

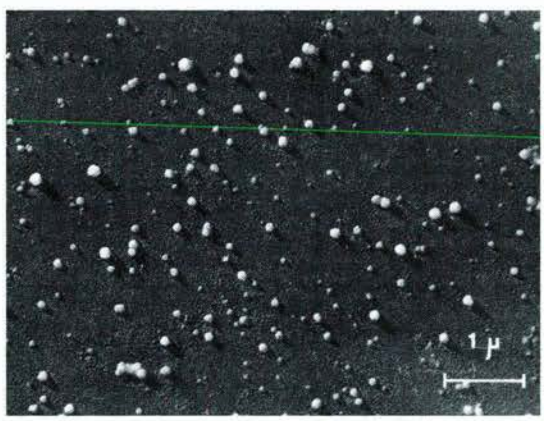

Figure 8

Pasteurized 85°C, continuous

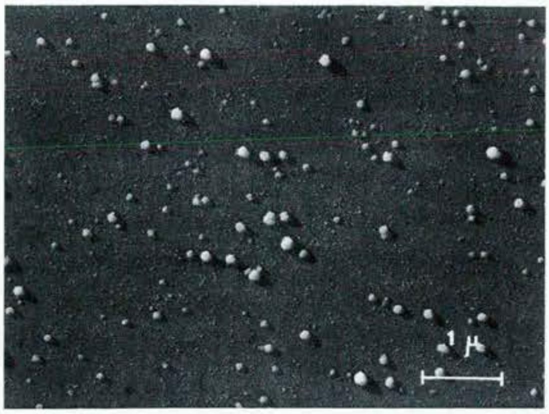

Figure 9

Uperized 150°C/2.4 s

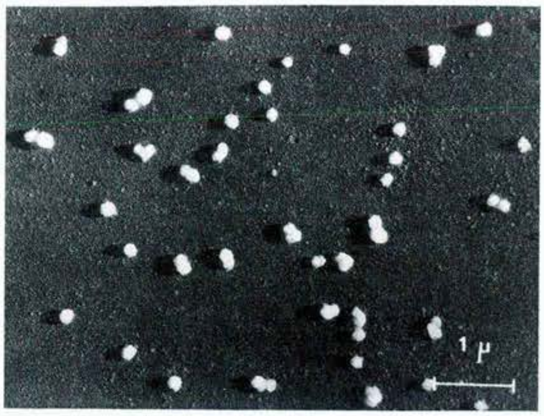

Figure 10

Sterilized in autoclave 117°C/15 min

Table 1. Protein fraction precipitated at pH 4.6

Test No	mg N per 100 g skimmilk			
	Raw Milk	pasteurized	uperized	sterilized
		85°C	150°C/2.4 s	117°C/15 min
1.	411.9	434.1	446.4	472.7
2.	428.1	445.6	446.4	492.6

Measurement of the particle diameter gave a mean value of 120 nm for sterilized milk and 83 nm for a raw milk.

The increase in size of the casein particles is a function of the content of fat free dry matter and of the intensity of the heat treatment. It is apparent in the 3 : 1 non-sweetened condensed milk (Hostettler, 1968). Since these experiments were carried out with skimmilk, homogenization was not necessary, so that no particle conglomerates were formed (Fig. 7 - 10). According to Ramauskas & Urbene (1970) intense heat treatment results in an increase in size of the casein particles, according to Nakanishi & Itoh (1970) in decomposition of the stabilized κ - casein, and according to Davidov, Kulebjakin & Jaroshkevitch (1970) in cross-linking of the casein micelles over β - lactoglobulin.

The reason why the Aschaffenburg turbidity test (1950) is always positive for UHT-milk is, that a considerable portion of whey protein remains in the serum of UHT-milk. O'Sullivan (1970) points out that conventional sterilization also does not result in complete denaturation of the whey proteins. The filtrate of conventionally sterilized milk saturated with sodium chloride lead to a limiting value for the denaturation of the whey proteins of approximately 80%. Burton & Perkin (1970) report, that in their investigations 82% of the β - lactoglobulin and 53% of the residual albumin were denatured in the indirect UHT-process and 66% and 40% respectively in the direct UHT-process.

c. Distribution of the milk fat

In the production of UHT-milk the consumer objects particularly to the development of "cream plugs" or cream layers during storage of one-trip containers for longer periods. (Kiermeier, 1962). Therefore special attention must be given to homogenization. The rising of cream can be counteracted by reduction of the mean diameter of the fat globules to 1 - 2 μ.

Deutsch & Jackson (1970) report that the quantity of fat in the uppermost 6 ml layer and in the layer adhering to the walls must not exceed 1 g after storage for 6 weeks at 15°C, if after 20 weeks the milk is still to show satisfactory physical properties. In order to obtain as little cream rising as possible in enriched UHT-milk, homogenization must be carried out in such a way, that less than 7% of the fat globules exceed a diameter of 1.25 μ.

d. Age thickening and gelation

Age thickening and gelation of UHT-heated milk and milk concentrates means an inclination of the product to become more viscous on storage and finally to coagulate under formation of a gel. Gelation can also occur only partially, so that the gelated portion in the container sinks to the bottom and on top of it an apparently unchanged portion of the milk amasses. This phenomenon is not to be confused with the heat coagulation due to insufficient stability of the potein/salt-system of the milk during heating.

Various articles have been published to deal with this feared phenomenon. Bell, Curran & Evans (1944) and Deysher, Webb & Holm (1944) found for the first time that evaporated milk (26% dm), treated by the high temperature short time heating process (135°C/30 s), age thickened and gelated during storage (30°C) within 6 - 16 weeks. The same milk sterilized by the conventional method in the autoclave (115°C/18 min) showed much better stability on storage.

When the UHT-process by steam injection (Uperization ®, Alpura AG Bern) was developed it was found, that the milk heated by this process (150°C/0.75 s) was often, though not always, inclined to age thickening and gelation during storage. A thorough investigation was undertaken to find the reason for this behaviour, which is undesirable for the marketing of the product. (Hostettler, Stein & Bruderer, 1957). The following changes were found to have taken place in the milk gelated during storage:

a. casein proteolysis resulting in the formation of soluble non-casein nitrogen-fraction

b. a reduction in the relative concentration of the β - casein in the electrophoresis picture of the total casein

c. change in the electrophoresis picture of the α - casein (cleavage of the α - casein gradient), similar to the change in casein brought about by the rennet enzyme

d. an increased sensitivity of the casein to calcium ions in the calcium ion test similar to that of rennet casein.

Based on these findings it was considered possible that an enzymatic process brought about by reactivated milk proteases is the root of these changes. Such a reactivation of milk proteases could not at all be ruled out, since Fuchs (1953) had detected a reactivation of alkaline phosphatase. Similar conclusions were drawn by Murthy, Herreid & Whitney (1958) and Leviton, Pallansch & Webb (1961) based on their investigations.

The tendency of uperized milk to gelate during storage could be kept under control by an increase of the holding time from 0.75 s to 2.4 s and packaging in aluminium cans instead of tin cans. Enzyme reactivation was not found in experiments carried out later by Wüthrich, Richterrich & Hostettler (1964). In spite of numerous further publications (quoted by Hostettler, Stein & Imhof (1968), the cause for the behaviour of unsweetened milk concentrates during storage varying with the specific heat treatment undergone could, however, not be elucidated. Thus further experiments had to be carried out. For this purpose the behaviour of uperized (150°C/ 2.5 s) and autoclaved (110°C/16 min) evaporated milk was compared during storage at room temperature. The uperized milk gelated after seven months, while the autoclaved milk was still liquid after 12 months. The experiments carried out in regular intervals over the period of 1 year (nitrogen distribution, pH measurement, electrophoresis, calcium ion test) showed striking differences in the behaviour of the 2 types of milk. Based on these and earlier experiments we came to the following result for the reactions leading to gelation of UHT-heated milk.

Due to complex formation of casein with the whey proteins (protein/protein interaction) during sterilization in the autoclave, the casein is protected against any possible later changes. In autoclaved milk the reaction between casein and whey proteins is irreversible. The small amount of heat which is conveyed to the milk in the UHT-process has the effect, that the aforesaid reaction proceeds incompletely and is reversible in UHT-heated milk.

This reveals itself in that after a certain building-up period during storage the casein/whey protein complex in the uperized milk is again dissociated into 2 fractions. One of these fractions retains the IEP of the casein, while the other takes up the properties of the whey proteins. The casein continuously destabilized in this way and no longer protected is thus exposed to further changes. Such changes are revealed in the cleavage of α - casein and the splitting off of a NPN-fraction which is soluble in 4% TAA. With participation of the calcium ions this is followed by gel formation.

This process became very clear in an investigation on partially gelated evaporated milk: In the gelated portion of the casein deposited at the bottom the cleavage in the α - gradient was very marked (Fig. 11), while the casein in the milky liquid portion on top of the sediment did not show such a cleavage (Fig. 12).

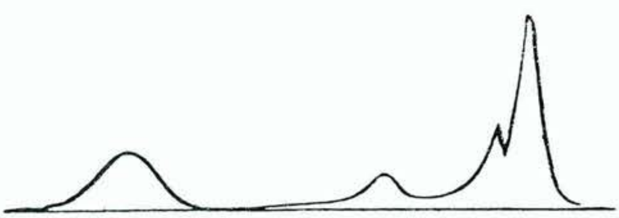

Figure 11

Figure 12

Partially gelated evaporated milk. Electrophoreses diagram of the casein in the gelated sediment (left). Electrophoreses diagram of the casein in the still milky liquid portion (right).

It is not yet completely understood how this cleavage comes about. The possibility that gelation is initiated by enzymatic action – proteolysis – cannot be ruled out. On the other hand the possibility that the change which the casein complex undergoes is due to a purely physico-chemical reaction must be taken into consideration. No proteolytic enzymes which survived the heating process or could be reactivated were found by Nakai, Wilson & Herreid (1964) in sterile concentrated milk, which gelated within 4 - 5 weeks. They conclude that such enzymes do not take part in the gelation process of concentrated UHT-heated milk. Samuelsson & Holm (1966) on the other hand express the view, that reactivation of proteolytic enzymes is the cause for gel formation. Fox et al. (1967) have expressed the view that gelation in UHT-heated milk is due to protease activity of spore-forming bacteria. Harper, Hidalgo & Mikolajeik (1970) showed that *Bacillus cereus* protease that partially survives UHT-heating, is inhibited by polyphosphate and activated by glutathione and disodiumphosphate. They express the view that the protease of *Bacillus cereus* is a factor in the gel formation of UHT-sterilized milk.

Liquist (1970) also is of the opinion that the slow coagulation of UHT-sterilized milk can be looked upon as a gentle enzymatic process. In order to obtain the greatest possible stability of UHT-products he recommends the use of bacteriologically satisfactory raw milk and storage at the lowest possible temperature, certainly not higher than 18°C, before the products are released for sale to the public. The storage properties of the products were improved by intense heat treatment prior to UHT-heating. Variations in time and temperature of UHT-heating proper has less effect than the pretreatment.

According to Swanson, Seehafer, Calbert & Geissler (1965) variation of the thermal treatment can result in some improvement; addition of polyphosphate, however, seems to have the best effect against gelation. In a more recent publication this has been confirmed by Seehafer (1969).

The various reports lead to the conclusion that the defect of gelation in UHT-heated milk and milk products can be successfully counteracted.

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CHAPTER 2b

APPEARANCE, FLAVOUR AND TEXTURE ASPECTS: RECENT DEVELOPMENTS

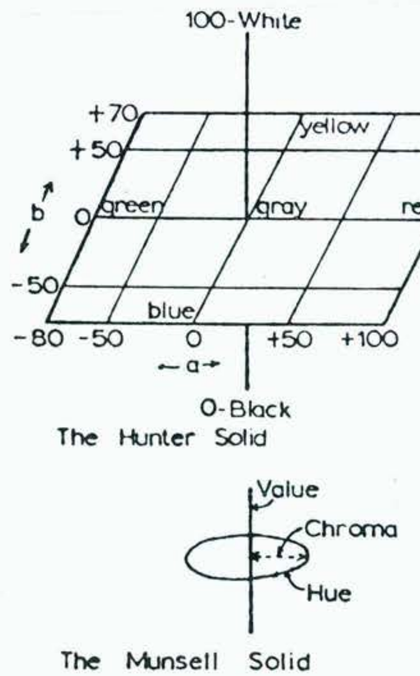
This chapter has been produced by Prof. Dr B. Blanc (Switzerland) and G. Odet (France) with the scientific assistance of Mr J. Adda (France) on questions of flavour, of Dr J.O. Bosset (Switzerland) on questions of colour and appearance, and of Dr M. Rüegg (Switzerland) for the section on texture and structure. Advice was also given by Dr E. Flückiger (Switzerland).

1. Appearance: colour and "aspect" of UHT milk.

Colour is the main sensory characteristic of milk which is immediately apparent and the only one which has been scientifically investigated on a practical basis. It is therefore the only aspect which will be expanded on in the following remarks. Hostettler (1972) has already dealt with the colour of UHT milk and the measurement of this colour in an earlier chapter (now chapter 2A) of this monograph. Although there have been no fundamentally new findings in the meantime, many aspects of this question which were already known have been confirmed or elaborated in more detail.

Most measurements of the colour of milk and milk products published so far (Francis, 1975; Clydesdale, 1975; cf. bibliography of Bosset et al., 1979) are measurements of the degree of reflectance of these products at one or several given wavelengths in the visible range. The values thus obtained cannot be translated directly into visual impressions. That is why some authors (Langsrud & Solberg, 1976; Bilinska & Klepacka, 1978; Bosset & Blanc, 1978; Bosset et al., 1977, 1978 and 1979) suggested using the tristimulus method according to Hunter (1958) to describe clearly and unambiguously the colours of these products (L, a, b) and the changes in them (Δ L, Δ a, Δ b) as a result of technological treatments (heating, homogenization) or storage. Consequently, the 3 parameters used are:

- lightness (or brightness) L : L = O black (minimum); L = 100: white (maximum);
- component a : a < O : green ; a = O : neutral ; a > O = red;
- component b : b < O : blue ; b = O : neutral ; a > O = yellow.



The Hunter and Munsell Color Solids.

Figure 1: according to Francis, F.J., in "Theory, determination and control of physical properties of food materials" (1975).

The photometers used all have filters or a monochromator and a continuous, constant light source. The new generation of multi-channel spectrophotometers with a "flash" lamp make it simultaneously possible to carry out colour analyses with different types of illuminants to establish reflectance and transmission spectrums and to calculate the tristimulus values, but they have apparently not yet been used for these purposes.

The specific influence of *homogenization* on the colour of whole and skimmed milk in the absence of any additional heat processing is shown in table 1 (Bosset et al., 1979).

Table 1: Influence of some homogenizations (in the absence of additional heat processing[1]) on skimmed and whole milk[2])

Homogenization pressure (bar)	Skimmed milk			Whole milk		
	L	a	b	L	a	b
0[3]	92.8	– 5.8	+ 11.8	93.7	– 2.3	+ 14.8
50	93.0	– 5.6	+ 11.8	95.0	– 2.1	+ 13.1
100	93.0	– 5.6	+ 11.8	95.3	– 2.0	+ 12.9
150	93.0	– 5.6	+ 11.8	95.5	– 2.0	+ 12.7
200	93.0	– 5.6	+ 11.8	95.5	– 2.0	+ 12.6
300	–	–	–	95.6	– 2.0	+ 12.4
400	–	–	–	95.8	– 2.0	+ 12.3

1) A slight amount of heating (approximately 50°C) is necessary.

2) The photometer is adjusted with the white standard.

3) Used as a reference.

After homogenization, the skimmed milk – and particularly its caseins – seems to show a small colour change which is characterised by a slight increase in lightness (L) and a slight decrease in the green component (– a). The yellow component (+ b) remains unchanged. On the other hand, whole milk – particularly its fat globules – shows a marked change in colour characterized by a considerable increase in lightness, a slight decrease in the green component and a very striking decrease in the yellow component. These results thus confirm those obtained by Zadow (1969), by Langsrud & Solberg (1976) and by Bilinska & Klepacka (1978). These variations have to be attributed to a considerable increase in the number and surface area of the fat globules following their fragmentation (Jones et al., 1964), to a more homogeneous distribution of these fat globules as well as their coloured vitamin A and β - carotene content (Buma et al., 1977) in the milk as well as to a slight change in the dispersion of the insoluble proteins. The predominant effect is a considerable increase in light scattering (cf. theory published by Burton, 1955b).

The specific influence of heat treatment on the colour of milk and milk products in general has been dealt with in various studies: the most recent results which compare raw, pasteurized and UHT milks before or after storage periods of varying durations are put forward in the publication of Blanc (1980) and Blanc et al. (1980). Table 2 shows the influence of the usual heating processes for whole milk with or without additional homogenization (Bosset et al., 1979).

Table 2: Influence of some heat treatments (with and without additional homogenization) on a whole milk[1]

(Temperature/duration)		Without additional homogenization			With homogenization at 200 bar[2]		
		L	a	b	L	a	b
1. None (reference)		93.7	– 2.3	+ 14.8	95.5	– 2.0	+ 12.6
2. Pasteurization	72°C/15 s	93.6	– 2.5	+ 14.8	95.6	– 2.1	+ 12.7
3. Pasteurization	92°C/20 s	94.8	– 3.0	+ 15.1	96.5	– 2.6	+ 13.2
4. Direct UHT	150°C/2.3 s	96.5	– 3.0	+ 13.8	96.9	– 2.8	+ 13.1
5. Indirect UHT	> 100°C/14 s[3]	96.4	– 3.7	+ 15.1	97.5	– 3.1	+ 13.3
6. Boiling (until the milk rises)[4]		95.1	– 3.4	+ 15.5	97.0	– 2.8	+ 13.5

1) the photometer is adjusted to the standard white

2) at 50°C, the minimum temperature at which the experiment functions

3) maximum 141°C

4) in a pan on an electric heating plate.

Burton was one of the first (1954, 1955a, 1955b and 1965, and Burton & Rowland, 1955) to demonstrate the influence of heating on the milk colour by measuring the degree of reflectance between 400 and 550 nm. His results were subsequently confirmed by many similar investigations (Jordan, 1968; Zadow, 1969 and 1970; Ismail & El Deeb, 1973; Vujicić et al., 1976; Langsrud, 1970; Langsrud & Solberg, 1976; Bosset et al., 1979).

The first effect of a heat treatment is an increase of the degree of reflectance and thus the lightness (whitening or paling of the milk) as a result of changes in casein size (Rüegg & Blanc, 1978), of the denaturation and precipitation of the whey proteins, particularly of the β - lactobulin (Burton, 1955a and Burton & Rowland, 1955; Dill et al., 1964; Melachouris & Tuckey, 1966; Jordan, 1968; Hostettler et al., 1965 and 1968; Hostettler, 1965; Blanc et al., 1974 and 1977; Rüegg et al., 1977) which increases the light scattering. Above a certain threshold, this effect is counteracted by browning reactions (Burton, 1954; Zadow, 1970; Langsrud & Solberg, 1977; Bosset et al., 1979) which then lowers the degree of reflectance and thus of the lightness. The green component as well as the yellow component show a striking increase. These non-enzymatic browning reactions in milk are closely linked to chemico-physical parameters, such as pH value of the medium, the temperature and duration of heat processing as well as the chemical composition of the milk (Burton, 1955b; Bosset et al., 1979). UHT treatment achieves maximum killing of bacteria with minimum browning (Burton, 1965), and seen in this respect, the direct UHT process causes less "damage" than the indirect UHT process (Zadow, 1969; Blanc, 1980). In addition, the steam injection used in the direct UHT process also homogenizes the milk to a certain degree (Zadow, 1969; Bosset et al., 1979).

The specific influence of *storage* has been studied by several authors, notably by Zadow (1970), Ismail and El Deeb (1973), Bosset & Blanc (1978) and Blanc et al. (1980). They note a decrease in lightness (L), a decrease in the green component and an increase in the yellow component. The higher the storage temperature, the more marked the variations (cf. 5 to 25°C).

The determination of the ferricyanide reducing (FR) substances or the protein reducing substances (PRS) (Choi, 1953) as well as the hydroxymethylfurfural (HMF) content have often been used to follow the browning reactions of milk, particularly following heating or storage (Zadow, 1969 and 1970). Skimmed milk subjected to direct or indirect UHT sterilization at 145°C for 3 s reveals higher FR and HMF values in the case of indirect processing than for direct processing. During storage at 2°C, the FR and HMF values decrease. This decrease occurs more rapidly in milk samples heated by the direct process than in those heated indirectly. The greatest decrease in FR and HMF values occurs during the first few days after treatment, a period during which a rapid change has been noted in the taste of UHT products. Three days after processing, direct-processed UHT milk shows only a low level of reducing properties and a small degree of intermediate browning products. When examined 3 days after treatment, UHT milk heated by the indirect process still contains a considerable percentage of highly reducing properties and a higher proportion of intermediate browning products (Hostettler, 1972).

UHT-treated condensed milk does not show any change of colour (browning) either as compared to pasteurized products (Seehafer, 1969). Colour stability during processing is an advantage which cannot be obtained during heating in an autoclave. Milk condensed in a 3/1 ratio and then uperized is clearly whiter than autoclaved milk (Hostettler, 1972).

A particularly striking colour difference between UHT and autoclaved milk shows up under ultra-violet light. Pasteurized and uperized milks show a yellow fluorescence whereas autoclaved milk has a blue fluorescence (Hostettler, 1972).

2. The texture of UHT milk

The term "texture" describes a sensory property of UHT milk, and "structure" a physical one. In other words, texture comprises the structural aspects which are relevant to the senses. Since there are direct links between texture, structure and physical and physico-chemical properties, it is necessary to mention at this point the numerous characteristics of UHT milk which will be discussed in detail hereafter.

The essential textural aspects of UHT milk and the structural changes which occur during storage have already been reviewed by Burton (1969) and later by Hostettler (1972) in the previous IDF monograph (see chapter 2A in this monograph). Since then, our basic knowledge of the subject has not changed significantly. However, mention should be made of the new methods of analysis applied, the expansion of knowledge and the confirmation of certain hypotheses.

a) Methods

Since the textural changes are mainly caused by changes in the substances which are colloidal or coarsely dispersed in the milk (fat globules, casein micelles, denatured whey proteins, colloidal salts), methods pertaining to electron microscopy along with analysis of the particle size have been used.

The following list shows what other methods are appropriate for studying the texture of milk, namely rheological, chemical and biochemical analyses. The importance of sensory examination should also be pointed out: admittedly, the method is subjective but it is nonetheless indispensable for ascertaining the acceptability of the milk.

It is sometimes difficult to compare the data published about UHT milk texture because many of the methods and terms have not been standardised and heating and homogenizing conditions are not always comparable. Particularly as far as sediment formation – a topic dealt with in the next section – is concerned, methodological differences have led to apparently contradictory findings.

METHODS APPLIED IN THE INVESTIGATION OF MILK TEXTURE AND STRUCTURE

Subjective methods

Sensory assessment

Objective methods

Physical techniques

Measurement of physico-chemical properties of milk and determination of physico-chemical parameters, and the structure of milk constituents

- viscosity
- surface tension
- thermal analysis
- optical analysis
- electric and dielectric measurements
- microscopy, ultramicroscopy and electron microscopy
- nuclear magnetic resonance (NMR)

Analysis of number, size, shape, solvation and fine structure of the dispersed particles

- microscopy, ultramicroscopy and electron microscopy
- electronic determination of the size and number of the particles
- centrifugation, ultracentrifugation
- gel permeation chromatography
- filtration, ultrafiltration
- hydrodynamic measurements (viscosity)

Chemical analysis of milk fractions

Distribution of milk proteins

- chemical separation (precipitation)
- electrophoresis
- chromatography

Chemical composition of dispersed and sedimented particles

- protein
- lipid
- organic compounds and mineral salts
- heat-induced complexes

Milk fat globules

- membrane analysis
- distribution of fat

b) Sedimentation and separating

Mechanical and thermal treatment of milk causes the formation of aggregates containing protein, fat, lactose as well as inorganic salts of varying composition. Depending on their size, specific weight and electric charge, these aggregates either sediment or clump together on the surface. Aggregates of a certain size give the sensory feeling of a "chalky" or "sandy" taste (Hostettler & Imhof, 1963). Moreover, deterioration in the fat globule membrane can cause the free fat to rise. The term "sediment" is not precisely defined. Some authors apply this term solely to layers which form without any centrifugation, and others use it to describe sediment produced under certain centrifugation conditions (Wilson et al., 1960; Samuelsson & Holm, 1966; Perkin et al., 1973; Blanc et al., 1980). This makes both the comparison of the results and interpretation of various authors difficult and leads to apparent contradictions (Perkin et al., 1973).

In general, the degree of sedimentation increases with the intensity of heat treatment (Wilson et al., 1960; Tome et al., 1964) but during certain processes, it can be reduced again by homogenization applied after heat treatment (Hostettler, 1972). Sediment formation depends on the process applied. However, it is only useful to compare processes when data is available about the intensity of the heat treatment and homogenization. It is understandable that the results obtained concerning sediment formation after direct and indirect UHT processing are contradictory. Perkin et al. (1973) note more sediment after application of direct heat treatment, a finding which coincides with the results of Corradini et al. (1967), in their turn recently confirmed by those of Blanc et al., (1980).

As yet, we have to precise data about the chemical composition of the sediments. Burton (1968) supposes that the sediments are similar to the matter deposited on the hot-plate surfaces in the heating apparatus. Under the electron microscope, fat and protein complexes can be distinguished in the sediment (Hostettler & Imhof, 1963). The quantity of sediment has usually been determined by gravimetry or by analysis of nitrogen ("protein sediment"). Corradini et al. (1967) compared the gels formed after storage with the sediment and found that their chemical compositions were similar.

Hostettler (1972) has already mentioned that the amount of sediment can be reduced by adding chemicals such as citrate, bicarbonate, hydrogen phosphate, etc. (Tome et al., 1964; Samuelsson et al., 1962; Samuelsson & Holm, 1966; Corradini, 1971) and by appropriate technological treatments, in particular during homogenization and heating. According to Snoeren et al. (1979), the addition of phosphate or polyphosphate does not seem to influence the enzymatic deterioration of the casein during storage.

The longer UHT milk is stored, the greater the amount of sediment. (Hostettler & Imhof, 1963; Corradini et al., 1967). In addition, Corradini et al. (1967) found a proportionality between the storage temperature and the amount of sediment. The amount of sediment produced by centrifugation decreases at the beginning of storage (Wilson et al., 1960; Blanc et al., 1980). Blanc et al. (1980) determined the protein content of sediment formed as a result of centrifugation and noted a marked decrease during the first 5 weeks of storage. After approximately 5 weeks, the amount of "protein sediment" increased slightly. The increase was independent of the storage temperature (5 and 25°C). By comparison, the increase observed in the amount of protein sediments was high in sterilized skimmed milk after 2 to 5 months (Aoki & Imamura, 1974; Aoki et al., 1977). The protein polymerizations observed by Andrews (1975) in stored UHT milk (Maillard reactions, disulphide bonds) explain in part this increase in sediment formation. The behaviour of the lipid phase of UHT milk has not been studied in as much depth; probably because creaming during the authorised storage period is avoided by sufficient homogenization (Kiermeier, 1962; Hostettler, 1972). Several authors have noted a specific effect of homogenization, particularly in the UHT process (Grosclaude, 1960; Kaliba et al., 1960; Zadow, 1969; Blanc, 1980). Zadow (1969) determined the distribution of fat globules having a diameter of 1 - 7 μm and found a greater fraction of smaller globules in milk treated by direct UHT processes compared to indirectly processed.

Table 3: Percentage distribution of fat globules in UHT milk (Zadow, 1969)

Diameter	Control	Direct heating					Indirect heating			
	Unheated	80°C	115°C	132°C	147°C	153°C	97°C	112°C	128°C	140°C
0-1 μ	7.6	45.9	69.7	83.7	88.5	88.3	10.6	26.6	28.1	31.5
1-3 μ	62.8	42.3	23.0	13.8	10.0	10.1	65.2	54.1	56.4	54.5
3-5 μ	21.9	9.9	6.0	2.4	1.4	1.6	19.7	16.9	15.4	14.0
5-7 μ	4.7	1.8	1.3	slight	slight	–	3.0	2.9	slight	slight
7 μ	3.0	slight	–	–	–	–	1.5	slight	slight	slight

The same group of researchers determined the stability of the lipid phase during storage by subjecting the milk to centrifugation and then analysing the fat distribution (Blanc et al., 1980). It was observed that the stability of the lipid phase is for the most part maintained when the storage temperature is 5°C but that at 25°C, a destabilisation of the lipid phase became apparent after some weeks. The following paragraph deals with the aggregates which are formed of fat globules and casein micelles.

c) Age thickening and gelation

It was realized at an early stage that milk products treated by UHT processes show a greater tendency to thickening and coagulating during storage than products sterilized traditionally in the autoclave (Bell et al., 1944; Deysher et al., 1944). The problem caused by this undesirable phenomenon is more serious for milk concentrates than for non-concentrated drinking milk. Normally, the tendency to gelation decreases when the intensity of the heat treatment is increased (Corradini, 1971; Samuelsson & Holms, 1966; Hostettler et al., 1968; Samel et al., 1971). It was also shown that the higher the intensity of heat used in UHT treatment, the smaller the micelle casein decomposition during storage (Farah, 1977; Blanc et al., 1980).

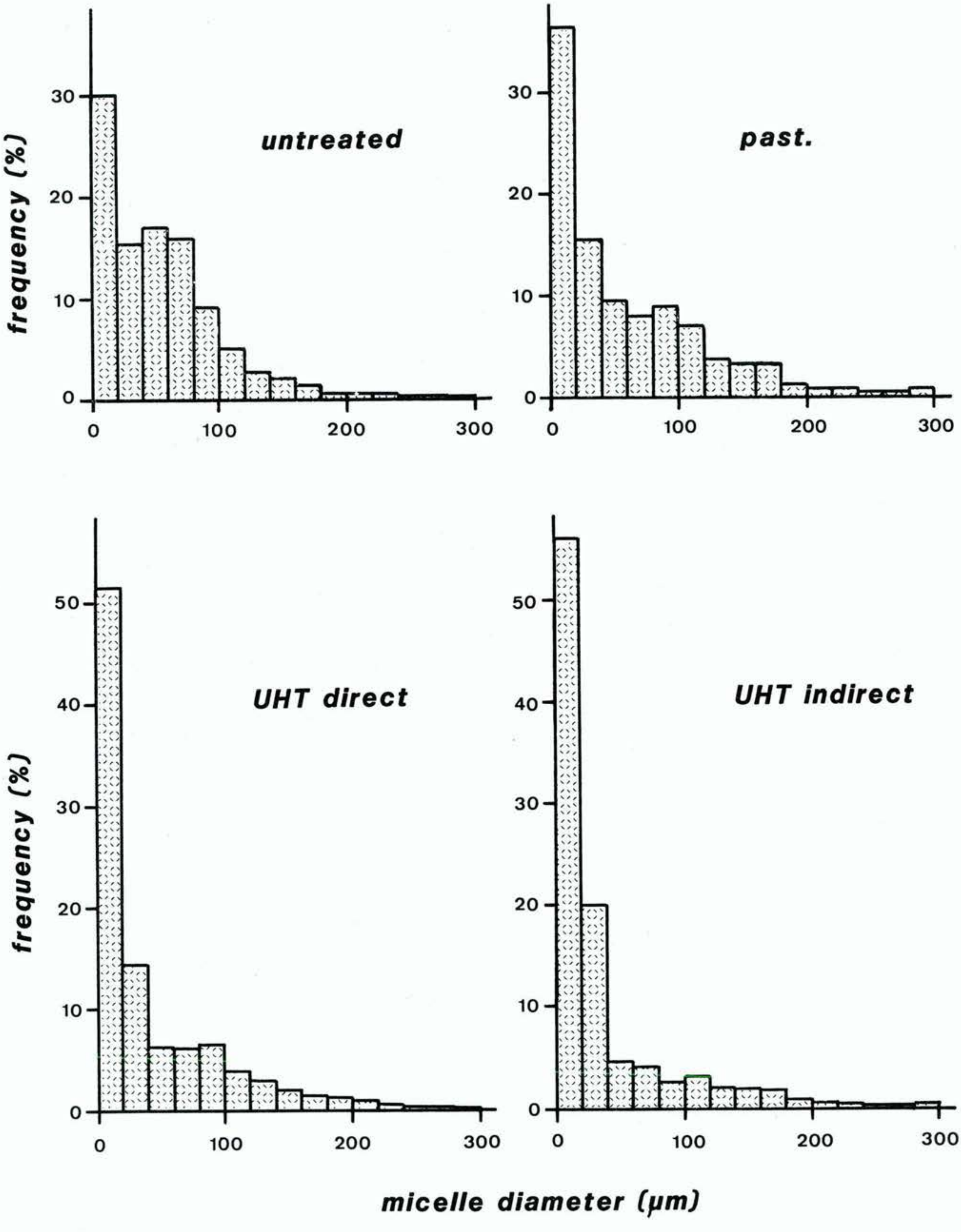


Figure 2: Size-distribution of casein micelles in raw, pasteurized and UHT-processed milk (Rüegg & Blanc, 1978).

Casein micelles are not the only components which contribute to the formation of the gel structure. Fat globules with newly formed membranes of caseins and whey proteins are also found in the 3 dimensional networks (Hostettler & Imhof, 1963; Andrews et al., 1977; Blanc et al., 1980).

The differences in gelation can be attributed, to a great extent, to the influences of processing on the casein micelles and fat globules. Other factors which are important are enzymes (see review of Law, 1979; Humbert & Alais, 1979) and the storage conditions. The heating and mechanical effects occurring during the UHT process and homogenization change the surface properties and size distribution of the dispersed particles. UHT treatment increases the number of free casein submicelles and, to a lesser extent, the proportion of extremely large casein micelles (Hostettler, 1965; Hostettler et al., 1965; Henstra & Schmidt, 1970: Rüegg & Blanc, 1978). Figure 1 gives examples of the casein micelle size distribution in raw and heated milks. Under the electron microscope, the surface of the micelles in heated milk looks "rough" and there are obvious distortions in comparison to the original shape (Andrews et al., 1977; Harwalker & Vreeman, 1978; Davies et al., 1978; Blanc et al., 1980). The adsorption of denatured whey proteins (Shalabi & Wheelock, 1967) and the elimination of calcium (Morr, 1975) make the micelles surface more hydrophobic (Rüegg et al., 1979).

During storage and particularly before gelation, the micelles structure changes still further. The storage temperature (Andrews et al., 1977) and the method of heat treatment (Blanc et al., 1980) both play a role in this change. In comparison to directly processed milks, the micelles of indirectly processed milk seem to change less (Blanc et al., 1980). Probably because the heat treatment is more intense and subsequently, the casein/whey protein complexes produced are more irreversible (Hostettler, 1972). Andrews et al., (1977) noted that differences become obvious when the storage temperature varies and also observed that there were structural differences between the various layers of packaged milk. In the upper layers with their higher fat content, fat globules linked by "casein bridges" were found, as is also the case with UHT cream. Whereas the casein particles in the fresh coagulum ferment, by a process of simple adsorption, a 3 dimensional reticulation, in UHT gels fibrous "casein bridges" have been observed between the micelles and the fat globules (see figure 2). Before gelation, the aggregates formed from fat and casein particles produce the "sandy" taste (Hostettler & Imhof, 1963).

The structural deteriorations observed mostly account for the rheological behaviour of UHT milk following processing and during storage. Immediately after processing, the viscosity of the milk increases by approximately 0.1 - 0.2 mPas (cp) as a result of homogenization and heating (Hostettler et al., 1965; Randhahn, 1973; Reuter & Randhahn, 1978; Jenness & Paton, 1959; Blanc et al., 1980). The change in viscosity during storage seems to depend mainly on the temperature (Blanc et al., 1980).

It remains constant for several weeks when the milk is stored in a cold place. If it is stored at room temperature, the viscosity increases during storage. Whitnah et al. (1956) found that at the beginning of storage, there is an almost linear relationship between viscosity and the logarithm of the duration of storage. Blanc et al. (1980) observed in certain cases that the initial exponential increase in viscosity at the beginning of the gelation process is followed by a decrease in viscosity. This phenomenon can be explained by a process of enzymatic coagulation in which protein hydrolysis precedes gelation (Payens, 1978). Since the rheological properties of milk are not ideal – unlike those of Newtonian liquids – the values published concerning viscosity are not always comparable. The viscosity of non-Newtonian liquids depends on the force applied for its measurement. The aggregates in milk can be disrupted during the measurement (Rha, 1975). Therefore, measurements of viscosity do not always give an accurate picture of milk texture.

Despite numerous experimental and theoretical studies on gelation in UHT milk, the phenomenon is still not fully understood. The following mechanisms – either individually or combined – have been suggested as possible interpretations of the experiment results:

PROCESSES INVOLVED IN THE AGE–THICKENING, GELATION OR COAGULATION OF UHT MILK

Physico-chemical processes

- Dissociation of the casein/whey protein complexes
- Crosslinking due to Maillard-type reactions
- Removal or binding of Ca ions
- Conformational changes of casein molecules
- General breakdown of micelle structure
- Interactions between β - lactoglobulin and χ - casein
- S–S exchange reactions
- pH change
- Dephosphorylization of the casein
- Interaction between χ - casein and carbohydrates

Biochemical processes

- Heat resistance and reactivation of natural milk proteinases
- Heat resistance and reactivation of bacterial proteinases of bacterial origin (psychrotrophic bacteria producing proteinases, bacteriological quality of raw milk)
- Survival of bacterial spores.

Several recent investigations have evidenced the presence of enzymic process (i.e. a slow proteolysis). Since the original bacterial condition of raw milk is related to the tendency to gelation (Snoeren et al., 1979), and as even freshly-processed milk with a very low germ content becomes gelated (Blanc et al., 1980), it seems that both native and bacterial proteases are present (see also reviews of Speck & Adams, 1976; Law, 1979, and Humbert & Alais, 1979). (*)

It has also been demonstrated that purely chemical processes such as the Maillard reaction and purely physical mechanisms, come into play. Therefore, gelation is generally caused by a combination of biochemical and physico chemical processes. The degree of influence exerted by the respective processes is determined by the basic quality of the original milk and by the heating and storage conditions.

The importance of this phenomenon depends on the authorised storage period which varies in length from country to country. Gelation could, to a large degree, be avoided if the storage period were reduced to a maximum of 2 to 3 months.

3. The flavour of UHT milk

One objective of the UHT process is still to obtain milk with a flavour comparable to that of good-quality pasteurized milk, but so far, success has only been partial. UHT milk can have certain specific and non-specific organoleptic shortcomings.

These taste defects are connected with the presence of substances derived from milk components. However, in most cases, the link between the presence of a substance and the flavour defect cannot be specified. Analytical chemistry research work has been carried out and the authors restricted themselves to mentioning the presence of certain volatile compounds without however being able to prove a correlation between the flavour defect and the presence of one or several of these compounds.

Sensory methods of assessment

The experts use 2 types of tests, one (1) of them based on a points system and the other (2) on comparison with a reference sample.

I. Mottar et al. (1979) apply the so-called "triangle" method, already described by Renner & Römer (1973) for the organoleptic investigation of UHT milk at different stages of conservation.

The panel comprises 10 people.

Assessment is based on a mark out of 5, namely:

5 : Excellent – conforming to standard quality
4 - 5 : Good – slight defects
3 - 4 : Satisfactory – clearly noticeable defects
2 - 3 : Pronounced defects
< 2 : Not acceptable – very pronounced taste defects

Each taster has 4 samples, including one reference sample.

In the case of UHT milk stored for 1, 2, 3 and 4 months at varying temperatures, the reference sample is milk kept for the same period at 1°C.

II. Blanc et al. (1980) carry out sensory tests with 2 panels of tasters, one group of trained people and one group of untrained people. The untrained panel is composed of adults and children.

The untrained tasters each receive 2 times 5 numbered milk samples and the aim is to classify the 2 groups of 5 samples according to preference, awarding the mark 1 to the best and 5 to the worst.

The tasters of the experienced panel receive 2 times 6 samples of milk including a reference sample and 5 samples marked as above. The tasters grade the samples as compared to the reference sample as follows:

Mark 1 : Very much superior to the reference sample
2 : Superior to the reference sample
3 : Identical to the reference sample
4 : Inferior to the reference sample
5 : Very much inferior to the reference sample.

4. Flavour defects

A catalogue of milk flavour and odour defects has been suggested by a group of American university researchers, Shipe et al. (1978) who use the following list, for which we quote the English terminology with the French translation.

(*) *see also report F–Doc 85 on heat resistant proteinases submitted to IDF Commission F in 1981*

Causes		Description ou association	
Heat induced	chauffage	– Cuit (chou)	Cooked (cabbagey)
		– Chauffé	Heated
		– Caramélisé	Caramelised
		– Brûlé	Scorched
Light induced	action de la lumière	– Lumière	Light
		– Lumière solaire	Sunlight
		– Activé	Activated
Lipolyzed	lipolyse	– Rance	Rancid
		– Butyrique	Butyric
		– Amer	Bitter
		– Lait de chèvre	Goat's milk
Microbial	action microbienne	– Acide	Acid
		– Amer	Bitter
		– Fruité	Fruity
		– Malté	Malted
		– Putride	Tainted
		– Impur	Impure
Oxidized	oxydation	– Papier	Paper
		– Carton	Cardboard
		– Métallique	Metallic
		– Huileux	Oily
		– Poisson	Fishy
Transmitted	transmission (par aliments)	– Fourrage	Fodder
		– Herbe	Grass
		– Vache	Cowy
		– Etable	Byre
Miscellaneous	causes diverses	– Astringent	Astringent
		– Amer	Bitter
		– Craie	Chalky
		– Chimique	Chemical
		– Plat	Flat
		– Etranger	Foreign
		– Manque de fraîcheur (vieux)	Not fresh (stale)
		– Salé	Salty

The authors point out that bitterness can come from different sources and is thus classed under different causes when it is not related to lipolysis or microbial developments. This catalogue can be used as a guide for UHT milk.

4.1 Flavour defects related to heat treatment

The effects of heating on milk components bring several groups of products into play:

a) Sulphur compounds

Dumont & Adda (1978) recently reminded us that sulphur compounds produced by the denaturation of whey proteins are connected with the boiled taste of milk. Large quantities of hydrogen sulphide are present in UHT milk after the heating process. This mainly results from the denaturation of the β - lactoglobulin. The authors also note traces of methyl sulphide (CH_3–S–CH_3) and of methyl disulphide (CH_3–S–S–CH_3).

The sulphur product content detected by chromatography differs in directly and indirectly processed milk. Zadow (1969) points out that direct heating produces less denaturation of soluble proteins than indirect heating.

Mottar & Naudts (1979) point out that the average percentage of whey protein is 68.1% in the case of indirect heating and 53.3% in that of direct heating.

There are noticeable differences between UHT and pasteurized milk. In the latter, the so-called cabbagey taste defect should be linked to the boiled taste which is the characteristic defect of over-heated pasteurized milk.

Badings et al. (1978) also note the link between the boiled taste and the presence of hydrogen sulphide and suggest the addition of L–cystin to the milk as a possible means of attenuating the defect.

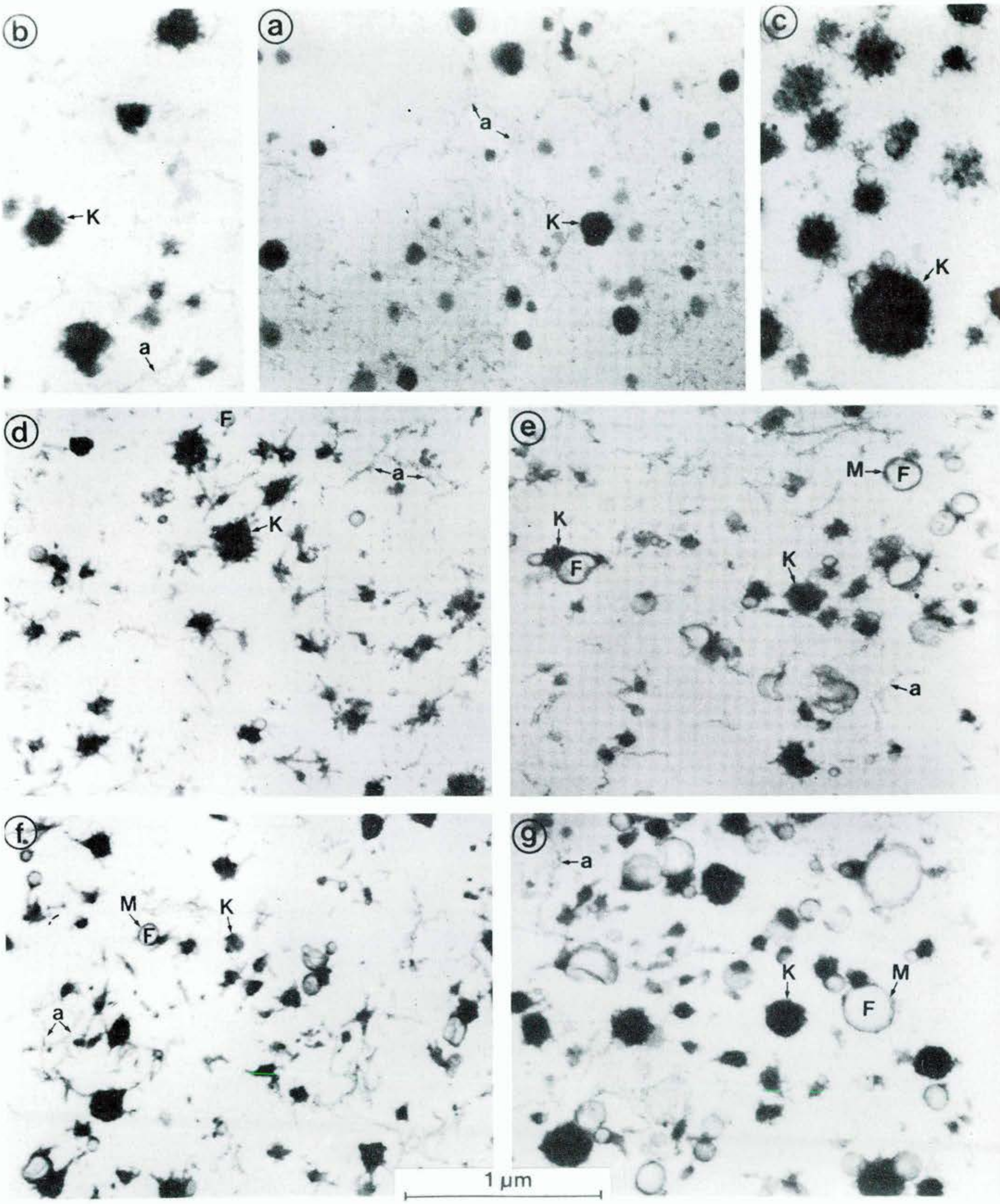


Figure 3: Electron micrographs of UHT milk (Ultra-thin sections of milk in agar gel, Blanc et al., 1980)

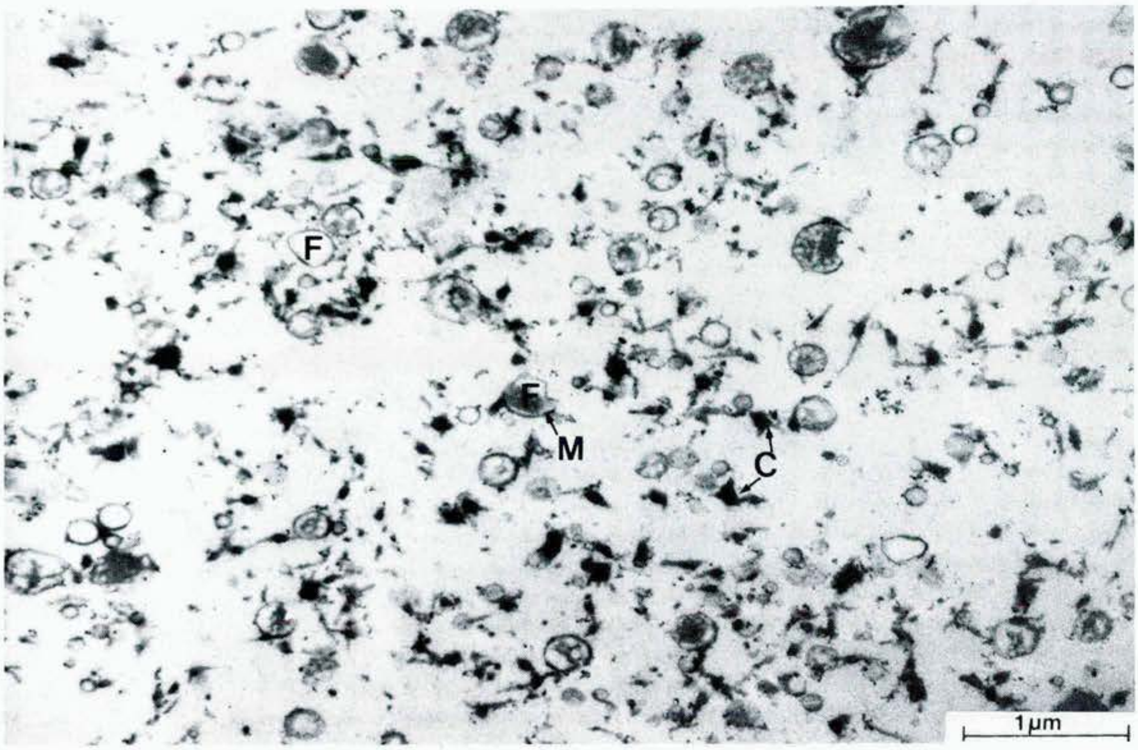
K: Casein micelles

F: Fat globules

M: Membranes

a: agar fibres (Not to be confused with the darker casein particles)

a) Whole raw milk
b) Milk freshly treated by direct UHT process
c) Milk freshly treated by indirect UHT process
d) Directly processed UHT milk after 12 months' storage at 5°C
e) Directly processed UHT milk after 12 months' storage at 25°C
f) Indirectly processed UHT milk after 12 months' storage at 5°C
g) Indirectly processed UHT milk after 12 months' storage at 25°C.



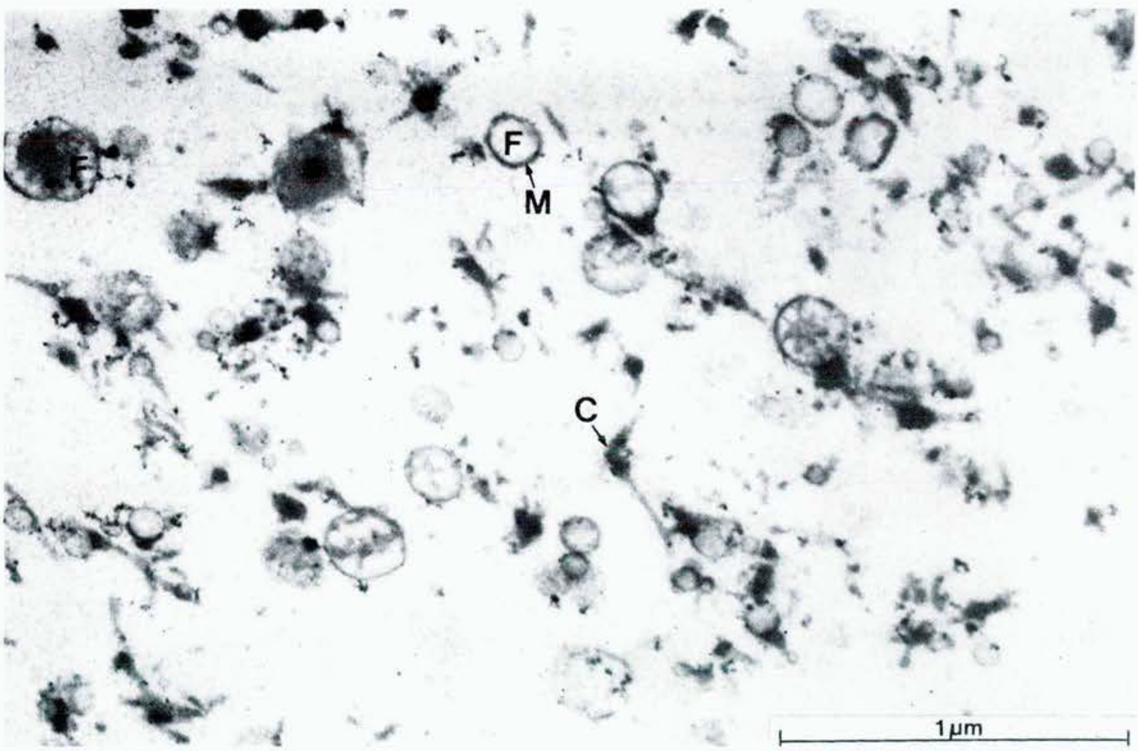


Figure 4: Electron micrographs of gelated UHT milk (Directly-processed UHT milk after 12 months' storage at 25°C) (Blanc et al., 1980).

K: Casein

F: Fat globules

M: Membranes

Research done at Shinfield by Haytham et al. (1978) shows the correlation between the volatile sulphur compound content and the cabbagey taste of UHT milk heated for between 3 and 90 s at 140°C. The sulphur compounds detected by the authors are hydrogen sulphide (H_2S), methane ethiol (CH_3SH), methyl sulphide (CH_3-S-CH_3) carbonyl sulphide (COS) and carbon sulphide (CS_2).

These sulphur compounds disappear more or less rapidly during the storage process. Methane ethiol is the only compound whose levels can be detected above the perception threshold after 4 months' storage at room temperature.

The boiled taste of UHT milk as related to the sulphur compounds brought out by the heating process decreases considerably during the first days of storage.

Dumont & Adda (1978) note that hydrogen sulphide is very plentiful during the first 3 days after UHT sterilization and then falls off rapidly during the first weeks of storage. Moreover, investigation of the decreasing curve shows that UHT milk behaves differently depending on whether it was sterilized by direct or indirect processes. In the case of directly processed milk, it takes approximately 10 days for H_2S to disappear sufficiently, whereas in the case of indirectly processed milk, 20 days are necessary to achieve this.

Blanc et al. (1980) also point out a decrease in the cabbagey taste at the beginning of storage in proportion to the decrease in volatile sulphur compounds produced by heating. This decrease is accelerated by oxygen and by a higher storage temperature.

Sensory comparisons with pasteurized milk made by the same authors showed that under experimental conditions, the quality of directly-heated UHT milk obtained from the same good-quality raw milk was almost equal to that of fresh pasteurized milk after the fourth week of storage at 5°C and for up to 8 weeks. After this point, however, the equality disappeared and the position of UHT milk deteriorated.

The decreases of the SH groups at the beginning of the UHT milk storage period might also be linked to the effects of a sulfhydryloxidase enzyme (Naudts, 1979).

b) The products of the Maillard reaction

One of the first products of the Maillard reaction is hydroxymethylfurfural (HMF) whose formation depends both on heating and storage temperature.

Mottar et al. (1979) point out HMF concentrations in UHT milk ranging from 0.5 to 2.0 ppm. These quantities lie below the estimated perception threshold of 5 ppm (Rothe et al., 1972).

However, the Maillard reaction has to be considered in relation to flavour changes as a result of heating.

Adrian (1975) shows that the organic components of whey, namely soluble proteins and lactose, are very sensitive to heat treatment and a Maillard reaction quickly becomes apparent when the milk is heated.

Jeon et al. (1978) report the presence of diacetyl in UHT milk; this could contribute to the taste and, according to Scanlan et al. (1968), would be a fission product of the Maillard reaction.

4.2 Flavour defects related to light

Both natural and artificial light affect the taste of milk.

The intensity of the light, the length of exposure and the wave-lengths below 500 nm cause flavour defects to appear.

This cause of flavour defects is not found in UHT milk packaged in aluminium coated films; effective protection is obtained by combining cardboard and polyethylene and interposing an aluminium lining.

4.3 Off-flavour related to lipolysis, proteolysis and the development of microbes

Off-flavour related to lipolysis and to the effects of microbial developments in the milk before heat processing should be investigated simultaneously.

Lipolysis and proteolysis are related to the survival of enzymes – lipases and proteases – in the milk after sterilization.

Whereas the milk's natural lipases are destroyed by heating, the microbial lipases are not rendered completely inactive by this same process.

Cogan (1977) reported on the heat resistance of microbial lipases and proteases using the following values:

D: Length of heating required to obtain a 90% reduction in enzyme activity at a given temperature.
Z: Temperature interval corresponding to a variation of 10 times D.

For a strain of Pseudomonas MC 60, Adams et al. (1975) give D at 149°C = 1.5 min.

Kishonti (1975) ascertained the inactivity characteristics of proteinase and lipase produced by Pseudomonas 21b:

Proteinase: D at 130°C = 8.8 min
Lipase : D at 130°C = 5.2 min

Thus the 2 enzymes are far from being rendered totally inactive by the UHT sterilization process. Bacterial proteases are obviously much more resistant to heat than lipases from the same source.

Adams et al. (1975) consider that the Pseudomonas MC 60 protease causes a bitter taste in UHT milk.

In this connection, Cogan (1977) notes that the same Pseudomonas produces 20 units of proteinase per ml in milk over a 2 day period at 4°C, whereas the population increases by 10^3 to 10^4 per ml. It has been calculated that to ensure conservation of UHT milk for one year, the raw milk should contain less than 0.1 unit of proteinase/ml.

Snoeren & Evers (1977) note proteolyses in UHT milk sterilized by direct heating processes. It has been demonstrated that this phenomenon is also produced in milk of high bacteriological quality. Experiments have been carried out with raw milk whose bacterial content was between 29,000 and 59,000 germs/ml, sterilized by direct heating for 4 s at 140°C. During the conservation process, the destruction of α and β casein was noted. In view of these results, the authors suggest that the milk's natural protease was involved. When heating is prolonged (34 s at 140°C), almost no destruction of the casein is noted, even after 4 months' storage at 28°C. During tests on storing UHT milk at different temperatures (4, 20 and 38°C), Schmidt (1975) notes the emergence of off-flavours after:

1 to 3 weeks at 38°C
3 to 6 weeks at 20°C.

These off-flavours are linked to the increase in free fatty acids in UHT milk sterilized by direct processes. Schmidt & Renner (1979) carried out similar investigations on UHT milk obtained by direct and indirect processes. The results of the sensory investigations are presented in table 4.

The authors conclude that sensory tests on UHT milk reveal that the length of the storage period has a very marked influence on the organoleptic qualities of the milk. Samples of directly-sterilized UHT milk, stored at 20°C, show fairly marked off-flavours after 6 weeks in comparison to the same milk stored at 4°C.

The same phenomenon can be observed with indirectly-heated milk, but with a lower fat content.

Table 4: Sensory changes in UHT milk at different storage temperatures.

Number of weeks stored	Direct process		Indirect process				
	35 g MG		17 g MG			35 g MG	
	20°C	38°C	20°C	38°C	20°C*	20°C	38°C
1	–	–	–	+		–	++
2	–	–	–	+++		–	+++
3	–	++				++	+++
4	–	–	–	+++		+++	+++
6	++	+++	+++	+++		++	–
8	++	+++	–	+++		+++	
10	–		–	+++			–
12	++		–		–		
14	+++		++		–		
16	–		–		–		
18			++		+++		
22			+		+++		
26			+		+++		

* *Comparison with newly processed UHT milk*

– No significant changes
\+ Little significant changes
++ Fairly significant changes
+++ Very significant changes

4.4 Off-flavours connected with oxidation

Jeon et al. (1978) carried out research into the volatile aromatic compounds in UHT milk during storage.

Methyl ketones are the largest single factor among the substances isolated. For example, in UHT milk stored at 35°C for 3 months, methyl ketones make up 79% of all the compounds and 2-hepatone alone 24%. However, it seems that the methyl ketones do not influence the flavour as much as one might think judging by their proportional predominance.

Aldehydes are the most important factor in the off-flavour connected with these compounds. After 3 months of storage, n-hexanal and propanal were present in concentrations just below the perception threshold.

The authors stress the possibility of synergy between various aromatic products, each of them below their respective perception thresholds. For example, a mixture of aliphatic aldehydes can give rise to a characteristic oxidized taste, with concentrations below perception thresholds.

In conclusion, the aromatic compounds identified are at least partly involved in the deterioration of UHT milk flavour during storage.

Mehta & Bassette (19) also point out the increase in the quantities of aldehydes (propanal, pentanal, hexanal) and the appearance of an oxidized taste (stale flavour) in UHT milk stored for 100 days at 22°C. Generally speaking, when the oxidized taste appears and develops, it is possible that it could be masked by the boiled taste and vice-versa.

4.5 Defects of various origins

Off-flavours caused by cattle fodder can be detected in sterilized UHT milk. However, the direct process, or the removal of the odours by vacuum treatment in the indirect process, generally eliminates these faults.

Finally, even without taste and aroma changes as previously defined, organoleptic deterioration occurs during the storage of UHT milk. This is related to chemical reactions between the constituents, and so far, not much information is available on this aspect.

An example of this is given by Jeon et al. (1978) in their publication on l-butanol. This element increases significantly during storage and is not affected by the different content of oxygen or ascorbic acid but is in relation to the storage temperature. The origin and mechanisms of l-butanol formation have not yet been clearly defined and give rise to several hypotheses.

5. CONCLUSIONS

In spite of the absence of microbial growth, as a result of the heat treatment, UHT milk is not completely stabilized. This is in direct relationship with the very principle of UHT heating which is of short time duration. UHT treatment causes protein denaturation to a lesser extent than a sterilization treatment in the autoclave and therefore, there remains a partial activity of the thermoresistant enzymes of protein nature.

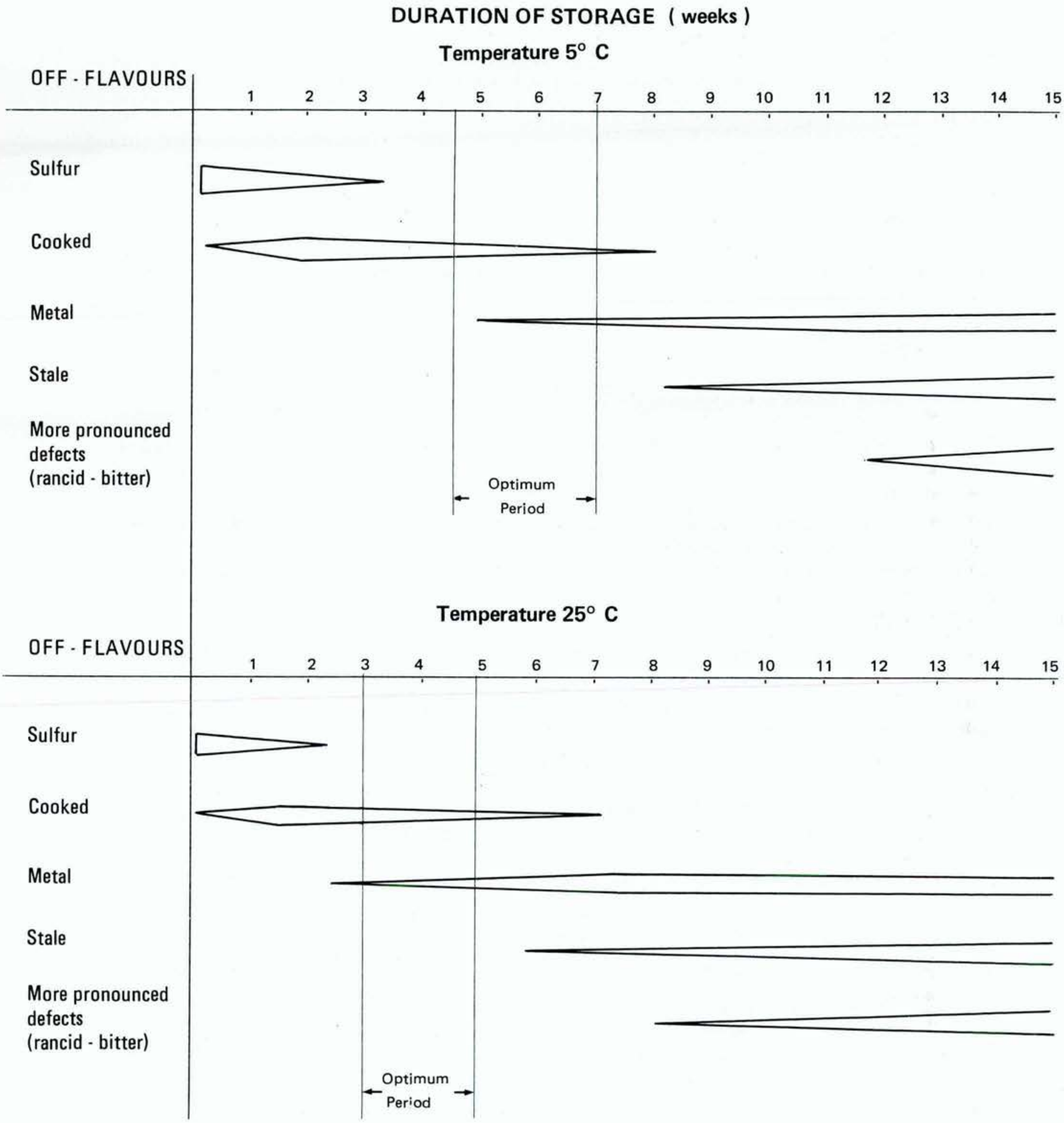
This explains to a large extent the evolution of UHT milk during storage, as well as the important role of the keeping temperature which affects the enzymatic activity, as well as all chemical changes of the milk constituents (e.g. vitamins). Although limited, the alterations directly attributable to the heating are perceptible and are related primarily to the whey protein, resulting in off-flavours. The level of these defects decreases charply at the beginning of the storage period.

On the other hand, off-flavours caused by chemical changes due to enzymes or off-flavours due to light or oxigen, develop generally after a few weeks, or earlier if the milk is not adequately protected from light. These defects will aggravate more or less over time, in conjunction with storage conditions.

For example, the organoleptic characteristics of UHT milk protected from light and in an airtight package, will reach an optimum level between the fourth and the seventh week of storage at 5°C, or between the third and the fifth week at 25°C.

The following figure (figure 5) attempts to illustrate examples of flavour changes in UHT milk during storage at 5 and 25°C.

Figure 5. Organoleptic changes in UHT milk.



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CHAPTER 3

CHEMICAL AND PHYSICO–CHEMICAL ASPECTS

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1. BASIS OF UHT–HEAT TREATMENT

Milk is heated for two purposes:

- to make certain that pathogenic organisms are destroyed
- to ensure a more or less great extension of the shelf life of milk by a reduction of the number of micro-organisms contained in it.

Pasteurization achieves the first goal without difficulty butthe shelf life of pasteurized milk is limited to a maximum of 8-10 days, under current industrial conditions common in Europe and North America.

Increasing the effect of heat treatment by increasing the temperature in order to kill as many microorganisms as possible will result in two types of reaction which must be borne in mind (1):

- destruction of microorganisms accompanied by chemical reactions within the microbial cell (protein denaturation, inactivation of enzymes, etc.)
- chemical or physico-chemical changes in milk constituents. These changes are usually undesired because they may have a deleterious effect on the nutritional value and the organoleptic properties of the milk.

All these reactions are accelerated by an increase in temperature but the rate of destruction of microorganisms is considerably greater than the rate of the chemical reactions. A measure of this is the Q10 value which indicates how much faster a reaction will take place when the temperature is increased by $10^{\circ}C$.

Fig. 1 shows that the Q_{10} values for the destruction of microorganisms and for the reduction in the number of spores range from 8 to 20 and are thus considerably higher than the Q_{10} values for most chemical reactions which range from 2-4 (2).

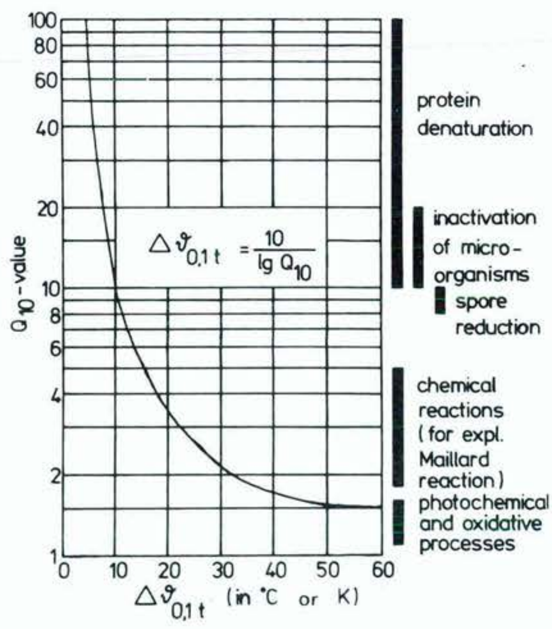

Fig. 1: The relationship between the Q_{10} value and the temperature difference (2).

The inactivation of the extracellular lipases of *Pseudomonas fluorescens* takes place in two stages. The first stage, the denaturation of proteins has a Q_{10} value of 103.9 and the second stage, chemical inactivation, a Q_{10} value of 1.9 (3). On the other hand, the Q_{10} value for the inactivation of the native milk protease is about 3.1

at 70°C and 2.2 at 130°C (4). A Q_{10} value of 9 is the basis for the destruction of *Bacillus stearothermophilus* (1). Fig. 2 shows the influence of processing temperature on the effect of sterilization.

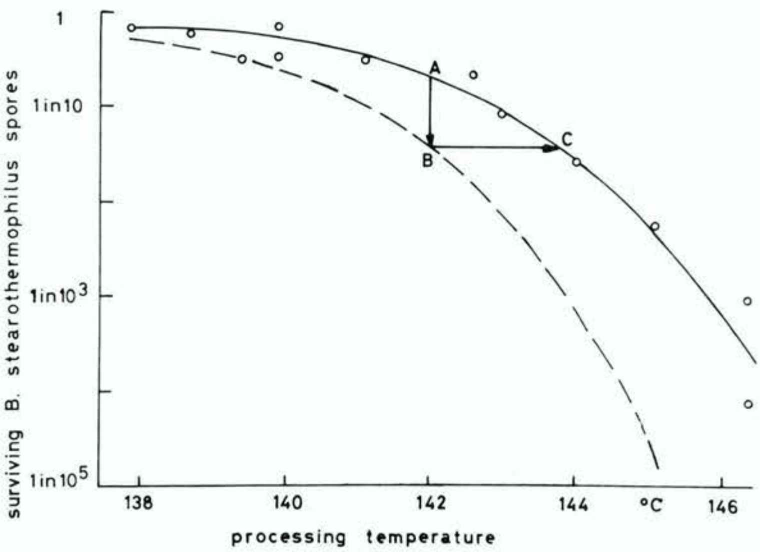

Fig. 2: The influence of processing temperature on the effect of sterilization (6).

results of experiments (mean holding time 3.1 s)

results calculated for double the holding time

Table 1 shows how the holding time necessary to achieve a certain degree of sterility decreases with increasing temperature and how the chemical changes taking place per unit time increase with increasing temperature. The table also shows that, due to the considerably shorter holding time necessary, chemical changes can be reduced to 3% of the initial value when the temperature is increased by 30°C (5).

Table 1. Effects of increases in temperature and of the holding time on chemical reactions (5).

Q_{10} value of heat destruction = 10 Q_{10} value of chemical changes = 3			
Increase in temperature °C	Time t necessary to achieve the same bactericidal effect A	Ratio of the chemical changes in unit time B	Changes in time t % A x B x 100
Initial temperature Δ_1	1	1	100
Δ_1 + 10°C	0.1	3	30
Δ_1 + 20°C	0.01	9	9
Δ_1 + 30°C	0.001	27	2.7

Taking a sterilization treatment at a temperature of 115°C and a holding time of 30 min as a basis, the results in table 1 mean the following: if the temperature is increased to 145°C the holding time can be reduced to about 2 s. This will have the advantage of considerably fewer chemical changes compared to the initial treatment (87). These findings formed the basis of the development and introduction of the UHT-treatment in the dairy industry.

2. CHANGES IN THE FAT FRACTION

The fat fraction of milk is regarded as the most important source of flavour and odour in milk and milk products because hydrolysis and oxidation produce a large number of flavour and odour substances, some of which are desirable and others undesirable.

2.1 Changes produced by oxidation

UHT-treatment and storage produce no changes or only very small ones in the percentage composition of the fatty acid spectrum of the triglycerides. After a storage time of 9 months at 20 and 38°C small decreases in the content of oleic, linoleic and linolenic acids were observed which suggest some changes due to oxidation (9). Autoxidation of unsaturated fatty acids produces a large number of saturated and unsaturated aldehydes (8) and a small amount of ketones (9).

According to Jeon et al. (10) fresh UHT-milk does not contain any aliphatic aldehydes apart from n-hexanal. However, after storage of 5 months at 22 and 35°C increases in the concentrations of n-pentanal, n-heptanal and n-octanal were observed. The extent of these changes was dependent on the storage temperature and the oxygen content. The amount of n-nonanal rose over the whole of the storage period and was independent of storage temperature while the concentration of n-decanal did not change. Fig. 3 depicts the effect of storage temperature on the concentration of n-hexanal. A maximum was reached after 90 days at 35°C, while at room temperature the concentration increased continuously over the whole of the storage period. This result is thought to be due to the fact that the oxygen content of milk is almost completely depleted after 90 days at 35°C and there is thus no more oxygen available for oxidation.

When e-ascorbic acid (200 mg/ℓ) was added the increase in hexanal content during storage was very small (fig. 3). There are several possible explanations of this observation:

- ascorbic acid uses up the available oxygen itself and thus prevents the oxidation of oxygen sensitive substances (11),
- the effect of ascorbic acid is due to a reduction of the red-ox potential (12),
- ascorbic acid acts as an inhibitor in a chain reaction which produces free radicals (13).

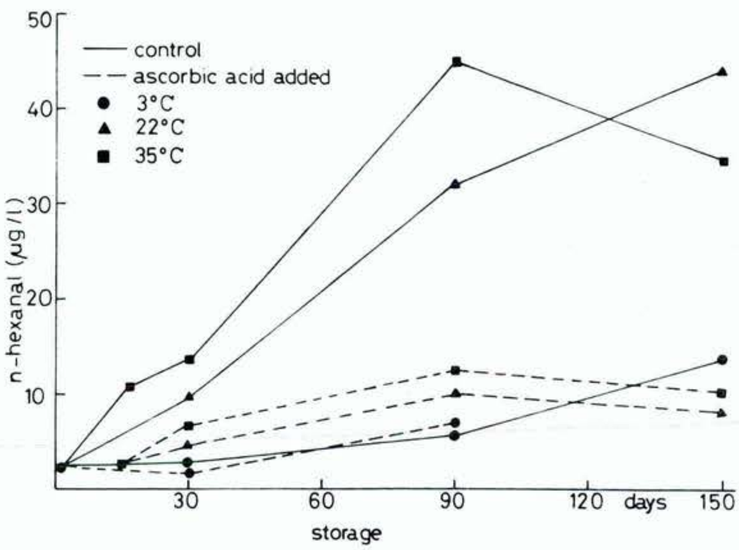

Fig. 3: Changes in the concentration of n-hexanal during storage of UHT-milk (10)

The concentrations of n-hexanal and n-propanal found after a storage period of 3 months were close to their flavour and odour threshold values and seem to contribute significantly to the "off flavour" of stored UHT-milk (10).

Mottar et al. (14) observed that the increase in TBA (thiobarbituric acid) values of UHT-milk stored uncooled for 6 months was not great enough to be responsible for flavour changes. They also found very little correlation between the original oxygen content of the milk and the TBA-values.

2.2 Non-oxidative changes

2.2.1 Methyl ketone

Methyl ketones are formed from ketoglycerides, which occur in milk fat at a concentration of 0.02-0.045%, mainly by hydrolysis and CO_2 release in the presence of small amounts of water (15, 16, 17).

In UHT-milk the concentration of methyl ketone increases during storage. The increase is mainly dependent on the storage temperature and is independent of the oxygen content and the concentration of ascorbic acid (10).

2.2.2 Free fatty acids

Free fatty acids (FFA) are produced in UHT-milk during storage by hydrolytic reactions taking place in the fat phase. The short chain and medium chain (C_4–C_{12}) free fatty acids produce unpleasant odours and flavours even at very small concentrations (18). These hydrolytic reactions are thought to be produced by incompletely inactivated heat resistant lipases of psychrotrophic microorganisms (3, 19).

Fig. 4 shows the changes in the content of FFA in an indirectly heated UHT-milk containing 1.5% of fat during storage for 8 weeks. Storage in a refrigerator did not produce a significant change in the FFA content but storage at room temperature produced an increase which could be detected organoleptically. Storage in an incubator doubled the amount of FFA after 8 weeks.

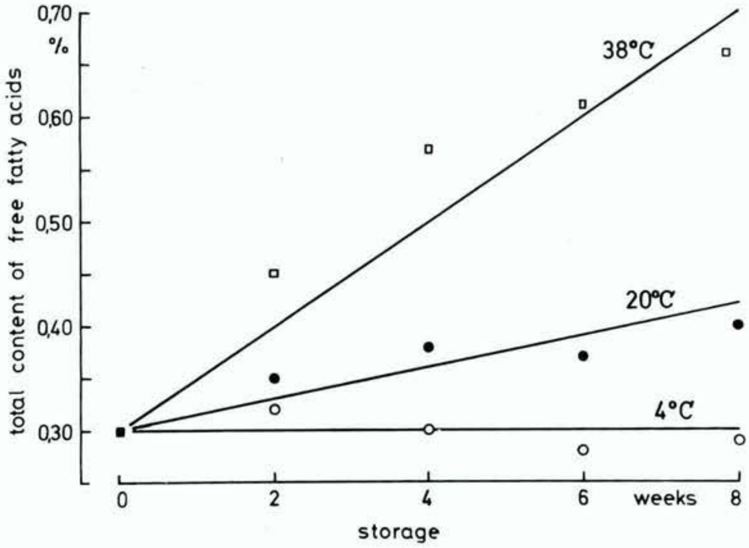

Fig. 4: Changes in the concentration of free fatty acids in a UHT-milk on storage at different temperatures (20, 90).

Table 2 summarises the increases in the content of short chain FFA in UHT-milk after a storage period of 4 months at room temperature. The reason for the smaller average increase in the content of short chain FFA in indirectly heated milk is thought to be the fact that in this process more heat is supplied to the milk which leads to a more complete inactivation of heat resistant lipases. However, in this study a great deal of variation was found in the results from the 2 processes as well as in replicate experiments using the same process (14).

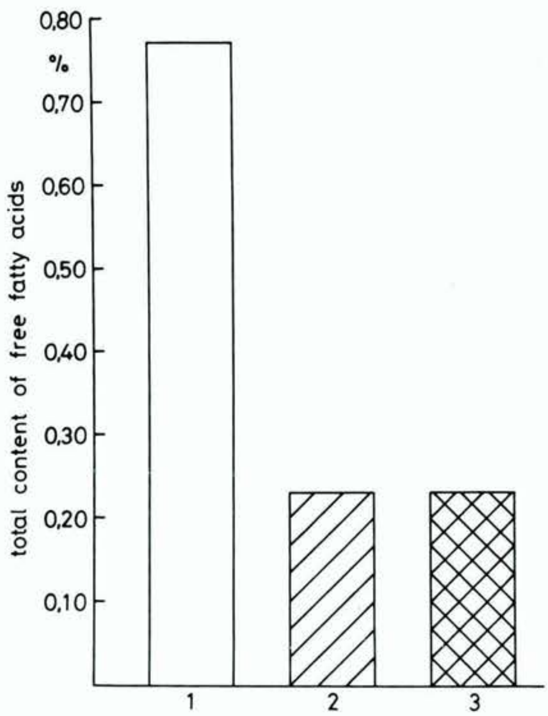

Fig. 5: The effect of pretreatment on the content of free fatty acids in UHT-milk (66).

1 = not preheated

2 = pre-pasteurized

3 = pre-pasteurized and stored for 24 h at 4°C

Table 2: Content of short chain free fatty acids (C_4-C_{12}) in stored UHT-milk (3.5% fat, 20°C) (14).

Processing method	initial value	free fatty acids (mg/ℓ) increase after 4 months	
		mean value	variability
indirect heating	15.8	+ 2.6	+ 0.5 to 5.5
direct heating	15.3	+ 7.4	+ 2.5 to 12.9

Schmidt & Renner (7) stored both directly heated and indirectly heated UHT-milk at 20 and at 38°C for 16 weeks and report that in both types of milk the increase in the concentration of short chain and medium chain FFA (C_6-C_{12}) was 2.1–2.2 mg/ℓ at 20°C and 10.8–13.1 mg/ℓ at 38°C. Although FFA do not produce a noticeable rancid flavour at these concentrations they contribute to detectable odour and flavour changes.

Fig. 5 shows that UHT-milk which has not been preheated has a considerably greater content of free fatty acids than milk which has been pasteurised before UHT treatment.

3. CHANGES IN THE PROTEIN FRACTION

In contrast to casein whey proteins are sensitive to heat. This property is mainly due to the lack of phosphorus to the small content of proline compared to casein and to the high content of cystine and methionine. In addition, β-lactoglobulin has a high concentration of cysteine with free SH-groups (21). Under the influence of heat the hydrogen bonds and the S-S bonds, which stabilise the three dimensional configuration, quickly break. The result is that the peptide chains unfold and new bonds are formed which eventually lead to aggregates of unfolded chains. Proline is important because it prevents the formation of hydrogen bonds (bridges) (fig. 6).

Casein contains 13.5% of proline, β-lactoglobulin 5% and α-lactalbumin only 1.5%. The number of hydrogen bridges formed decreases with an increase in proline content and the higher the proline content of a protein molecule, the smaller is its tendency to denaturation (21). The temperatures of denaturation or coagulation of a number of milk proteins and enzymes are collected in table 3. According to other studies (43), the first signs of denaturation are shown by immunoglobulin after heating at 74°C for 15 s, by serum albumin and β-lactoglobulin after the same time at 84-86°C, while α-lactalbumin must be heated for at least 5 min at 100°C.

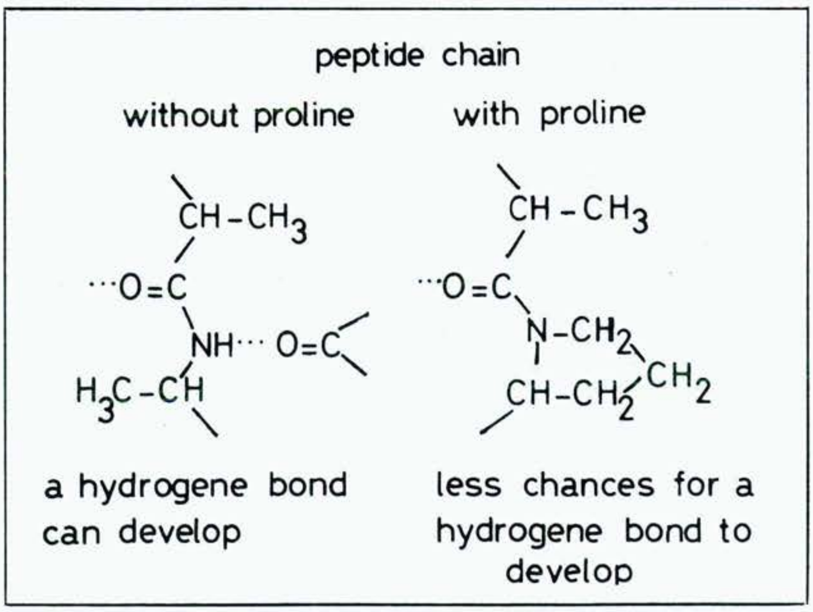

Fig. 6: The effect of proline on the formation of hydrogen bridges (21).

Table 3: Temperature of denaturation of milk proteins (22)

Protein	Temperature of denaturation °C
serum albumin	66–68
α-lactalbumin	72–73
β-lactoglobulin	70–75
casein	160–200
lipase	70–74
alkaline phosphatase	66–70
acid phosphatase	90–100
xanthine oxidase	76–80

As the indirect ultra high temperature heat treatment process generally supplies more heat (85) than the direct one, the degree of denaturation in milk heated by the former method is greater than that in milk treated by the latter one (14, 23, 60) Lyster et al. (24) cite e.g. for β-lactoglobulin an average value for the degree of denaturation of 68% in directly heated UHT-milk compared to 82% for milk processed by indirect heating. The degree of denaturation in pasteurised milk is only 10% while the whey proteins in sterilized milk are almost completely denatured.

The denaturation of whey proteins is accompanied by an aggregation of molecules which may be caused by intermolecular disulphide bridges or by the agglomeration of denatured whey proteins with casein particles.

This complex formation between casein and whey proteins is caused chiefly by the interaction of κ-casein and β-lactoglobulin, possibly with the inclusion of α-lactalbumin (fig 7) and the extent of complex formation depends on the amount of heat received. (table 4).

Table 4: Binding of whey proteins to casein in heated milk (26).

Conditions of heating	% of whey proteins bound to casein
150°C/0,8 s	42
150°C/2.4 s	46
142°C/10 s	49
129°C/100 s	64
116°C/17 min	68

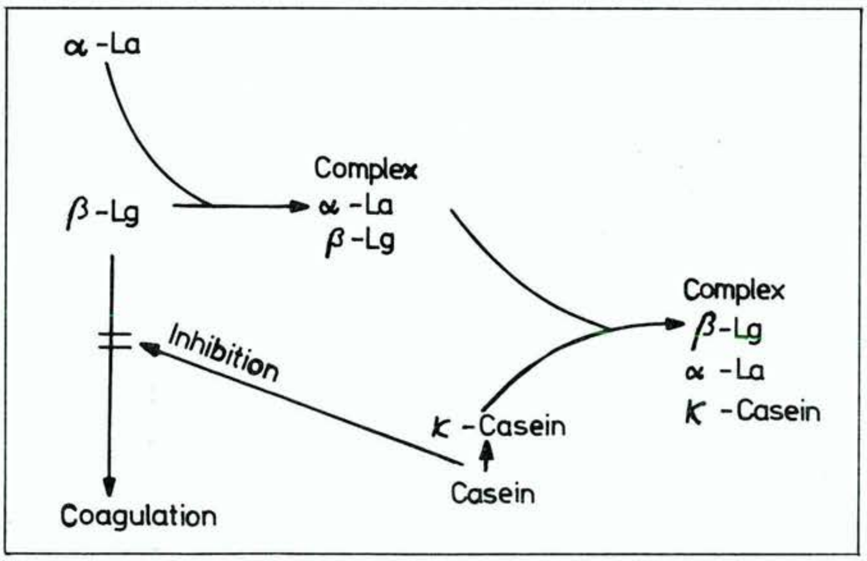

Fig. 7: Diagrammatic representation of the hypothesis of the interaction of α lactalbumin (LA) β lactoglobulin (LG) and κ - casein during the heating of milk (25).

However, the complex of whey proteins and casein dissociates again slowly during storage. The complex formation is therefore partially reversible. Not only the extent of complex formation but also the stability of the complexes is thought to be dependent on the extent of the heat treatment. (27, 28).

In addition, the heat coagulation of the whey proteins leads to the formation of a sediment to which, however, the casein also contributes to a certain extent (21). Samuelson & Holm found more sediment in an indirectly heat treated UHT-milk than in an directly heated one (29). In contrast to this, Perkin et al. (30) found twice as much sediment in packs containing directly heated UHT-milk than in indirectly heated milk. It is thought that the sediment in UHT-milk consists of the same material as the deposits on heated surfaces. In a direct UHT-heating plant there are hardly any surfaces on which deposits can form and it is thought that in this case the precipitated material remains in suspension in the milk whereas it forms deposits in indirect UHT plants which have large surfaces on which deposits may form. Kessler et al. (31), who came to the same conclusion, suggest that every sudden change in temperature during processing produces an increase in sediment formation. During storage the sediment was observed to disintegrate and the amount of sediment (in the directly heated milk) approached that in the indirectly heated one (fig. 8).

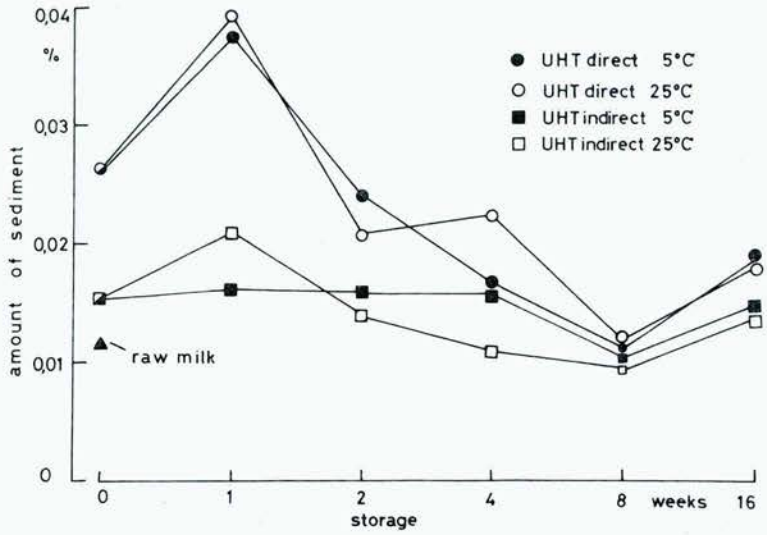

Fig. 8: Changes in the amount of protein sediment as a function of the method of heating, the storage temperature and the storage time (23).

Another result of the heat denaturation of the whey proteins is the production of relatively large amounts of reactive sulphydryl groups in UHT-milk (32, 33, 34). Several studies suggest that β lactoglobulin, which contains 2 SH- and 4 SS-groups per dimer of molecular weight of 36 000, is the main source of the SH-groups (35, 36, 37). It is undisputed that there is a direct correlation between the appearance of a cooked flavour and the amount of reactive SH-groups produced by heating. The extent of SH-group formation can vary considerably depending on the method of heating used. Badings (38) found values ranging from 82.5 to 10.6 μg H_2S/kg in indirectly heated milk and 11.8 μg/ kg in directly heated UHT-milk.

The concentration of SH-groups decreases considerably through oxidation, already during the first day of storage. The decrease is dependent on the oxygen content of the milk and the storage temperature and the concentration of SH-groups reaches a constant value after about a week (fig. 9). This process is more rapid at room temperature than at 4°C (33).

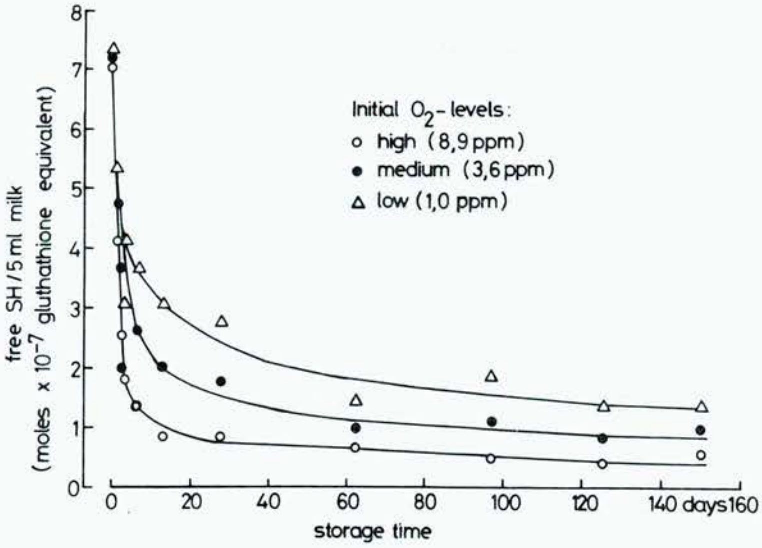

Fig. 9: The effect of the original content of dissolved oxygen on the concentration of free SH in indirectly heated UHT-milk stored in the dark at 20 ± 4°C (39).

Several methods of reducing the cooked flavour of heated milk have been suggested:

Samuelsson & Borgström (34) obtained the best results by adding 5-25 mg/kg of potassium iodate or bromate.

Ferretti (40, 41) found thiosulphonate and thiosulphate useful. Badings (38) recommends an addition of 30-70 mg/ℓ of L-cystine (table 5). This method has no effect in milk which has been sterilized by the conventional process as here the H_2S content is relatively low and the typical sterilized milk flavour is more the result of the Maillard reaction which is quite pronounced.

Table 5: Effect of additions of L-cystine on the H_2S content of UHT milk (38) (indirect process: 137°C, 5.0 s).

Added L-cystine mg/kg	Storage period days at 3°C	Odour and flavour	Cooked flavour	H_2S µg/kg
0	0	5.1	2.8	10.6
	1	5.4	2.3	4.0
	7	5.6	2.0	1.2
	14	5.8	1.3	0.3
30	0	5.8	1.8	5.8
	1	5.9	1.1	0.6
	7	6.1	0.8	0.5
	14	6.5	0.7	0.2
70	0	6.3	1.0	1.9
	1	6.4	0.7	0.5
	7	6.6	0.3	0.2
	14	6.6	0.2	0.1

key: odour and flavour: 3 = very bad
8 = very good

cooked flavour: 0 = none
4 = very strong

Depending on the amount of volatile SH-groups released, losses of up to 34% in sulphur containing amino-acids (cystine, cysteine and methionine) are observed in UHT milk.

Casein is not denatured by the process of UHT heating, but a certain unfolding of the peptide chain can be observed (43). Examination with an electron microscope showed that UHT-heated milk had a larger number of free casein sub-units and a slight increase in the number of casein particles. The latter is responsible for an increase in the mean diameter of casein particles by about 25% (44). The observed release of sialic acid, which is contained in the glycomacropeptide of κ-casein, on unfolding of the protein molecules due to UHT-heating is reduced (32, 45). The electrophoretic appearance of casein is not changed in fresh UHT-milk (46, 47), during storage, however, some pronounced changes occur which lead finally to thickening and gelation and thus clearly limit the storage life of UHT milk. The causes of this process are not yet clearly understood.

Bjork (46) found in a partial decomposition of β - casein into TS-, R- and γ -casein in indirectly heated UHT-milk after storage for 15 weeks at room temperature.

This could be caused by purely chemical or physical processes, but on the other hand, proteases could be detected in UHT-milk which could decompose β -casein to the previously mentioned minor caseins (45, 48, 49). Law et al. (48) and Bertsson et al. (45) report on gelation of UHT-milk caused by heat resistant proteases, which decompose κ -casein and are derived from psychrotrophic pseudomonas types. The mechanism of decomposition of κ -casein is supposed to be similar to that taking place during rennet coagulation. In this process glycomacropeptides are split off and sialic acid is liberated.

Apart from proteases of bacterial origin, the native ones also play a part since they can also survive heating to UHT-temperatures (4, 50, 51). In this case β casein is also decomposed into R-, S-, TS- and γ -casein: α casein is split 2 or 3 times more slowly than β casein. In contrast to the bacterial proteases the native proteases do not attack κ -casein, i.e. para-casein is not formed (4, 51). Due to proteolysis by native milk proteases milk coagulates after 90 days' storage at 23°C without the formation of the typical gel structure. Since native proteases are not inactivated at the heating conditions of 142°C/4 s, an increase in the holding time to 16 s has been proposed (Fig. 10).

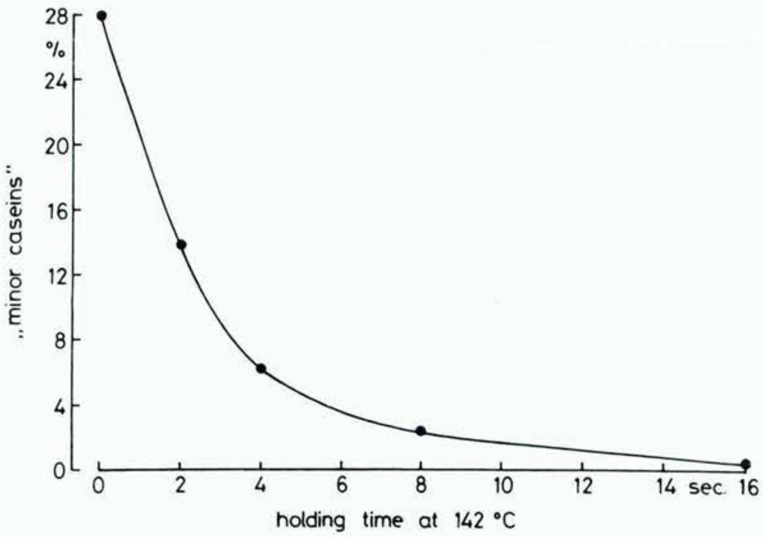

Fig. 10: Formation of minor caseins as a function of holding time in a direct UHT plants.

But since bacterial proteases survived even heating to 149°C at a holding time of 10 s, investigators have come to the conclusion that their thermal destruction can only be achieved at the cost of serious damage to the milk (52). On the other hand, a 10 min pasteurizing treatment at 55°C will lead to a 99% inactivation of this enzyme (53).

Samel et al. who stored UHT-milk at 4, 20, 30 and 37°C were unable to find a direct relationship between protein decomposition and gel formation (54). Samples stored at 4, 20 and 30°C had gelled after storage for 13 months, but the samples stored at 37°C had not gelled although in them protein decomposition was the most pronounced. The reason for this behaviour is thought to be the fact that the Maillard reaction is more pronounced under these conditions and thus prevents the lysine from contributing to the coagulation of the casein micelles (55). It was supposed that the reasons for coagulation were slow changes in the casein surface, combined with interaction between casein micelles which finally lead to casein aggregates.

Electron microscopic studies (56) have shown that casein micelles of UHT-milk stored for 34 months at 4°C form an extensive network. At 20 or 30°C this was less pronounced; the average size of the micelles was, however, significantly enlarged in comparison with those of freshly prepared UHT-milk.

Just as Samel et al. (54), Cheng & Gelda (57) also do not attribute gel formation in UHT-treated and stored milk to a residual activity of proteases.

It is thought that in the chemical reactions which lead to gel formation in stored UHT-milk a part is played not only by the Maillard reaction (58, 59) but also by changes in the interaction of Ca-ions with heat denatured β-lactoglobulin and its casein complex (61). Watanabe & Klostermeyer (36) as well as Patrick & Swaisgood (33) point out that SH-initiated SS-exchange reactions are important in the formation of high molecular weight polymers, however, only in the presence of oxygen. Harwalkar & Vreeman (62) were unable to confirm the postulated effects of pH-changes (63) or of a dephosphorization of caseins (64). They were only able to show a connection between the extent of gel formation and changes in viscosity and in stability towards alcohol.

Table 6 shows that UHT-milk remains fluid longer at very high or at low storage temperatures than at temperatures between 20 and 30°C. Higher storage temperatures are, however, unsuitable because of the increased Maillard reaction which causes flavour defects and also because of increased losses in vitamins.

Table 6: The influence of heating and storage conditions on the gelation of UHT-milk (65).

UHT-conditions	Storage temperature °C	Time to gelation days
140°C/3 s	30	96–99
145°C/3 s	30	110–113
140°C/5 s	30	117–120
140°C/3 s	2	> 208
140°C/3 s	40	> 208

4. HYDROXY METHYL FURFURAL

The reactions products of the Maillard reaction could be responsible for the organoleptic changes which occur in UHT-milk during extended storage. One of the first steps in this reaction leads to a reaction product between free amino groups mainly the c amino groups of lysine and the reducing groups of lactose, while in a second step yellow-brown melanoids are formed which lead to a browning of the product (43). Other basic amino acids such as arginine and histidine play only a secondary part (91).

The content of hydroxymethylfurfural (HMF) one of the first reaction products, serves often as a means of detecting non-enzymatic browning reactions and as a check of the thermal stress. The Maillard reaction does not yet occur in pasteurized milk, but it occurs in fresh UHT-milk, although there is as yet no browning but more or less increased HMF values (66, 67) are found which depend on the processing method. During storage at room temperature for 16 weeks UHT-milk showed an increase in HMF content from about 5 to 7 μmol/ℓ, and when stored at 38°C for the same period, a level of more than 12 μmol/ℓ was reached (20). Since HMF is only an intermediate product in the Maillard reaction, it is possible that a loss in HMF is quoted as between 2 and 5 ppm which corresponds to 16 and 40 μmol/ℓ respectively (69, 70). Therefore when UHT-milk is stored at room temperature, pronouced organoleptic changes due to the Maillard reaction are not to be expected within the given period of shelf life.

Turner et al. (71) state that in UHT-milk between 0.8 and 1.5% of the lactose is bound to the milk protein and the casein rich fraction is especially preferred. It is thought that the stability of the protein fraction during storage is influenced by the reaction of lactose with κ -casein, and that it also promotes the combination of protein chains to form larger complexes which can finally lead to gel formation.

In dairy products, the first stable product of the Maillard reaction is probably lactulose lysine, which is formed from lactosylamine by an Amadori-rearrangement. In UHT-milk stored at 30 to 37°C for 6 months to 3 years, 10 to 30% of the lysine present were used up for the formation of lactulose lysine. The fructose lysine was an average 10% of the lactulose lysine content (72, 73). Lysine losses due to UHT treatment are quoted as being 1 to 4% and are somewhat higher when the indirect process is used, than with the direct heating process (23, 43).

5. MINERALS

The proportion of soluble calcium and phosphorus decreases when milk is heated and the extent of the decrease depends on the intensity of the heat treatment. For soluble calcium in UHT and sterilized milk it is approximately 40 - 50%. The process is reversible. From the point of view of the physiology of nutrition this has no consequences since, in experiments with rats, it was shown that the availability of calcium in UHT-heated and sterilized milk was not affected when compared with raw milk (32, 43).

6. ENZYMES

It has already been mentioned that some proteases and lipases are not completely inactivated by UHT heating. Blanc (23) states that this is also true for ribonuclease and amylase, but most other enzymes are completely inactivated under these conditions of heat treatment.

7. OXYGEN CONTENT

The oxygen content of UHT-milk is first of all dependent on the manufacturing process, but it can also depend on the air in the headspace of the packages and on the amount of oxygen which permeates through the packaging material (92). A relatively high oxygen content of 4 - 9 mg/ℓ can be encountered in indirectly heated non-deaerated milk after manufacture. UHT-milk which has been indirectly heated but deaerated, and milk processed by direct heating have an oxygen content of less than 1 ppm. Deaeration is sometimes not carried out very effectively, however, so that between 2 to 6 mg O_2/ℓ are found in deaerated milks (6, 14, 66). Tote (66) mentions that a higher oxygen content is found in UHT-milk which passes through an interspaced sterile holding tank than milk which is filled immediately. Fig. 11 shows the effect of deaeration and of the type of packaging on the changes in oxygen content during storage of UHT milk.

In UHT-milk packed without headspace and not deaerated the oxygen content decreases continuously over the first 14 days as a result of reactions with milk constituents and then remains relatively constant for some time at about 3 mg/ℓ. The oxygen content of milk filled after direct heating or of deaerated, indirectly heated milk remains at an initial low level over the whole of the storage period. In packages with headspace, the advantage of deaerated milk as regards oxygen content is quickly nullified. Not deaerated, indirectly heated UHT-milk, filled into packages with headspace shows a stable oxygen content of 6 - 7 mg/ℓ of oxygen over the whole storage period since used-up oxygen is replaced by diffusion from the headspace.

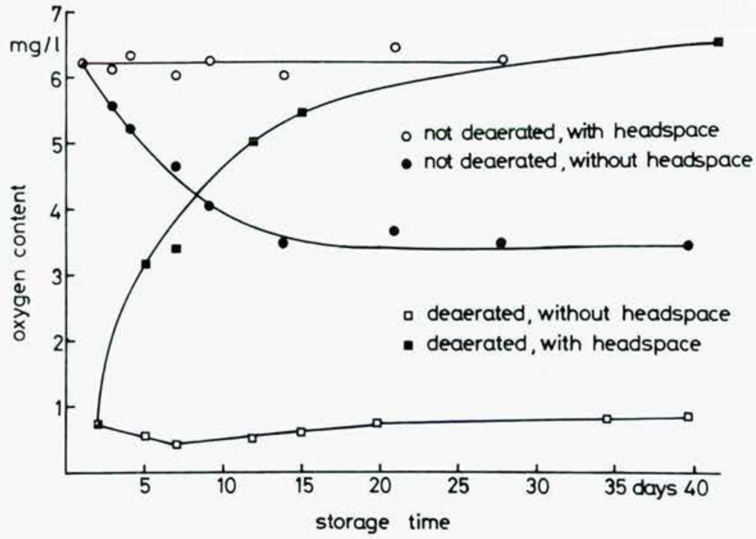

Fig 11: Changes in the oxygen content of deaerated and not deaerated UHT milk with and without headspace.

The low oxygen content in deaerated UHT-milk causes a somewhat slower oxidation of the sulphydryl groups and results in a somewhat worse assessment of the organoleptic properties of deaerated UHT-milk in the first few days after processing (fig. 12). This is. however, of little importance as UHT-milk is hardly ever consumed within this period (75) and some preference for directly heated UHT-milk has been reported when tested during the period of consumption (14, 66, 76). Zadow & Birtwistle (77) found that a UHT-milk with a medium content of oxygen was rated best in organoleptic tests during a storage period of 1 to 12 weeks.

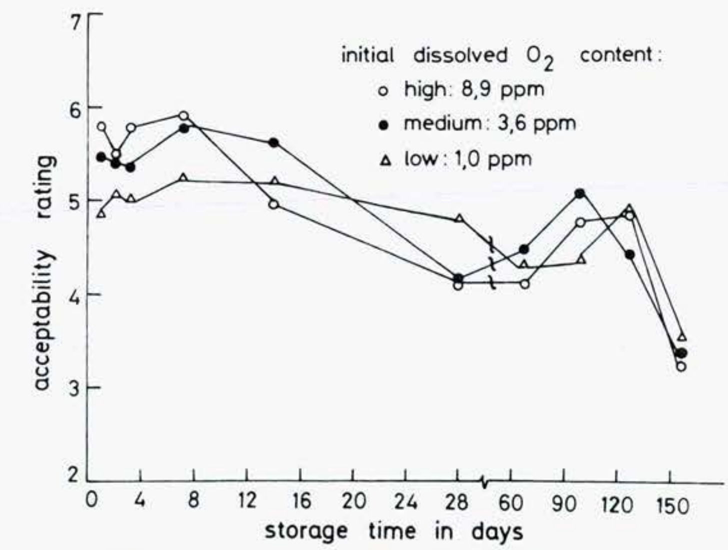

Fig. 12: Acceptability of UHT-milk stored in the dark at 20°C (6 - 7 tasters, rating 1 - 8 points) as a function of the initial dissolved oxygen content.

A high initial oxygen content leads to a more rapid oxidation of sulphydryl groups but promotes the development of oxidative flavour defects on long storage and it produces, most of all, a rapid reduction in the content of ascorbic and folic acids (39, 78, 84, 86, 88). This can be seen from fig. 13.

Ford (93) has shown that an oxygen content of 1 ppm is sufficient to oxidise the whole of the ascorbic acid in a period of 2 weeks. One should therefore try to:

a) deaerate indirectly heated milk as completely as possible;
b) fill deaerated milk into packages without head space;
c) keep an interspaced sterile hoding tank in an atmosphere of nitrogen.

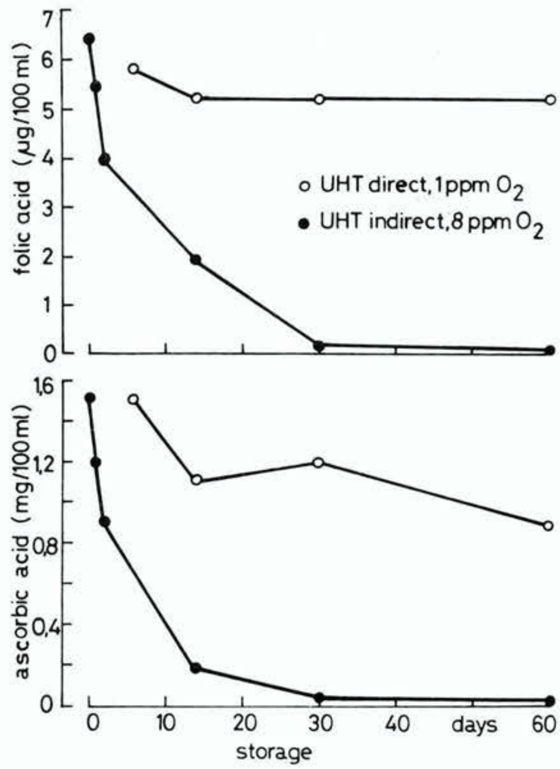

Fig. 13: The effect of the residual oxygen content in UHT-milk on the stability of ascorbic and folic acids during storage (87).

8. VITAMINS

The fat soluble vitamins A, D and E as well as the vitamins of the B-complex riboflavin, thiamin, pantothenic acid, biotin and niacin are relatively insensitive to heat so that no losses occur as a result of UHT-processing. Even on storage for 90 days no decrease in the content of these vitamins could be detected. UHT-treatment produces small losses in vitamin B_6 and B_{12}. These losses can rise to 50% during a storage period of 3 months. Ascorbic acid and folic acid losses are around 20% (93, 43, 79); the possible further decomposition of these vitamins during storage in relation to the oxygen content has already been mentioned (see fig. 13). The fact should be noted that the loss of vitamin C is of importance not only from the point of view of the physiology of nutrition but also because the vitamin acts as an antioxidant and can therefore prevent oxidative flavour changes (10, 80).

Since UHT-milk is sometimes offered in light permeable packages, it should be mentioned that there may be losses in vitamins due to the influence of light. Riboflavin (fig. 14) and ascorbic acid have been found to be most sensitive to light. The vitamins B_6, B_{12}, folic acid, A and K are less so. 70% of vitamin C may be lost in an hour under the influence of sun light.

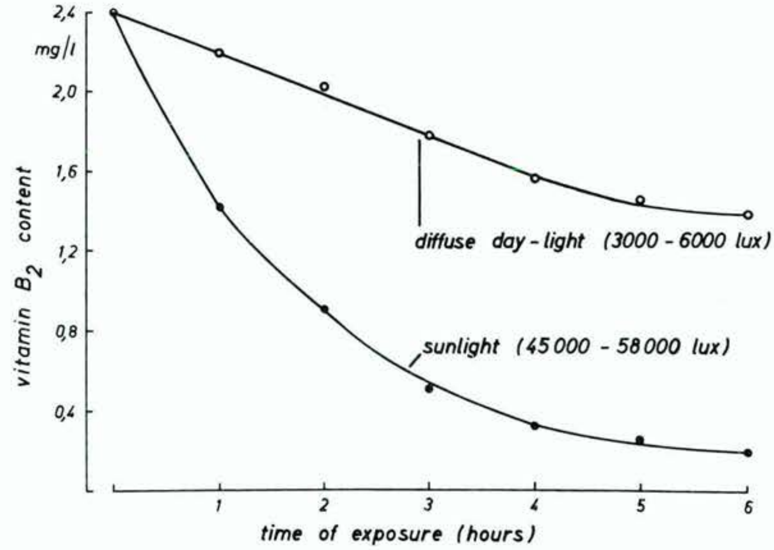

Fig. 14: The effect of natural illumination on the riboflavin content of milk (81).

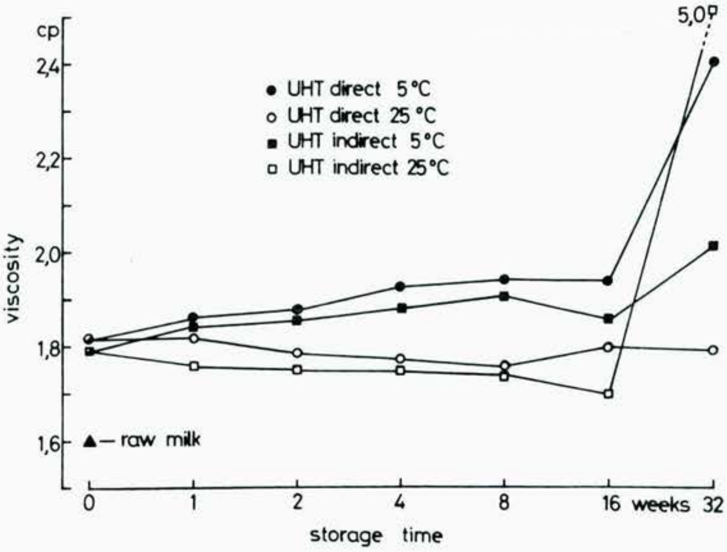

Fig. 15: Viscosity of UHT-milk as a function of the duration and temperature of storage (82).

9. VISCOSITY

UHT-milk has a higher viscosity than raw milk. Blanc (82) reports various changes in viscosity in stored UHT-milk as a function of the method of heating and the storage temperature (fig. 15). The viscosity of a UHT-milk stored at 5°C rose fairly steadily over a period of 32 weeks. This rise was more pronouced in directly heated milk than in indirectly heated milk. Storage at 25°C caused a small decrease in viscosity in milks produced by both methods of heating during the first 8 to 16 weeks of storage but the indirectly heated milk showed a considerable increase in viscosity after 32 weeks. A rise in viscosity in stored UHT-milk has also been reported by other authors (21, 62, 83).

10. pH–VALUE

None or only very small changes in pH-value were observed in UHT-milk compared to the initial values of raw milk (23, 32, 62). Only in milk which had been stored for a long time could a small reduction in the pH-value be observed (63). This reduction has been connected with the interaction between lactose and milk proteins, with the hydrolytic dephosphorization of casein and with changes in the calcium-phosphorus equilibrium (32, 54).

11. COAGULABILITY

Compared to raw milk the coagulability of UHT-milk is distinctly reduced, but there are considerable differences which depend on the method of processing. Blanc (82) states that the coagulation time of both directly and indirectly heated UHT-milk is increased to 4 to 10 times of its initial value. The coagulation time tends to decrease during storage.

12. SURFACE TENSION

Changes in the surface tension of UHT-milk as a function of the processing method and storage temperature are also described by Blanc (82). While the value for raw milk is given as 42.8 dyn/cm^2, the surface tension of UHT-milk varies between 46 and 47 dyn/cm^2.

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CHAPTER 4

THE NUTRITIVE VALUE OF UHT MILK

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From time immemorial the milk of domestical herbivores has formed an important part of the diet of mankind.

The present chapter will be concerned with bovine milk, partly because of its predominant economic importance, and partly because of a paucity of relevant published information on milks of other species. But the effects of UHT-processing on the nutritional quality, described here for bovine milk, would probably be much the same for milk of other animals.

'Milk' is of course not a uniform product; its composition varies markedly between mammalian species, and to a lesser degree even within species. Thus, the milks of Friesian and Channel Island cows differ markedly in fat and carotene content, and the composition of both varies with season and stage of lactation and other factors. Table 1 shows representative values for the main constituents of nutritional importance in the milk of Friesian cows.

As a component of a mixed diet, milk is of particular value as a source of high quality protein, calcium and several of the vitamins. For example, 0.5 ℓ of milk per day provides 40% of the protein, 70% of the calcium and riboflavin, and about 30% of the thiamin, folic acid and vitamin A needed by a 5 year old child.

In the developed countries very little milk is consumed in the raw state; virtually all market milk undergoes heat treatment before it reaches the consumer. Besides the beneficial effects (destruction of spoilage organisms and pathogens; enhancement of keeping quality; inactivation of milk enzymes that would produce off-flavours) the heat treatment may damage or destroy heat-labile nutrients and so reduce the nutritional value. This is of course undesirable, more especially so when the milk is intended as a major component of the dietary, as in the artificial rearing of infants. So it is important that milk processors and distributors should be alert to the possibility of such changes, and of the practical means that are available for reducing them.

Clearly the first requirement is to select forms of heat treatment that provide satisfactory control of microbial contamination with the least possible loss of nutrients. The constituents of milk differ in their stability to heat. Thus the fat, fat-soluble vitamins, carbohydrates and minerals are essentially unchanged by heat treatment, whereas certain of the water-soluble vitamins and the proteins may be adversely affected, to an extent depending on the severity of the heating. The whey proteins are partially denatured even by relatively mild heat treatment, but their nutritive value is generally not impaired. More severe heating may cause browning of the milk, due to occurrence of the Maillard reaction between lactose and lysine molecules in the milk proteins, and is accompanied by a measurable loss of protein quality. Of the water soluble vitamins, vitamin C, thiamin, vitamin B, vitamin B_{12} and folic acid are lost in varying degrees, depending on the severity of the heat treatment.

Most of the milk destined for the liquid market is pasteurized, generally by the high-temperature-short-time (HTST) process. This is a comparatively mild form of heat-treatment; it gives a product that is little altered in appearance and flavour, and can be stored safely for several days in the domestic refrigerator. Pasteurization involves no serious loss of nutritional quality: the only change of any significance is a fall of about 25% in the content of vitamin C, which results from destruction of dehydroascorbic acid formed by oxidation of ascorbic acid during the time interval between milking and heat-processing.

For longer-term storage it is necessary to ensure sterility of the milk. In the traditional in-bottle process the milk is pre-heated and homogenized, and then filled into bottles which are capped and heated in a steam autoclave at 110-115°C for 20-40 min. This drastic treatment imparts a strong cooked flavour, and a richer colour and texture than does pasteurization. In-bottle sterilization causes some impairment of protein nutritional quality and measurable destruction of certain vitamins. The extent of these losses varies but it would be of about 6% in the biological value for rats of the milk proteins, up to 30% of the thiamin, 50% of the vitamin C and folic acid, and 90% of the vitamin B_{12}.

With increase in processing temperature there is a striking increase in the ratio: rate of bactericidal effect to rate of chemical change. At temperatures in the range 135-150°, usually referred to as "ultra-high-temperatures", the processing time needs be only a few seconds to give a sterilizing effect fully equivalent to a conventional autoclave sterilization process and with a very much smaller amount of chemical change. So, for example, 1.2 s at 145° is equivalent in bactericidal effect to 8 min at 121° but causes only about 0.02 of the chemical change (Burton, 1975). Milk sterilized by this ultra-high-temperature (UHT) procedure undergoes less change in colour and flavour than conventionally sterilized milk, and if aseptically filled into suitable containers which exclude light and oxygen it will remain in good condition for several months, even when stored without refrigeration.

UHT processing is sometimes combined with a 'mild' in-bottle sterilization treatment – typically 110-112° for 15-20 min. The resulting product has been less severely heated than in the conventional in-bottle process and the cooked flavour and the impairment of nutritional quality are less pronouced (see Table 2). It is however classified as sterilized milk, not UHT.

In recent years several groups of workers have studied the nutritional value of UHT milk and the published work has been reviewed by, among others, Burton, 1975; Blanc, 1978; Causeret, 1972; Porter & Thompson, 1972. It is now well established that the effects of the UHT process of itself on the nutritional quality must be considered separately from the changes that may occur during subsequent storage of the product (Lembke, Frahm & Wegener, 1968; Ford, Porter, Thompson, Toothill & Edwards-Webb, 1969; Burton, Ford, Perkin, Porter, Scott, Thompson, Toothill & Edwards-Webb, 1970; Goussault, Gagnepain & Luquet, 1978).

EFFECTS OF UHT PROCESSING

Protein. UHT processing causes fairly extensive denaturation of the whey proteins. The direct process generally causes less denaturation (60-70%) than the indirect (75-80%), and with both processes the β - lactoglobulin is affected to a much greater extent than the α - lactalbumin. Some slight modification of the milk casein occurs, and small changes in the size and composition of the casein micelles. However, protein denaturation does not necessarily connote impairment of the nutritional quality, and there is indeed strong evidence from tests with rats that the process causes no measurable change in biological value or true digestibility (Henry & Porter, 1959; Lembke, Frahm & Wegener, 1968) or in capacity to promote growth (Blanc, 1978; Renner, 1976). A long-term feeding experiment, carried out over several generations, showed that UHT treatment of milk had no effect on the nutritional quality as indicated by growth curves, sizes of litters and weights of young at birth and weaning, weight of dam during lactation, weight of various organs, and histopathological analysis of organs from male rats of the F6 and F9 generations (Blanc & Sieber, 1978). Renner (1976) found a small loss of available lysine (3-4%) and Blanc (1978) detected even smaller losses (direct process, 0.4%; indirect process, 0.8%) which were clearly of no nutritional significance. Aboshama & Hansen (1977) reported a fall of about 34% in the content of sulphur-containing amino acids, but this finding seems inconsistent with the weight of evidence from biological and other tests, as does the loss of about 9% in essential amino acid content described by Tylkin & Tsaberyabaya (1976).

Young calves grow less well with UHT milk than with raw milk, as they do when given any milk diet containing more than about 50% of the whey proteins in a denatured state (Roy, 1964). UHT treatment, especially the indirect process, reduces the rate of clotting under the influence of pepsin or rennin (Perkin, Henschel & Burton, 1973), and Braude, Newport & Porter (1971) related reduced clotting ability to a propensity of heated milk to promote scouring in early-weaned piglets. But with human infants there is no evidence that the denaturation has any such adverse effects. Certainly UHT-processed milk and milk-based formula feeds have been successfully used in infant feeding; and roller-dried milk and sterilized evaporated milk in which the whey proteins are extensively denatured form the basis of many formulas for baby feeding.

Lipids, minerals, carbohydrates. There are no changes of nutritional importance in the content of these nutrients on UHT processing, though there may be some loss of unsaturated fatty acids in milk triglycerides (Pol & Groot, 1960).

Vitamins. There is convincing evidence that the content of vitamins A, D and E, and of the vitamin A precursor, β - carotene, is affected very little if at all by UHT processing using direct or indirect heating. Any effects of heat processing on the levels of these constituents are negligibly small in relation to the much larger effects of season and diet. Of the B complex vitamins, thiamin, riboflavin, pantothenic acid, biotin, nicotinic acid, vitamin B_6 and vitamin B_{12} suffer no significant loss, but up to 20% of the folic acid may be destroyed. Processing destroys any dehydroascorbic acid present in the milk, but does not affect the content of ascorbic acid.

The exigencies of milk distribution may sometimes require that the milk be heated more than once before it reaches the consumer and Burton et al. (1967) studied the effects of such repeated heat treatments of milk on its content of vitamin B_6, vitamin B_{12}, thiamin and folic acid. Losses of thiamin and vitamin B_6 were cumulative, and increased with frequency and severity of heating. With folic acid, the first heat treatment potentiated the destructive effect of subsequent treatments; in contrast, the loss of vitamin B_{12} was markedly reduced by preliminary HTST pasteurization.

The effects of different pasteurizing and sterilizing processes on the vitamin composition are set out for comparison in Table 2.

CHANGES IN NUTRITIONAL QUALITY ON STORAGE

Protein. The milk proteins undergo chemical change during storage, mainly by the Maillard reaction between lactose and the E-amino groups of lysine residues, and their nutritional quality is very slowly degraded. Several groups of workers have studied this process. Thus, Möller, Andrews & Cheeseman (1977 a, b, c) found that the casein became progressively more resistant to enzymic hydrolysis with increase in time and temperature of storage.

After prolonged storage at high ambient temperatures (6 months – 3 years at 30-37°C), 10-30% of the lysine residues were present as lactulose lysine, which is nutritionally unavailable. The nutritional damage was not confined to lysine, apparently because the presence of modified lysine residues in the peptide chain hindered the enzymic release of adjacent amino acids. The residual oxygen content of the milk and the nature of the packaging were relatively unimportant to the progress of this deterioration (Andrews, 1975).

Cheeseman (1977) has stressed the need for better understanding of the changes in physico-chemical and nutritional properties of milk that occur during and after thermal processing. Certainly the non-enzymatic browning reaction is an important problem in the food industry, and it continues to be the subject of extensive research.

Suggestions that certain Maillard reaction products might prove harmful to health have evoked concern, and there are scattered reports concerning possible adverse effects of feeding browned foods to experimental animals (cf Tanaka, Kimiagar, Tung-Ching Lee & Chichester, 1977; Fink, Schlie & Ruge, 1958; Adrian, 1974; Lee, 1974).

But with packaged UHT milk, under normal conditions of storage in temperate geographical regions, there is little or no measurable change in protein nutritional quality resulting from incipient Maillard reactions, and no evidence of any other deleterious change involving the milk proteins (see Lembke, Frahm & Wegener, 1968; Blanc, 1978; Bundesanstalt für Milchforschung, 1973).

Lipids. Blanc (1968) showed that lipolysis occurs during storage at 25°. After 4 weeks the increase in free fatty acids was somewhat greater with directly heated milk.

Vitamins. Several recent studies have reinforced the evidence that protection of milk from light and access of oxygen is necessary to preserve the nutritional quality and postpone the development of off-flavours. Of the vitamins, vitamin C and folic acid are particularly vulnerable to oxidative destruction, but in hermetically packed UHT milk from which the dissolved oxygen has been removed during processing, both are stable indefinitely, even during exposure to sunlight which, in the presence of oxygen, would cause their rapid destruction.

If the milk is saturated with oxygen, then loss of vitamin C and folic acid is complete within 2-3 weeks. The figure page 69 shows the influence of residual oxygen in the milk on the stability of folic acid and ascorbic acid during storage in foil-lined Tetra Pak cartons at room temperature (ca. 20°C).

The low oxygen content necessary for the preservation of these vitamins can be obtained by use of the direct-heating sterilization system or by incorporation of a de-aerator into an indirect system. It can only be retained, however, by packing the sterile milk in hermetic containers, and unfortunately some popular types of packaging materials are permeable to oxygen; e.g. polythene-paper laminates, polythene film sachets, and blow-moulded polythene bottles. Flückiger & Heuscher (1966) showed that the oxygen content of milk in polythene-paper or polythene containers increased from 0.4 ppm to 3.4 ppm during 24 h in air at 10°C, and Burton (1975) deplored what he described as a retrograde tendency to use packs that are permeable to oxygen.

Renner et al. (1976) examined UHT milk from 36 centres in the German Federal Republic, and found that it varied considerably in flavour and in ascorbic acid content after storage for 1 and 2 weeks at room temperature. Flavour ranged from 'pasteurized' (12% of samples) to 'sterilized', and ascorbic acid content from 1.1 to 19.5 mg/ℓ. Quality was usually somewhat better in low-fat samples, but was not greatly affected by the intensity of the heat treatment. Flavour was best and ascorbic acid content highest when processing treatment favoured elimination of dissolved oxygen. The authors emphasized that production methods are available that can raise the present very variable quality of UHT milk to a satisfactory high level. Thomas et al. (1975) confirmed that high initial oxygen content caused rapid loss of vitamin C and folic acid during storage. Losses of vitamin B_{12} were small, but were marginally greater in milk of high oxygen content. The flavour of milk of high initial oxygen content was preferred up to 8-13 days, but on longer storage the flavour acceptability was unrelated to oxygen level. The authors concluded that the beneficial effect of oxygen on flavour was so slight and confined to such a short period in the early life of the milk as to be heavily outweighed by the adverse nutritional effects.

During prolonged storage there may be significant losses of other vitamins besides vitamin C and folic acid. There is a progressive loss of vitamin B_6, reaching 50% after 3 months. Similarly with vitamin B_{12}, the content declines during storage, though to a lesser extent than with vitamin B_6 (Ford et al. 1969). Addition of ascorbic acid to milk before UHT processing effectively removed residual oxygen and preserved the milk folate during 60 d storage at 20°, but loss of vitamin B_{12} was sharply increased (Ford, Porter & Thompson, 1974).

The action of sunlight in promoting the destruction of riboflavin and ascorbic acid is well known. Sunlight also accelerates the loss of vitamin B_{12}, vitamin B_6 and folic acid during storage. With vitamin B_{12} and folic acid the extent of the loss is limited by the availability of oxygen. With vitamin B_6 as with riboflavin the stability towards light is not influenced by the oxygen content.

The fat soluble vitamins A, D and E are stable to the heat treatments used in milk processing, and in absence of light are stable for at least 90 days (cf Ford et al. 1969; Burton, Pien & Thieulin, 1965; Bundesanstalt für Milchforschung, 1973). More recent findings (Blanc, 1978) confirmed the stability of vitamin A to UHT processing and storage in Tetrapak cartons for 32 weeks at 25°.

Causeret et al. (1961) examined the stability of vitamin A in sterilized milk during storage at 20° in clear glass bottles. They found no loss after 14 days storage in darkness, but a 45% loss after storage in diffuse daylight.

Thompson, S.Y. (unpublished) found similar losses in UHT milk and in milk replacement formulas for infants, during storage in clear-glass bottles in room daylight. Thompson & Erdody (1974) found that vitamin A in homogenized milk was rapidly destroyed by sunlight at ambient temperature. In artificial light the natural vitamin A was comparatively stable, but added vitamin A (water-dispersible retinyl palmitate) proved labile.

Lactose intolerance and low-lactose milk. With the advent of the UHT process, liquid milk is finding new markets in areas of the world where hitherto it has been a negligible item in the diet, and where increase in milk consumption might create a nutritional problem because of the limited tolerance of lactose found among some ethnic groups. The subject of lactose intolerance is outside the scope of the present chapter. It is comprehensively treated in Annotated Bibliography No 27 (1979). But it seems warranted here to suggest that the magnitude of the problem may have been generally exaggerated. Certainly there is evidence that the standard lactose tolerance test is an unreliable predictor of milk intolerance and that, in lactose malabsorbing populations, milk may be widely consumed in nutritionally useful amounts without provoking severe discomfort. Garza & Scrimshaw (1976) studied the relationship of milk intolerance to lactose intolerance in 99 children (69 black and 30 white).

They reported that "of the black children studies, 11% of those 4 to 5 years old, 50% of those 6 to 7 years old, and 72% of those 8 to 9 years old, were found to be lactose-intolerant, yet no child was intolerant to 240 ml milk". Stephenson & Latham (1974) reported on lactose-intolerant adults who drank normal quantities of milk without adverse effect, and Jackson & Latham (1979) point out that the Masai regularly drink considerable quantities of milk without apparent symptoms, despite the high incidence of lactose malabsorbers (62%) in a sample group. However, there can be no doubting that lactose malabsorption might limit consumption of milk and dairy products in a large segment of the world's population. In a study on Mexican-American adults, Woteki et al. (1977) found that some lactose malabsorbers curtailed milk-drinking because of symptoms, though "many continued milk ingestion specifically for its laxative effect". And other studies show that the individual's milk-drinking habits may be conditioned by its ability to digest lactose (cf Bose & Welsh, 1973; Bayless et al. 1975).

A possible solution to the problem is to reduce the lactose content of the milk. Centrale del Latte, Milan, is commercially preparing milk with > 75% of its lactose hydrolysed before UHT sterilization and aseptic packaging. A batch process is used, in which 4000-8000 ℓ milk are treated with β - galactosidase bound to cellulose triacetate fibres (Pastore, 1978). Dahlqvist, Asp, Burvall & Rausing (1977) investigated a different approach, adding minute amounts of lactase to sterilized milk before aseptic packaging, and allowing the hydrolysis to proceed during subsequent storage at room temperature. The hydrolysis products, glucose and galactose, are both more reactive than lactose in the Maillard reaction and their presence sharply accelerates the deterioration in nutritional quality during storage. However, at room temperature there was no significant loss of biologically available lysine after 1 month. After 3-5 months the loss amounted to 8-13%, and after 8 months, 26%.

CONCLUSIONS

UHT processing of milk causes very little impairment of the nutritional quality, but during storage after aseptic filling there may be significant losses of several nutrients. Of critical importance in this connection are the temperature of storage, the initial oxygen content of the milk, and the nature of the packaging material (opacity, and permeability to oxygen). The nutritional quality is best conserved by hermetic packaging of deaerated milk into opaque containers and, ideally, storing under refrigeration.

Table 1. Representative values for the content of important nutrients in the milk of Friesian cows

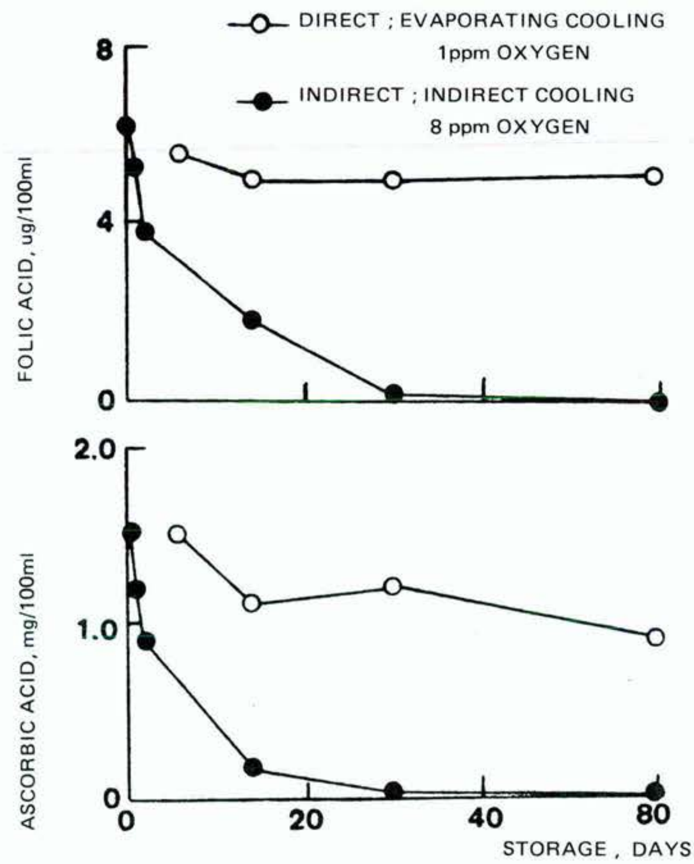
Fat	3.6	g/100 g	Vitamin C	2 mg/100 g	
Protein (N x 6.25)	3.25	g/100 g	Thiamin	40	μg/100 g
Carbohydrate	4.7	g/100 g	Riboflavin	180	μg/100 g
Calcium	0.12	g/100 g	Nicotinic acid	80	μg/100 g
Vitamin A	30	μg/100 g	Pantothenic acid	350	μg/100 g
Carotene	20	μg/100 g	Vitamin B_6	35	μg/100 g
Vitamin D	0.02	μg/100 g	Folic acid	5	μg/100 g
Vitamin E	80	μg/100 g	Biotin	2	μg/100 g
			Vitamin B_{12}	0.3	μg/100 g

Table 2. Influence of heat-treatment of milk on the vitamin composition. Typical values representing the vitamin content and the percentage losses on heating.

Vitamin	Raw Milk Vitamin 100 g	Pasteurized		In-bottle sterilized		UHT sterilized
		HTST	Holder	115° 30 min	110° 15 min after UHT pre-treatment	Direct or indirect processes
Thiamin	45 µg	< 10	< 10	30	20	10
Riboflavin	180 µg	ns	ns	ns	ns	ns
Nicotinic acid	80 µg	ns	ns	ns	ns	ns
Vitamin B_6	40 µg	< 10	< 10	20	15	10
Vitamin B_{12}	0.3 µg	< 10	< 10	< 90	< 60	10
Pantothenic acid	350 µg	ns	ns	ns	ns	ns
Biotin	2.0mg	ns	ns	ns	ns	ns
Folic acid	5.0 µg	< 10	< 10	50	< 30	15
Vitamin C	2.0g	20	20	90	60	25
Vitamin A	30 µg	ns	ns	ns	ns	ns
Vitamin D	22 ng	ns	ns	ns	ns	ns
Vitamin E	86 µg	ns	ns	ns	ns	ns
β - carotene	17 µg	ns	ns	ns	ns	ns

ns – no significant loss

FIGURE – Influence of residual oxygen on the stability of folic acid and scorbic acid during storage.



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CHAPTER 5

BASIC ENGINEERING PRINCIPLES

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Thermal preservation of a foodstuff involves heating the medium to a certain temperature (sterilization temperature), keeping it at this temperature for a certain period of time (holding time) and then cooling it down to a lower temperature for packing under aseptic conditions. This paper discusses the physical and technical background for such processes of the continuous-flow type (UHT) and for different types of apparatuses used. The continuous-flow system was developed from the batch process because an increased sterilization temperature combined with a decreased holding time and having the same lethal effect on micro-organism means a lower ratio for other chemical reactions e.g. those denaturating the product. Furthermore, in a continuous flow process the product temperature may be increased and decreased much quicker than in a batch process. The time distribution for the different parts of the product is also more even.

The time-temperature programme of the process is defined by the lethal effect desired. As already mentioned the ratio of chemical changes is decreasing at increased sterilization temperature and it is therefore advantageous to choose this temperature as high as possible. For technical reasons heating of the product to the sterilization temperature and cooling back normally cannot be made instantaneously and the heating and cooling periods are therefore also of importance when considering lethal effect and chemical changes (1, 2, 3). It becomes important to make the heating and cooling periods as short as possible.

The technically available methods for **heating** the product are mainly the following:

I Indirect heat exchange; the product and the heating medium are separated by means of a wall – the heating surface. The source of energy may be steam or hot water. The following alternatives are at present being used for sterilization purposes:

   a) tubular heat exchangers (for example Ahrens-Bode, Cherry-Burrell, Creamery Package, Stork)
   b) plate heat exchangers (for example Ahlborn, Alfa-Laval, APV, Frau, Schmidt-Bretten, Sordi)
   c) scraped surface heat exchangers (for example Cherry-Burrell, Creamery Package).

II. Direct heat exchange; the product and the heating medium are in direct contact and are therefore mixed. The only heating medium applicable to milk products is steam. Two alternatives are available:

   a) injection ("steam into milk"); the product is the continuous phase in the mixing device and steam is injected into this phase (for example Alfa-Laval, APV (uperizer), Cherry-Burrell, Creamery Package, Rossi-Catelli)
   b) infusion ("milk into steam"); the steam is the continuous phase in the mixing device and the product is injected into this phase either as droplets or as a film (for example Dasi, Pasilac).

III. Electrical methods; these methods may logically be devoted to either of the above-mentioned groups but are treated here in a special group. Theoretically the following alternatives are possible:

   a) resistance heating (for example Elecster, Actini)
   b) induction heating is physically not possible with milk products
   c) dielectric heating: according to this method heat is generated in the product and there is no heating surface. This method is therefore theoretically very attractive, especially for viscous products. However, so far no commercial sterilization equipment is on the market, but according to patent literature development work is going on.

IV. Mechanical friction heat; this method is also signified by the fact that heat is generated in the product itself. The energy is supplied as mechanical work and the energy source normally electricity. Equipment is developed in France and a commercial machine is available.

V. Heat radiation; this implies a heating method by means of electromagnetic waves, e.g. infrared radiation. The heat source is electricity (for example Stoutz-Actini).

For **holding** the product at the sterilization temperature during the pre-determined period of time tubes are normally used.

For **cooling** the product from the sterilization temperature the most common methods are:

I. Indirect heat exchange;

a) tubular heat exchangers
b) plate heat exchangers
c) scraped surface heat exchangers

II. Direct heat exchange;

a) evaporative cooling (expansion cooling, flash cooling) which means boiling of the product caused by reducing the pressure
b) recirculation of already cooled product

The following technical-physical discussion of the above-mentioned methods (for heating only I and II) will be considered:

different products
flow conditions and heat transfer
burning-on, fouling
time-temperature programmes
time-temperature distribution
heating and cooling media

DIFFERENT PRODUCTS

The engineering aspects on different products regard mainly those physical properties of interest for flow conditions and heat transfer. To be considered are for instance if the product is homogeneous or heterogeneous, density, viscosity and thermal properties. The following groups are of interest:

homogeneous products

Newtonian or almost Newtonian
low-viscous (milk)
high-viscous (cream)

non-Newtonian (puddings)

heterogeneous products

particulate products (dispersions, slurries)

The very first plants developed were designed for milk and therefore calculating heat transfer and pressure drops involved no real problems. The development towards more viscous products complicated calculation and design. If only one product is to be processed in the same plant a good technical solution is almost always possible. Viscosity is the biggest problem resulting in increased pressure drop and decreased heat transfer. This means larger heating surfaces and increased residence time in each section of the plant.

The big problem is however the combined plant which shall be able to process a wide range of different products – all at processing conditions being optimal for each product. This is an almost impossible technical task and the result must be a compromise with regard to product quality and costs (investment, running costs: operation, running time, cleaning, energy, water). Processing industry pressing the manufacturer too far with regard to flexibility ends up with an expensive plant which is complicated and expensive to run.

In recent years there has been an increasing interest for products containing particulate material. Mainly two aspects should then be considered: the mechanical behaviour of the particles and the time-temperature development of the central parts of the particles. The first matter means eventual demand for special design of valves, pumps, heat exchanger passages etc. to avoid both clogging and mechanical denaturation of the product. Further mechanical seals may involve problems. The other aspect regards heat transfer. In a liquid heat is mainly transferred as convection while in a solid material as conduction. Conduction is much slower implying a delayed temperature change in the (thermal) centre of the particles. This means for instance that at the outlet of a heater where the liquid is raised to a certain temperature the particle center has not yet reached the same temperature. The heating, holding and cooling sections have to be designed accordingly. Of importance are the physical properties of the particles and their size. (4, 5).

FLOW CONDITIONS AND HEAT TRANSFER

In indirect heat exchange heat transfer, pressure drop and to some extent burning-on are related to the flow conditions. These are defined by the geometrical shape of the flow passage, the flow velocity and the physical properties of the liquid; this is expressed by means of the Reynold number which for Newtonian fluids is defined

$$Re = \frac{v D_H \rho}{\eta}$$

The hydraulic diameter DH is defined as 4 x ratio between flow area and wetted periphery.

At low Re-values the flow is streamlined (laminar) giving a velocity profile from the centre of the channel towards the wall which may be mathematically expressed as a second degree parable. This type of flow is further characterized by relatively poor heat transfer and unfavourable holding time distribution (maximum velocity is 2 x mean velocity). At high Reynolds numbers (above a critical value Re_{CR}) the flow conditions are different and the flow is turbulent. This involves a rather thin boundary layer close to the wall and the velocity profile is approaching a seven degree parable. Turbulent flow is for many reasons more favourable than laminar: higher heat transfer rate and better holding time distribution. These patterns are more complicated when it comes to non-Newtonian fluids.

The mathematical expression of the Reynolds number shows a direct proportionality to flow velocity. Furthermore, the Reynolds number is inversely proportional to the product viscosity – low viscosity giving a high Re. A viscous product means a greater risk of getting streamlined flow but this could be compensated by increasing the flow velocity which in turn requires a larger pump and a higher power consumption.

Tubular and plate heat exchangers are interesting to compare with regard to the critical Reynolds number. The flow is changing from laminar to turbulent at $Re_{CR} \cong 2100$ for tubes but at $Re_{CR} \cong 150$ for plate heat exchangers. This means that the turbulent flow appears at a much lower velocity in plate heat exchangers than in tubes at the same value of D_H.

The rate of heat transfer is a function of the geometrical shape of the flow channel, the flow velocity and the physical properties of the fluid (Nu = f [Re, Pr]). Thus, the different heating methods mentioned give different values of the heat transfer coefficient α. The overall heat transfer coefficient k is further dependent on the heat transfer characteristics of the wall and the heating medium

$$\frac{1}{k} = \frac{1}{\alpha_1} + \frac{\delta_f}{\lambda_f} + \frac{\delta_w}{\lambda_w} + \frac{1}{\alpha_2}$$

A further term (δ_f / λ_f) stands for the resistance to heat transfer of the deposits on the heating surface (burning-on, fouling, fig. 1). The heat transfer surface, e.g. the size of the apparatus, however, also depends on the temperature difference (υ) between the heating medium and the treated product. In this way it is possible to calculate the heat transfer surface needed in the different cases.

This surface will vary according to which heat exchanger design is used. For comparisons the size of the heat transfer surface as such may however be of less primary importance for two reasons. The square meter price for the different systems varies and, further, the residence volume calculated per square meter surface is not the same for the different designs. Therefore the total price and the total heating up time, the latter being calculated from the volume of the total heating section, are of general interest. The residence time is discussed below.

Flow conditions in direct heat exchange are much more complicated. In injectors very small steam bubbles are injected into the product. An intensive heat transfer (condensation) is taking place at the interface steam-product and after a very short interval of time the bubble collapses. The details of this phenomenon are still unkown. In the second alternative – infusion – steam is condensing on the surface of a droplet or a film of product. In both cases the heat transfer is very fast and accordingly the heating-up time very short.

BURNING–ON, FOULING

During practical runs of sterilization plants deposits are formed in the heating, holding and cooling sections. These deposits create some practical problems such as: the heat transfer capacity of the heating surface is decreased thus lowering the flow capacity or requiring a higher temperature difference (fig. 1). In both cases it limits the possible length of the plant running time between cleaning intervals. Furthermore the product pressure drop is increased: this increase also depends on the type of heat exchanger.

Many factors are likely to control the formation of these deposits (6). One of these factors is the super-heating of the wall compared to the average flow temperature (7). Tests in commercial plants have confirmed that a low temperature difference between the wall and the thermal centre is favourable and gives longer runs between cleaning (8).

An increase of the turbulence diminishes the temperature difference. discussed. Turbulence is effected by a high liquid velocity (tube and plate exchangers) or by means of agitation (scraped surface heat exchangers).

However, deposits also are formed in an isothermal system such as the holding section (9). The formation of deposits in holding tubes at 140°C has been investigated. Different tube materials and different surface treatments have been tested. The choice of material seems to be of less importance but the surface finish is important at least with regard to cleaning.

In the direct heating methods there is no wall separating the heating medium and the product. The steam is condensing into the liquid and the condensate and the product are then mixed. It is reasonable to believe that increased turbulence promotes rapid mixing of the condensate and the product and also in this case favours a high heating velocity. It has been claimed that one drawback of these methods is a direct contact between high-temperature steam and product even if this contact period is very short. As said, how this takes place is not yet known in detail. However, from other similar processes it is reasonable to believe that a film of condensed steam is protecting the product from heat damage. This sequence is very short and condensing is very fast, faster than mixing the condensate film into the product and thus hindering product molecules to reach the bubble surface to contact hot steam. This theory is based on the physical fact that condensing is much faster than mixing (convection) and diffusion.

TIME–TEMPERATURE PROGRAMMES

The different processes listed above differ very much with regard to time-temperature relationships. For instance heating-up time is less than 1 s for the direct methods while more than 120 s for some of the indirect methods. In order to get an engineering tool to evaluate and compare these processes with regard to sterilization effect and product denaturation mathematical modelling may be used (3, 10). Time-temperature programmes for the processes are expressed in mathematical terms. These are combined with kinetic models for chemical, biological and physical changes taking place in the product. In this way the resulting changes during the whole process may be predicted. The method may be used for evaluation and optimization of a process as well as comparison between processes. In fig. 2 a direct and an indirect process have been compared using F- and C-values as being well known from the canning industry. For destruction of micro-organisms Z is normally 8.5–10, for browning of milk Z = 21 (11) and for average chemical values Z = 25 (12) is used. Instead of F- and C-values also a modified Arrhenius equation may be used (3). A similar method has been used by Renner 1977 (13). From these evaluations it is obvious that a short heating-up (and cooling-down) time is of importance. It also becomes clear that a higher overall heat transfer coefficient k gives a smaller heat transfer surface for the same temperature programme (same υ). If the hydraulic diameter of the channels are also the same this means that the liquid will get the same heat treatment in the apparatus with the higher k in a shorter time. It is convenient to define the "heating velocity" as the number of degrees centigrade of heat treatment per s of residence time in the heater ($\Delta t / \Delta \tau$ °C/s.). From the general expressions mentioned earlier it is possible to deduce an equation for the average heating velocity:

$$\frac{\Delta t}{\Delta \tau} = \frac{k}{\rho \cdot c} \cdot \frac{4}{D_H} \cdot \upsilon$$

The following conclusions may be drawn:

a) Treating the same product (same δ and c) at the same temperature difference (υ), the average temperature change per second is proportional to the overall heat transfer coefficient (k) and inversely proportional to the tube diameter or the plate distance.

b) The average heating velocity increases in proportion to the temperature difference (υ) if other parameters are constant. Increasing temperature difference, however, also has disadvantages: it means a high wall temperature involving a greater risk for burning-on. Furthermore, an increasing temperature difference in the regenerative section necessitates an increasing temperature treatment in the heater thus raising the steam consumption.

Average time-temperature relations for some examples of the heating systems mentioned are shown in table 1. These data are theoretically calculated but the temperature programmes are roughly identical to those representative for different types of plants. The table shows the relations both for milk and cream and the theoretical expression above is verified: cream with higher viscosity than milk causes a lower overall heat transfer coefficient (k). Treatment in the same type of heat exchanger at the same temperature difference (υ) gives a longer treatment time for cream than for milk.

The influence of the temperature difference in the regenerative section is illustrated in fig. 3. For a plate system the total residence time (regeneration section and heater) and the steam consumption have been calculated for different values of the temperature differences. The temperature rise in the heater and the temperature difference in the regenerative section are changed simultaneously. Consequently the wall temperature and accordingly the risk of burning-on are changed, as already mentioned. The size of the heating surface varies (the capital cost) and the product pressure drop (pumping energy – operating costs). The total picture is thus very complicated.

TIME–TEMPERATURE DISTRIBUTION

The deciding factor for the required effect of heat treatment – in this case the lethal effect – is the lowest temperature in the product at each individual moment. This geometrical point is often defined as the thermal centre.

Conversely, with regard to unwanted effects – for instance heat denaturation – the highest temperature in the product during the heat treatment is decisive. Consequently, the ideal heat treatment should be carried out in such a way that the temperature difference within the product is as small as possible, e.g. all molecules should be heated (and cooled) as uniformly as possible.

So far only average temperatures and average residence times have been discussed. A closer examination shows that all molecules are not uniformly heated; the liquid close to the heat exchange surface acquires the surface temperature while liquid in the centre of the channel has a lower temperature. As already discussed, this temperature disparity depends on the heat transfer conditions and the total temperature difference (υ). The surface temperature depends in the total temperature difference (fig. 1), the wall thickness and the flow conditions (velocity, physical properties). Theoretically it is possible that the same molecule is travelling close to the wall along the whole heat exchanger and is thus exposed to a heat treatment much more severe than the "average molecule". The outlet temperature after the heat exchanger is an average temperature after mixing all molecules and this is the temperature which is measured and used to control the plant.

In direct heating methods the temperature distribution seems to be sensitive to flow parameters. Great temperature variations may occur, as reported by Stroup et al. 1972 (14).

As already mentioned the flow velocity is not equal across the flow passage but approaches zero close to the wall and reaches a maximum at the centre of the channel. As a result of this some molecules pass the apparatus faster than others, and a time distribution curve can be drawn for every type of flow channel. For isothermal tubular systems such investigations have been done (15, 16). For scraped surface heat exchangers Bateson (17) developed a computer program for calculations, considering partly these effects, but for most designs and complete systems detailed information is still lacking. It should be an interesting piece of research work to study the result of combining these two effects – temperature distribution and residence time distribution – to get maximum and minimum time-temperature treatment in a defined plant. In figure 4 these conditions are outlined.

HEATING AND COOLING MEDIA

The heating stage normally consists of pre-heating by means of the sterilized product to a certain temperature and from this point to the final sterilization temperature by means of steam or hot water. The preheating section is thus a heat exchanger between two streams of the product with a flow ratio of 1:1. When the intermediate temperature between the preheater and the final heater is fixed nothing in this respect can be done with regard to temperature difference and burning conditions, heating-up and cooling-down times, and heat economy. When the product is very viscous and thus the heat transfer coefficient low, the overall heat transfer coefficient of such a regenerative section becomes insufficient. For such systems the manufacturers normally arrange a separate water circuit where water is heated up in cooling the sterilized product and is then used to pre-heat the untreated product. This means another heat exchanger section but the arrangement raises the overall heat transfer coefficient, minimizes the burning-on risk, increases heating and cooling speed at an almost maintained heat economy.

In the indirect steam heater the temperature difference is, of course, quite high at the product inlet and then decreases towards the outlet. This fact is a drawback with regard to risk for burning-on, especially if the temperature rise in the heater is rather high. In some plants this has been avoided by using hot water heating also in this part of the heat exchanger. The water is then heated by steam and might also be incorporated in the above-mentioned hot water circulation system.

The direct steam heaters necessitate potable steam, free from compounds not allowed in food products. Regulations in this respect are different in different countries. However, it has also been found that the content of non-condensible gases is of great importance for the behaviour of the plant. A high content of these gases disturbs the condensation of the steam in the product thus jeopardizing the control function and the sterilization result.

Using the direct steam methods the steam condensate dilutes the product and the water balance has to be re-established. After the holding section the product is therefore flash-cooled whereby water is boiled-off after a pressure relief. The problem in this process is the control of how to get the same water content of the product after flash cooling as before steam condensation. The present methods on the market are controlled by means of temperature. This is not quite satisfactory as some errors may occur: normally in dairies the steam produced is not dry and saturated. Furthermore the vapour formed at flash-cooling could be wet. These two items call for calibration of the plant and then demand the same steam and vapour quality at every operation.

Direct heating in combination with direct cooling (flash cooling) involves a high temperature rise in the final step: naturally this implies a bad heat economy which is the price we have to pay for the very short heating and cooling times.

FINAL CONSIDERATION – CHOICE OF TEMPERATURE PROGRAMME

Most of the process combinations involve pre-heating by means of the sterilized product to an intermediate temperature and from this point up to the sterilization temperature final heating by means of steam.

The choice of the intermediate temperature is a compromise: the higher the intermediate temperature the lower the steam consumption and the lower the temperature difference the less risk for burning-on. But at the same time this means a greater heating surface in the regenerative section and longer heating-up and cooling-down times. The last figure (5) is an attempt to illustrate these complicated and partly contradictory interactions.

LIST OF SYMBOLS

$$Re = \frac{v \cdot D_H \cdot \rho}{\eta} = \text{Reynold number}$$

$$Nu = \frac{\alpha \cdot D_H}{\lambda} \equiv \text{Nusselt number}$$

$$Pr = \frac{\eta \cdot c}{\lambda} = \text{Prandtl number}$$

c	=	specific heat	J/kg K
D_H	=	hydraulic diameter $(4 \times \frac{\text{flow area}}{\text{wetted periphery}})$	m
k	=	overall heat transfer coefficient	J/m^2 K s
Δt	=	temperature change in a heat exchanger	K (°C)
v	=	flow velocity	m/s
α	=	heat transfer coefficient	J/m^2 K s
α_1	=	heat transfer coefficient of the treated product	J/m^2 K s
α_2	=	heat transfer coefficient of the heating medium	J/m^2 K s
δ_f	=	thickness of the deposits	m
δ_w	=	wall thickness	m
η	=	dynamic viscosity	kg/m s
υ	=	temperature difference	K (°C)
λ	=	thermal conductivity of the product	J/m K s
λ_f	=	thermal conductivity of the deposits	J/m K s
λ_w	=	thermal conductivity of the wall	J/m K s
ρ	=	density	kg/m^3
$\Delta \tau$	=	treatment time (residence time) in a heat exchanger	s

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Table 1. Calculated residence time for examples of UHT plants.

	Double tube heat exchanger	Plate heat exchanger	Scraped surface heat exchanger	Direct steam heating Flash cooling
Annular or plate Distance, m m	4-6	∿ 5	9.5	–
Temp. program °C	75-110-140-75	72-125-140-75	75-140-75	75-140-75
MILK				
Heating-up residence time, s	32	18	16	Less than 1
Cooling-down residence time, s	15	10	3	Less than 1
CREAM (35% fat)				
Heating-up residence time, s	65	35	31	Less than 1
Cooling-down residence time, s	25	18	5	Less than 1

Fig. 1-Fouling of the heating surface and its influence on temperatures.

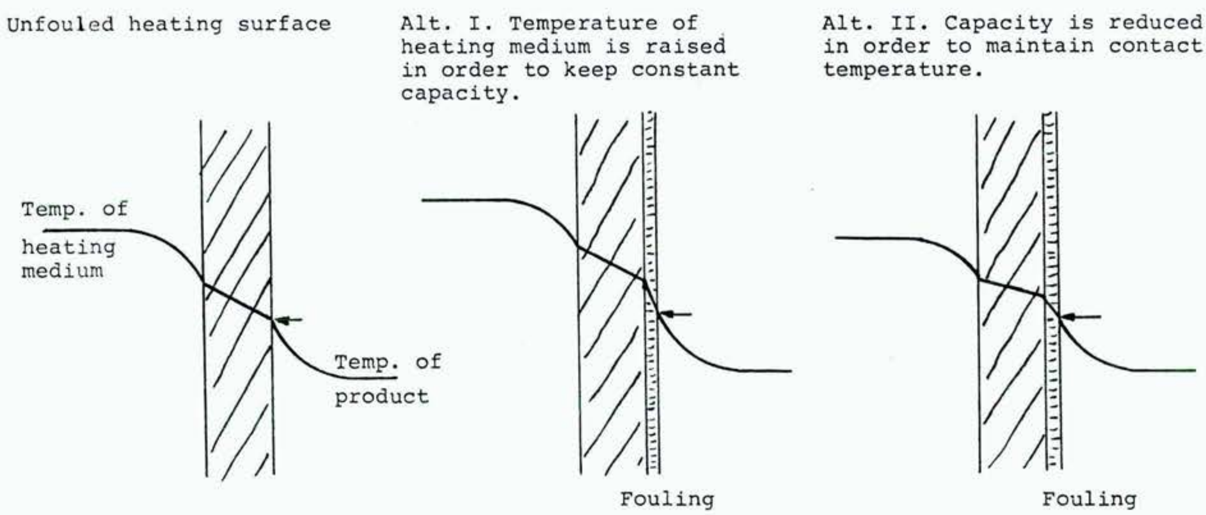

Fig. 2. F- and C-values indirect/direct UHT systems.

F_z thermal death time at 121°C (250°F) for organisms with z °C/min

C_z "cook-value" at 100°C (212°F) for a constituent having z °C/min

z elevation of temperature necessary to reduce the number of organisms resp. the concentration of a constituent to one tenth of its value

T_o reference temperature

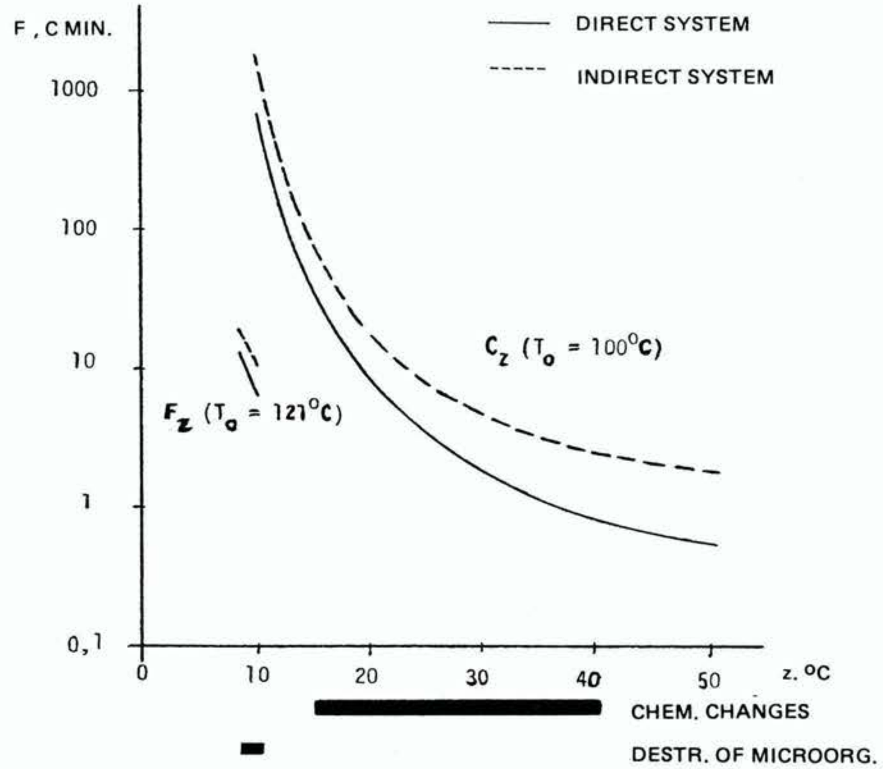

Fig. 3 Indirect heating of milk

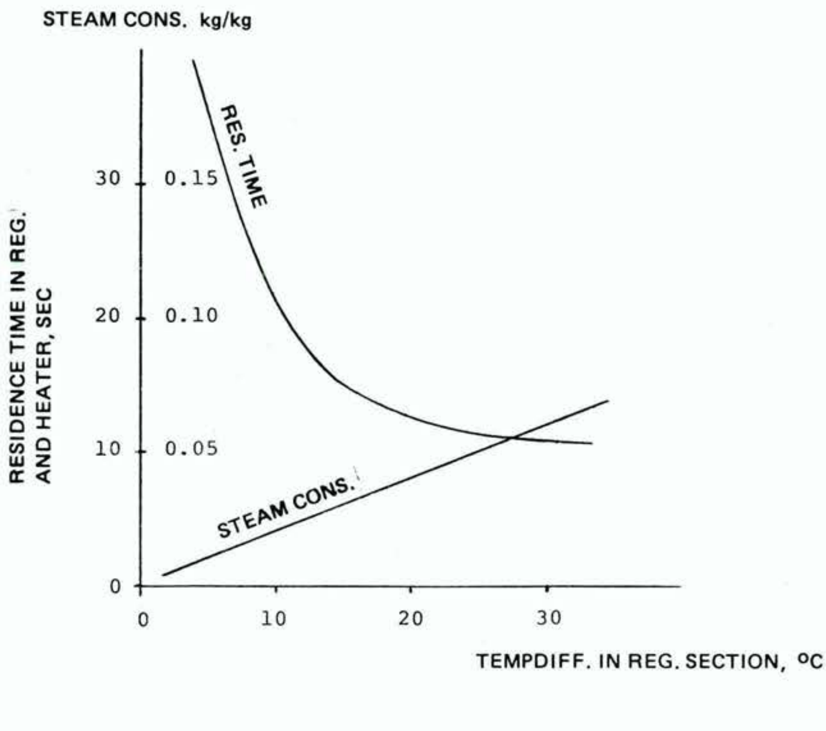

Fig 4. Theoretical time-temperature distribution in the total process

——— Max. heat treatment; combination of max. temperature/max. residence time in heating, holding and cooling sections.

—·—·—· Average heat treatment; combination of calculated average time-temperature distribution in all sections.

– – – – Min. heat treatment; combination of min. temperature/min. residence time in all sections.

It is assumed that complete mixing occurs in the holding section, e.g. temperatures are equalized.

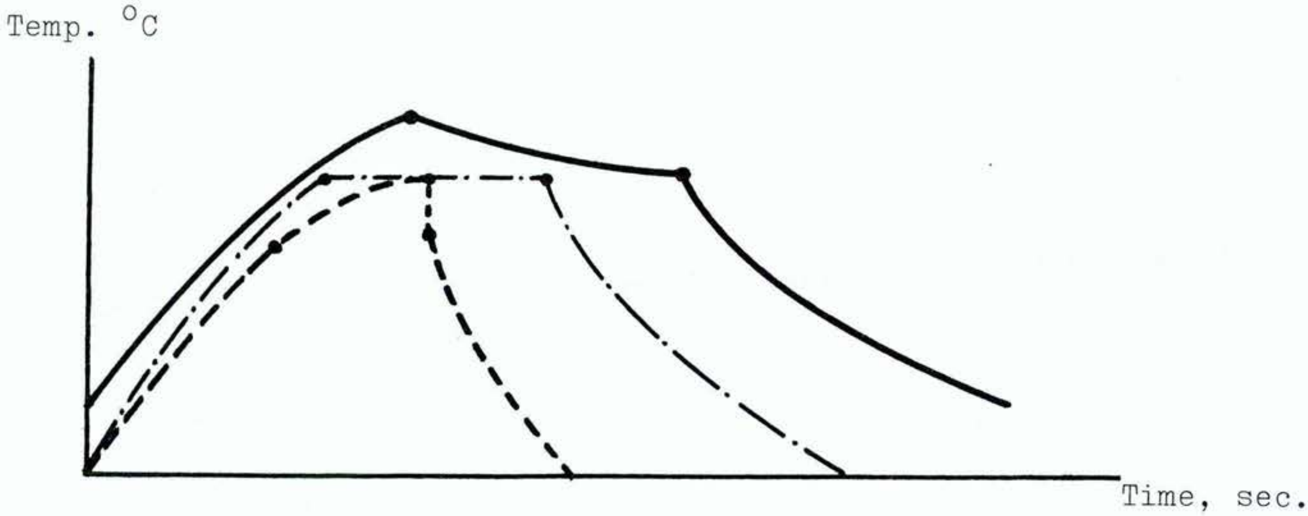

Fig. 5. Influence of some parameters at the choice of process

Hydraulic diameter D_H	Small D_H (small diam. tube, double tubes with annular distance, plate)				Big D_H (Big diam. tube)			
Overall heat transfer coeff. k	High value		Low value		High value		Low value	
Mean temp. difference in pre-heater, √ °C	Big √	Small √	Big √	Small √	Big √	Small √	Big √	Small √
Size of heating surface m^2/kg product	①				①			
Steam consumption kg/kg product		①		①		①		①
Heating-up speed $\frac{\Delta t}{\Delta \tau}$ °C/s.	①							
Wall superheating °C		①		①		①		①

CHAPTER 6

UHT PROCESSING SYSTEMS FOR MILK AND MILK PRODUCTS

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For the advantages of an ultra-high-temperature process to be realized fully, operating temperatures above 130°C are needed. The holding times required to give a good sterilizing process in practice are similar to those shown in Fig. 1, and are therefore only a few seconds. Longer holding times than those shown at any temperature are likely to represent over-processing, and may harm the delicate flavour of a product such as liquid milk. Longer times may, however, be needed with dairy products such as custards and puddings, where an element of cooking is needed.

It can be seen from Fig. 1 that the times required are so short that there is no possibility of obtaining them with an in-container process, because of the low heat transfer rates that can be reached across container walls. A heat exchanger must therefore be used, in which a bulk of product is heated in continuous flow to the required processing temperature.

The times required at temperatures below 135°C are so long that they require long holding sections if they are to be obtained in a continuous flow system. Conversely, the times required above 150°C are so short that they can be controlled in practice only with difficulty. This is particularly true with heating systems where a part of the effective treatment time is taken up by heating and cooling periods. Consequently the ultra-high-temperature processing range in practice is between 135 and 150°C.

The heat exchangers used can traditionally be divided into 2 types, direct heating and indirect heating. With a heat exchanger using direct heating, the product is mixed with high-pressure steam. Condensation of the steam into the product gives rapid heat transfer rates, but causes dilution of the product which normally has to be compensated in some way.

With heat exchangers using indirect heating, there is a physical heat-conducting barrier, usually of stainless steel, between the product and the heating medium, which is either steam or pressurized hot water.

Both direct and indirect systems incorporate heat regeneration between the outgoing heated product and the incoming cool product, and the regeneration is always by indirect heating. There is therefore in practice no truly direct heating system, but only systems in which a proportion of the total heating is done by direct means.

Other UHT plants have recently appeared which are not classical heat exchangers, but are more truly 'energy exchangers', with electrical energy being converted into process heat in the product. The electrical energy may be applied to give radiant heating by means of incandescent resistance elements, or to give conduction heating of stainless steel tubes through which the product flows with, it is claimed, an additional heating component through ohmic power loss in the product itself. In one system, the product is heated by friction as it passes through the narrow space between a stator and an electrically driven high-speed rotor.

The alternative methods used for UHT processing are summarized in Fig. 2.

There are considerable differences in the time-temperature cycles to which products are subjected in these different types of process, because of the different heat transfer rates which are attainable. Extreme forms of time-temperature curve, for a traditional direct-heating system (a) and a traditional indirect-heating system (b), are shown in Fig. 3. Time-temperature curves up to temperatures of 80-100°C will be generally similar in all types of process because of the need for indirect regenerative pre-heating and cooling. Only above this temperature range will the different processes lead to markedly different temperature profiles. It seems probable that the newer, less conventional heating systems will give time-temperature curves intermediate between the extremes shown in Fig. 1.

There are many manufacturers offering different kinds of UHT sterilizing plant: some make more than one type. It is not possible to describe the variants in detail, and the descriptions will be kept general but with the important principles considered as far as possible. Table 1 summarizes the plants that are commercially available as far as is known, with their country of origin, although the list is not necessarily complete.

1. METHODS OF INDIRECT HEATING

Indirect-heating types of UHT plant are available which use assemblies of corrugated plates, tubes, or 'scraped surface' heat exchangers. Corrugated plate heat-transfer surfaces, as are widely used in commercial milk pasteurizers, give high induced turbulence to the heating medium and heated product, and this results in high heat transfer rates, low temperature differences between heating and heated fluids, and relatively low pressure drops in the product circuit.

Plates can be assembled to give a wide variety of heating and cooling sections of different performances. However, the plates are sealed by compression rubber or plastics gaskets at their edges, and in spite of steady development in plate design and gasket materials and design, these set upper limits to the internal pressures that can be used within the heat exchanger.

Stainless steel tubes do not cause induced turbulence in the product, and natural turbulence resulting from high flow velocities is needed to give high heat transfer rates. Pressure drops through the heat exchanger and temperature differentials between heating and heated fluids are therefore higher than with plates because of the need for high velocities. However, because of the inherent strength of tubes, much higher internal pressures can be withstood during operation. Single tubes can be used, carrying the product in a chamber filled with heating or cooling fluid, or double or triple concentric tubes. With double tubes, the heating and heated fluids flow in the outer annulus and the inner tube respectively, separated by the wall of the inner tube: this arrangement is particularly suitable for regeneration. Triple tubes are normally used in the high-temperature, steam-heated sections where the maximum heat transfer is required. The heating medium is supplied to the inner tube and the outer annulus, the intermediate space being occupied by the product. This arrangement gives almost twice the heat transfer rate of a single tube in a heating chamber.

Combined systems are now available, which have plate heat exchangers in the lower-temperature sections, and tubular sections at the highest temperatures, where the internal pressures are also highest.

Scraped surface heat exchangers are suitable for viscous products, where satisfactory heat transfer rates cannot be obtained by reliance on induced turbulence from corrugated plates or natural turbulence from high product velocities. The product flows axially inside a stainless steel cylinder, heated from the outside. A rotating shaft on the axis of the cylinder carries scrapers which move across the heated wall of the cylinder, so braking down any stationary layer of viscous product and inducing turbulence in the body of the fluid.

SYSTEMS USING PLATE–TYPE HEAT EXCHANGERS

A typical plate-heat-exchanger system for milk processing is shown schematically in Fig. 4. Milk is pumped from the input balance tank (1) through a regenerative section (2) to the homogenizer (3). It then passes through two further regenerative heating sections, (4) and (5). Between these sections there may be a holding section to help to reduce deposit formation in the higher-temperature sections. The final section (6), brings the milk to its final temperature, under the control of controller C. The heating medium may be steam, as shown here, or pressurized circulated hot water. The milk passes through a holding section (7) suitably dimensioned to give the required holding time, and is cooled in the regenerative sections (5), (4) and (2). Valve 8 supplies a back pressure of about 300 kPa (3 atm) to prevent boiling of the milk at the sterilizing temperature.

In combined systems, tubular heating sections may be used for the final steam-heating section, and for a part of the regeneration.

A deaerator is sometimes fitted before the final heating section (6), or between 2 of the regenerative sections. The purpose of such a deaerator is obscure: it is sometimes claimed that it removes flavours developed during the heat treatment process, but this seems unlikely. A deaerator will remove much of the dissolved oxygen from the milk, and so stabilize some of the vitamins during subsequent storage.

Before processing begins, a UHT sterilizer must itself be sterilized, usually by the recirculation of hot water at the full sterilizing temperature, without any cooling between the final sterilizing section of the plant (6) and the filler. With heat exchangers having a high level of regeneration to reduce energy costs (85-90% is now common for indirect-heating systems), the time required to raise all the recirculating water to the full sterilization temperature becomes impractically long. This can be avoided by the use of an auxiliary heater to be used only during plant sterilization (9, Fig. 4), or by by-passing the heating sides of the regenerators sections (2), (4) and (5). The cooling sides of the regenerators must never be by-passed, as some parts of the plant which will later handle sterile product will not have been fully sterilized.

If the recirculation system is completed through an unpressurized balance tank, the circulating water must be cooled between the fillers and the balance tank to a temperature below boiling point by a further heat exchanger section (10).

Instead of milk-to-milk regeneration as shown in Fig. 4, an intermediate closed water circuit may be used so that the heat transfer path is milk-water-milk. This system can be extended to include water heating in the final sterilization section as part of the intermediate circuit. Such a system is shown diagrammatically in Fig. 5.

SYSTEMS USING TUBULAR HEAT EXCHANGERS

The flow diagram of a typical system using only tubular heat exchangers is shown in Fig. 6. The operation is generally similar to that shown in Fig. 4 for plate heat exchangers, and includes an additional heating section and a recirculation cooler, both for use during plant sterilization. The components of the plant are numbered to correspond with the similar components in Fig. 3.

As tubular systems are able to withstand much higher internal pressures than plates, it is possible to isolate the high-pressure pump section of the homogenizer from the homogenizing valves. It is therefore possible if required to homogenize after the product sterilization stage without using an expensive aseptic form of high-pressure pump.

SYSTEMS USING SCRAPED–SURFACE HEAT EXCHANGERS

Scraped-surface heat exchangers are relatively expensive, and it is difficult to arrange for regeneration. They are therefore only used in those parts of a sterilizing circuit where the product is viscous and the special advantages of these heat exchangers for viscous products are essential.

Different products may call for scraped-surface heat exchangers in different parts of the process. For example, a viscous product whose viscosity falls with temperature in the normal way may require scraped-surface units for preheating and final cooling, but not in the higher-temperature sections. On the other hand, many milk-based products such as custards only develop a high viscosity after cooling at high temperature, so that scraped-surface units may be needed only for the final heating stage and for cooling.

CONTROL SYSTEMS FOR INDIRECT HEATING

Control systems are required to maintain the proper final sterilizing temperature, as shown at C in Figs 3, 4 and 5. Intermediate temperatures may also need to be controlled in the same way. Conventional methods are used, in which a temperature-sensing element immersed in the product acts through a controller to vary the temperature of the heating medium.

The control system for the final temperature, or a second independent system sensing the final temperature, is used to operate safety circuits if the product temperature falls too low for bacteriological safety. A flow-diversion valve may be actuated, which diverts product at the outlet of the final heating section and before the holding section. Usually this underheated product is passed through a cooling circuit in the diversion line, and returned to the balance tank for reprocessing.

Alternatively, a visible and audible warning may be given if the processing temperature falls to some preset level, followed by an automatic change to water processing and shut-down if the temperature falls further.

Product flow rates are determined by the homogenizer. Centrifugal pumps in series with the homogenizer present no problems if the system is completely closed as in Figs 4, 5 and 6. However, if deaerator vessels are included within the circuit, the rate of product extraction from the vessel must equal the rate of supply, while a suitable pressure head is maintained at the inlet to the extraction pump. Different ways of achieving this are used by different manufacturers.

A variation in plant throughput may be required to meet different filling conditions. A variable-speed homogenizer must then be used: modern solid-state electronics makes this simple. However, any reduction in flow rate below the maximum for which the plant has been designed means an increase in the flow times through all stages of the plant. Variation in plant volume in accordance with throughput to maintain the same flow times is not practicable. A partial solution to this problem is shown in Fig. 6, where the effective length of the steam heating section (6) is reduced as the flow rate is lowered, by the action of a series of condensate outlets which are separately controlled. As condensate builds up in the sections of the heating coil where the outlets are closed, these sections become inoperative. However, the flow time at lower temperatures must necessarily become longer.

2. METHODS OF DIRECT HEATING

Two alternative methods of direct heating are possible: steam may be injected into the product stream to produce the required sterilizing temperature, or the product may be sprayed into a chamber which contains steam at the sterilizing temperature. With both methods, the product is preheated by indirect methods to a suitable temperature (not normally less than about 80°C) before it is mixed with the steam. This preheating may be by regeneration, hot water or vacuum steam, or a combination of these.

This method of heating causes a dilution of product with condensed steam, amounting to about 10% of the plant throughput. With some products, this dilution may be unimportant, and can be allowed for in the product composition. With others, and particularly liquid milk, it is important that the added water is removed so that the composition is not changed by the process. This is achieved by cooling the milk from the sterilization temperature by spraying it into a vacuum chamber. This form of cooling also gives a rapid drop in milk temperature analogous to the rapid heating obtainable with the direct system (see Fig. 3 [a]). Furthermore if the temperature of the milk or vapour leaving the expansion chamber is close to that of the milk before mixing with steam, then all the added water will be removed during cooling.

Expansion cooling is followed by further indirect cooling by regeneration or cold water to give the required filling temperature.

With direct heating systems, the homogenizer is normally placed after the sterilization stage. Certain texture defects brought about by the direct treatment of milk are then reduced, and the tendency of direct heating to agglomerate fat in milk which has been previously homogenized is avoided. The homogenizer therefore has to be of the aseptic type, capable of sterilization and fitted with steam seals to prevent contamination during operation.

STEAM–INTO–MILK SYSTEMS

A typical flow diagram for such a system is shown in Fig. 7.

The product is pumped from a balance tank (1) through a regenerator (2) heated by the outgoing product, and an indirect heater (3) supplied with vacuum steam. A high-pressure pump delivers the product to the steam injector (4) at a pressure of about 500 kPa (5 atm). Steam is injected at (4) to give the correct sterilizing temperature under the control of C_1, and the diluted product passes through a restricting orifice at the and of the holding tube into the expansion chamber (5). The vacuum in the expansion chamber is maintained at a suitable, constant level by a water-jet condenser (6).

The preheating temperature is controlled by the supply of vacuum steam to the preheater (3), to maintain the temperature of the milk before steam injection slightly below the temperature of the vapour leaving the expansion chamber. The difference in temperature required for accurate compensation of product composition can only be determined by experiment but, once determined, it is controlled by C_2.

Product is extracted from the vacuum chamber by an aseptic centrifugal pump, homogenized in an aseptic homogenizer (7) and finally cooled by regeneration (2).

It is necessary to keep a liquid pool as a seal at the bottom of the expansion chamber (5). A level controller, L, maintains the product level by actuating a restrictor valve before the steam injector.

Different manufacturers use different types of steam injector, with the aim of obtaining maximum stability of temperatures and pressures during operation, the lowest supply pressure for steam at the injector, and the least effect of build-up of solids within the injector during operation. The regenerative systems may also differ. Instead of having a separate condenser, a regenerative heat exchanger may act as the condenser with a backing pump for the removal of incondensible gases. In a further system, the condenser may be a water-cooled plate condenser, with the cooling water circulated through a plate-type regenerator section in the product-preheating line.

MILK–INTO–STEAM SYSTEMS

These systems are essentially the same as those described in the previous section. The difference is in the replacement of the steam injector (4, Fig. 7) by a steam infuser vessel into which the milk is sprayed, so that it is heated as it falls to the bottom. A vacuum chamber is again used to cool the product after the holding period, and to correct the product composition. The heating and cooling arrangements for a typical system are shown in Fig. 8.

The importance of control of product level in process vessels has been referred to previously in relation to deaerators in indirect-heating systems and to expansion cooling vessels. The problem is even more important with sterilizers of the 'milk-into-steam' type, as a pool of product in the bottom of the infusion vessel can represent a considerable addition to the holding time at sterilization temperature. Slight variations in level can mean substantial changes in holding time, so that close control is essential. Level control in the expansion cooling vessel is, of course, still needed.

In the system illustrated in Fig. 8, levels are maintained through variable-speed pumps. Product is preheated as in the injection systems, and is then supplied by a positive-displacement pump (1) to a steam pressure chamber (2), maintained at a pressure controlled by C_1 to give the required sterilizing temperature. Product is removed from the base of the pressure chamber by a positive-displacement pump (3) controlled by L_1 to maintain a constant product level. This pump transfers the product through a restriction valve (4) to the expansion chamber (5), which is maintained at a suitable vacuum by the water-jet condenser and backing pump (6). Product is removed from the expansion chamber by an aseptic centrifugal pump (7) and passed to a variable-speed aseptic homogenizer (8), the speed of which is determined by a level controller which senses the product level in the expansion vessel. The product is then cooled by combinations of regeneration and water cooling.

CONTROL SYSTEMS FOR DIRECT HEATING

These are more complex than those needed for indirect heating. Temperature controllers are needed both for the final sterilizing temperature and to maintain the correct product composition. Since an expansion vessel is always part of the process, a system of level control is needed: for milk-into-steam systems a further level control is needed for the heating vessel which may be interlinked with the first.

The control system for sterilizing temperature is conventional and similar to that used for indirect systems, although it must remain stable under conditions of much more rapid temperature change. The sterilizing-temperature sensing element will operate safety circuits of the kind already described for indirect systems. If a flow-diversion valve is included, the diverted product line must include a second expansion vessel similar to that in the main forward flow line, or the composition of the returned diverted product will not be correct.

The control of product composition is, as explained above, a matter of ensuring that the expansion temperature is slightly higher (approx. 2°C) than the temperature of the product before mixing with steam. The required temperature differential depends markedly on the heat loss from the system, and this loss varies from one installation to another (Perkin & Burton, 1970). It is therefore necessary to determine by experiment for each individual plant the temperature differential which gives the correct composition. The control systems can then be set to maintain this differential.

The product temperature before mixing with steam is measured by a sensing element in the product line: the temperature after evaporation can be measured either in the product line or in the vapour leaving the expansion chamber. Either the vacuum in the expansion vessel is held constant and the preheat temperature varied by the controller, or the preheat temperature is held constant and the vacuum varied. The former is usually preferred, as it is claimed that a fluctuating vacuum in the expansion vessel may cause carry-over of product into the vacuum line and so interfere with compositional control.

SUPPLY OF STEAM FOR DIRECT–HEATING SYSTEMS

Steam to be mixed directly with a product must be of the highest quality. It should be dry and saturated, in order that the systems for compositional control can work correctly, and it should contain no foreign substances, solid, liquid or volatile, that might adversely affect the quality of the product.

Additives are normally used with boiler feed water to prevent boiler and steam line corrosion, control sludge formation and reduce priming. These additives should not be toxic, in case they are transferred from the steam to the milk. Recommendations for the production of so-called 'culinary' steam, and lists of permitted boiler water treatment compounds, have been published in the USA and in the United Kingdom (Standards, 1967; Circular, 1972; Regulations, 1977).

It is always preferable not to use the normal factory steam supply for direct heating systems, but to instal a separate steam-raising plant fed with softened, potable water and using the minimum amount of chemical feed-water treatment. This plant may consist of a small, primary boiler, oil or gas-fired, or a secondary boiler heated by steam from the main factory supply. According to Holm (1969), the steam supply pressure to a secondary boiler must be about 400 kPa (4 atm) higher than that of the generated steam.

3. OTHER TYPES OF STERILIZER

The UHT sterilizers in which electricity is used as a source of thermal energy comprise two different designs. In one, the electricity heats to incandescence spiral resistance elements which are wound round quartz tubes through which the milk passes. The milk is heated from 95 to 140°C by a combination of infra-red radiation and heat conduction through the quartz tubes: the earlier stages of heating are by regeneration. The overall time-temperature cycle of the plant is similar to that shown in Fig. 3 (b). From the standpoint of performance, this sterilizer is therefore similar to a conventional indirectly-heated sterilizer.

In the second design milk is heated to 115°C by regeneration and is then finally heated to the sterilizing temperature in a stainless steel tube through which electric current passes. The current heats the tube, which in turn heats the milk. Although some very small amount of current will pass through the milk, the heating effect from this source will be negligible, and the sterilizer is effectively a tubular heater but with the tube walls heated by electricity. Cooling is by regeneration. It might be expected that the performance of the sterilizer would be similar to that of a tubular sterilizer of similar capacity with the tube wall heated by very hot water or steam.

The friction sterilizer is unique. It comprises a rotor in the form of a thin disc, about 400 mm diameter, which is driven at high speed (4000-5000 rev/min) by an electric motor. The disc is housed in a stator with a clearance between the side walls of the disc and the stator of about 0.3 mm. Product enters this clearance space at the axis, passes radially across the face of the disc, and is discharged at the periphery, being heated as it passes by the intense shearing forces imposed. Product is preheated to about 80°C by tubular regenerators before it enters the friction sterilizer. It is heated to 130-150°C in about 0.02 s by friction, the final temperature being determined and controlled by a valve which regulates the product flow rate. Cooling is by regeneration. Some homogenization occurs because of the mechanical forces applied to the product.

Because of the rapid rate of heating, the friction sterilizer is likely to be similar in performance to the conventional direct-heating sterilizers. Because all cooling is by indirect regeneration and there is no expansion cooling stage, cooling will be slower than with direct-heating sterilizers. However this is unlikely to give rise to a significant difference.

As with all pipelines and valves carrying sterile product, the pipes and valves controlling the flow of product or cleaning fluids into or out of the tank need to be connected with great care to prevent contamination entering the tank. Pairs of valves may be connected in series, with the space between them when they are closed filled with steam. Valves and seals may also be provided with steam channels to block the entry of contaminants.

6. COMPARISON OF HEATING SYSTEMS

As can be seen from Table 1, most commercial UHT sterilizers can be divided into 2 groups, the indirectly heated and the directly heated types. The ability to use shorter processing times in the high-temperature sections of directly heated sterilizers, as illustrated in Fig. 3, has been claimed to lead to a better quality product. Studies on the milk produced by commercial UHT plants in Germany have tended to demonstrate that direct processing gives a better-flavoured milk than indirect processing, although there are substantial differences within each type (Renner et al., 1976). However, experiments in which direct and indirect processes were carefully chosen to give equal sterilizing efficiencies did not show any difference in flavour after the first few days of storage between milks produced by the 2 methods, and within this first period the indirectly processed milk was preferred (Thomas et al., 1975). Discrepancies of this kind are difficult to resolve, but it may be that most indirect plants, when operated commercially, give a more severe sterilization process than most direct plants, because the sporicidal effect of the heating and cooling periods has been underestimated.

It also appears that high rates of temperature change in a sterilizer do not necessarily lead to great advantages in nutritional quality. When equal sterilizing processes are compared, the differences in chemical and biochemical characteristics of milk processed by direct and indirect processes are less than has been supposed (see, for example, Burton, 1977).

The main nutritional advantage of direct processing lies in the removal of oxygen during the expansion cooling stage, which prevents the loss of some of the vitamins during storage. This is not a consequence of high heat transfer rates, however: it would not happen with other methods giving high rates of temperature change unless they incorporated a deaeration stage, and conversely the same advantage could be obtained with indirect systems having relatively slow temperature changes provided a deaerator was included.

There is therefore comparatively little evidence that different processes, whether conventional direct or indirect, or whether they obtain high rates of temperature change by other methods, lead to significant differences in product quality when giving the same severity of sterilizing process. The main proven factor is the presence or absence of oxygen, and the advantages of oxygen removal can be applied to any processing method.

Increasingly, the important differences between different processes are economic, in first costs and running costs. Direct-heating systems are in general significantly higher in first costs for the same throughput than are plate or tubular heat exchangers. The additional complication of the direct-heating system, which requires additional pumps, expansion vessels, controls, and an aseptic homogenizer, is responsible. The requirement for steam of culinary quality also increases the cost of steam supply. Tubular heat exchangers are more expensive than those using plates, but of the indirect types probably only scraped-surface heat exchangers compare with the capital costs of direct systems for similar throughput.

Running costs are in part determined by pumping and homogenization costs, but increasingly the cost of thermal energy input is the controlling factor. This cost can be restricted by an increase in regeneration in the heat exchange system. However, with direct-heating systems in which the product is heated from about 85°C to the sterilization temperature by mixing with steam, regeneration is limited to 45-50%. Higher levels of regeneration can only be obtained by raising the product to a higher temperature before mixing with steam: this makes the operation of the sterilizer closer to that of an indirect system, and reduces any differences that there might be between direct and indirect processing. A tendency to raise the preheat temperature, e.g. up to 90°C, and so increase the possible level of regeneration with direct systems has already appeared, but no truly direct system can approach the current levels of 80-90% regeneration which are being used with indirect systems.

One manufacturer now offers a type of sterilizer which can be operated with complete flexibility with any preheat temperature above about 85°C for direct processing, which gives a relatively low level of regeneration. As the preheat temperature is raised, the proportion of direct processing to indirect processing decreases, with a corresponding improvement in regeneration. In the limit, the sterilizer can be operated fully indirectly, with no contribution from direct heating: the regeneration level is then at its maximum. It is proposed that suitable operating conditions would be selected according to the product being processed.

The least expensive system in capital and running costs is the plate-type indirect system. However, this system is particularly affected by deposit formation from the product on the heating surfaces. This either restricts the flow passages and increases the pressure within the heat exchanger, or limits heat transfer to the product and causes the heating medium-product temperature differential to rise. In both cases, the possible operating period of the heat exchanger is limited. When operating with milk, deposit formation can be reduced by preholding, e.g. for 4-6 min at 85°C or 30 s at 105°C, but there is a risk of an adverse affect on flavour. An alternative way of dealing

4. METHODS OF CLEANING AND STERILIZATION

Experience has shown that the cleaning and sterilization of heat exchangers for UHT processing are vital for the satisfactory performance of the process. The operations should preferably be under automatic control, with the times and temperature of the different parts of the cleaning and sterilization cycles controlled by instruments.

However, such fully-automatic systems are expensive, and a cheaper, manually-controlled plant may have to be installed. In such a case, the importance of strict supervision of the system and close adherence to the specified cleaning and sterilizing routine cannot be over-emphasized.

Normally, circulation cleaning follows immediately after a processing run. Sterilization of the sterilizer and associated equipment takes place immediately before the following day's operation.

For cleaning, the product is followed by softened mains water, and when rinsing is complete, the cleaning fluids are circulated through the plant. It is common to use a 2-stage cleaning cycle, with caustic soda solution followed by dilute nitric acid. A water rinse is interposed between the 2 solutions, and the plant is well rinsed with water after the nitric acid circulation. More complex detergent circulations may be recommended in some circumstances.

If processing has been continued for a long period, it may be necessary to use manual cleaning of certain parts of the plant. For example, the steam injection head of directly heated plant may need special attention.

It may also be necessary, particularly with some types of indirect-heating sterilizer, to clean during a processing run because of a build-up of internal pressure in the plant. It is then important to maintain sterility during the cleaning cycle so that further time is not wasted in re-sterilizing after cleaning. All the stages of cleaning are therefore carried out while the plant continues to operate under sterilization temperature conditions. The cleaning process, from operating on product before cleaning to operating on product after cleaning, must be under automatic control because of the complex sequence of events, and the importance of each one of them.

Sterilization should be carried out immediately before the start of a processing run. Either steam or recirculated hot water can be used. If a sterilizer incorporates a large amount of regeneration, e.g. more than about 50% regeneration, the time required to reach plant sterilization temperatures throughout when circulating water can be very long and operationally unacceptable, as has been already mentioned. This effect can be avoided either by having an additional steam-heated heat exchanger in series with the product line, as shown in Figs 3 and 5, or by by-passing the heating side of the regenerator sections so that they are inoperative. During sterilization, no cooling water is applied to cooling sections, so that the circulating water remains at the sterilization temperature up to and beyond the interconnection point with the fillers. A cooling section then reduces the temperature to below boiling point if the water is to be recirculated through an open balance tank.

Water circulation can continue after plant sterilization is complete while temperatures suitable for product processing are established, and the water is then replaced by product. This change is normally automatic.

5. INTERCONNECTION OF A STERILIZING PLANT WITH A FILLER

With relatively small installations it is possible to use a single UHT sterilizer connected directly to a single aseptic filler, the capacities of the 2 being matched. This arrangement is simple but inflexible, since the sterilizer must operate if the filler is to be supplied with product, and if the filler stops for any reason the sterilizer must be shut down or else sterile product must be diverted to a non-sterile use or recirculated for re-processing.

More commonly, a series of fillers is supplied by a single sterilizer which is sized to match the total filler demand. A reduction in the number of fillers in operation can be balanced by a reduction in the plant throughput, through the use of a variable-speed homogenizer: change in the homogenizer speed can be automatically varied according to the number of fillers in operation. A reduction in the flow rate will normally lead to an increase in processing times, although it is possible to make some compensation by the system described earlier and shown in Fig. 5. This increase in processing time may possibly have an effect on the product through increasing the amount of chemical change during the process.

A more flexible way of connecting a sterilizing plant with several filling machines is by interposing an aseptic balance tank. In this way, the operation of the sterilizer can be separated entirely from the operation of the fillers, and variation in the number of fillers in use need have no effect on the sterilization conditions.

Aseptic tanks are cleaned by normal circulation cleaning methods using spray balls, and sterilized with steam under pressure (about 250 kPa, 2½ atm) to give an internal temperature of 135-140°C for the required time.

The cleaning and sterilization is automatically controlled, and independent of the cleaning and sterilization of the heat exchanger and filling systems. When sterilization is complete, the tank may be cooled by circulating water in an enclosing jacket, while an excess internal pressure is maintained with oil-free sterile air. This excess pressure is maintained above the product as long as the tank is in use, to resist the entry of contaminants from the surroundings and to provide the necessary product pressure at the fillers.

with the problem is by a periodic on-line cleaning operation as described above, while product supply to the fillers is maintained from an aseptic balance tank. Such an operating method incurs extra costs in plant complication and in reduced utilization of the heat exchanger, and these must be set against the intrinsically lower costs of the plate system.

Tubular heat exchangers and scraped surface heat exchangers are both less influenced by deposit formation, but they are more expensive to buy, and in other ways more expensive to operate. In particular, scraped-surface heat exchangers are only likely to be used when the product characteristics leave no alternative.

The true costs of a UHT system are therefore very difficult to assess, as they depend on a great many factors. Much will depend on the type of product which is to be processed. If it has a low viscosity such as milk, all types of heat exchanger may be used and a full comparison of their relative costs and characteristics is essential. If the viscosity is higher, plate type heat exchangers may not be practicable because of pressure problems, and only tubular or direct systems might be considered. Finally, with products of high viscosity, only scraped-surface heat exchangers may be practicable.

There is insufficient evidence as yet to assess the true operating characteristics of the systems which use electricity as the energy source in one way or another, although product quality is not likely to be very different from that given by other types of plant. Electricity is usually a more expensive form of process heat than steam or hot water produced in a factory boiler, since it is commonly generated at an efficiency of only 30-50% determined by the heat cycle in a thermal power station. Electricity must therefore have substantial compensating benefits before it is likely to be used widely.

7. SPECIAL PROBLEMS OF MILK–BASED PRODUCTS

It is not possible to generalize about the problems of milk-based products, since these are specific to each product. Custards form a type of product in which a high viscosity is desirable in the final form. A prolonged holding time at the sterilizing temperature is normally incorporated in the UHT plant in order to cook the starches in the product mix so as to develop a desirable viscosity. However, it is better if a high viscosity is only developed some time after cooling, after packing and during storage, so that problems do not arise because of high viscosity developing within the heat exchanger. This is a question of suitable formulation of the custard mix. A high filling temperature, e.g. 60°C, helps to keep the viscosity low but may cause flavour problems, or difficulties in some forms of aseptic filling. If the viscosity can be controlled sufficiently well, custards can be processed in plate heat exchangers: if such a control is not possible, a type of heat exchanger better able to withstand high internal pressures may have to be used.

In extreme cases of high viscosity, a scraped surface heat exchanger will be needed. A scraped surface heat exchanger is also the only practicable type if solid particles are present in the product: the sterilizing time will then have to be increased to allow heat penetration into the particles to give adequate sterility.

Whenever a product is formulated, the bacteriological quality of each component must be examined. It may be that one constituent contains a large number of resistant spores. The UHT sterilizing conditions will then have to be increased in severity to allow for this additional contamination.

With milk products depending on volatile components for their characteristic flavour, expansion cooling in a direct heating system or the use of deaerators in an indirect system may cause damage to the flavour. An indirect system without a deaerator avoids this difficulty.

Cream of fat contents up to about 40% can be processed in UHT equipment. The problem here is one of maintaining a satisfactory physical structure of the cream after processing: this depends on combination of heat treatment and homogenization conditions which are difficult to forecast.

In general, if a product is being developed for UHT processing, it is wise to carry out extended pilot studies before production on a commercial scale, to determine the optimum product composition and processing conditions to meet the specified requirements.

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TABLE 1

TYPES OF ALUTRA–HIGH–TEMPERATURE PROCESSING PLANT

Type	Manufacturer	Country of origin
(a) INDIRECT HEATING		
(i) Tubular	Cherry Burrell Nuova Frau (Sterflux) Stork (Sterideal)	U.S.A. Italy The Netherlands
(ii) Plate	Ahlborn Alfa-Laval (Steritherm) APV (Ultramatic) Sordi	W. Germany Sweden United Kingdom Italy
(iii) Combination plates and tubes	APV (Ultramatic T) Cherry Burrell Schmidt	United Kingdom U.S.A. W. Germany
(iv) Scraped surface	Alfa-Laval Cherry Burrell Crepaco Johnson	Sweden U.S.A. U.S.A. Sweden
(b) DIRECT HEATING		
(i) Steam-into-milk (injection)	Alfa-Laval (VTIS) APV (Uperiser) Cherry Burrell Rossi & Catelli Stork (Steritwin)	Sweden United Kingdom U.S.A. Italy The Netherlands
(ii) Milk-into-steam (infusion)	Crepaco (Ultratherm) Laguilharre Nuova Frau-Dasi Pasilac (Palarisator)	U.S.A. France Italy/U.S.A. Denmark
(c) OTHER TYPES		
(i) Electric resistance heating of incandescent elements surrounding quartz tubes	Actini-France	France
(ii) Electric resistance heating of stainless steel tubes	Elecster	Finland
(iii) Friction	Atad	France

Fig. 1 – Variation with temperature of the holding time required for a good sterilizing process for milk.

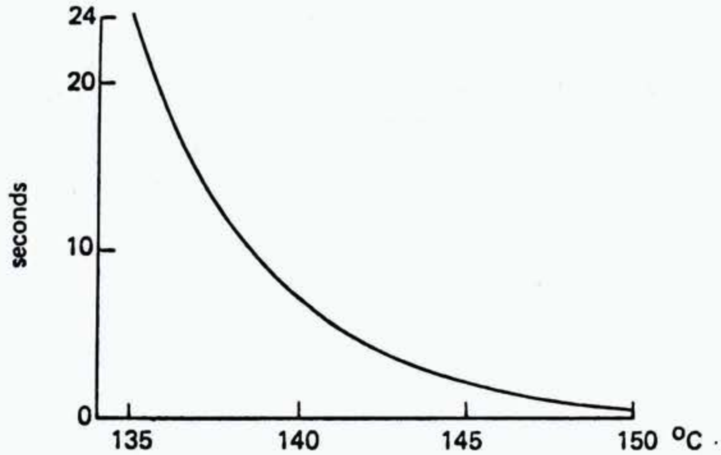


Fig. 2 – Systems used for UHT processing.

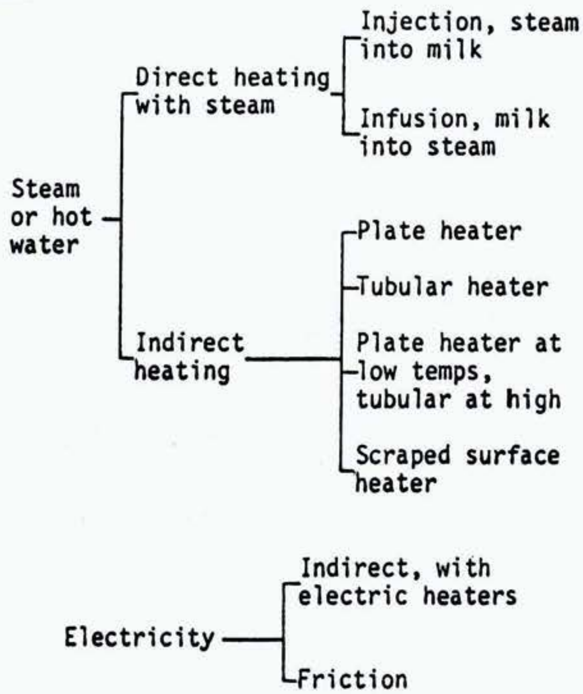
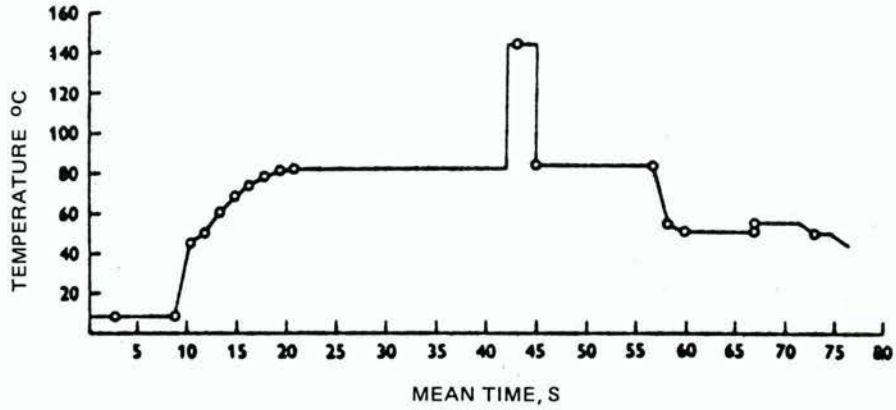


Fig. 3 – Typical temperature-time curves for (a) steam-into-milk direct heating UHT plant, and (b) plate-type indirect heating UHT plant.



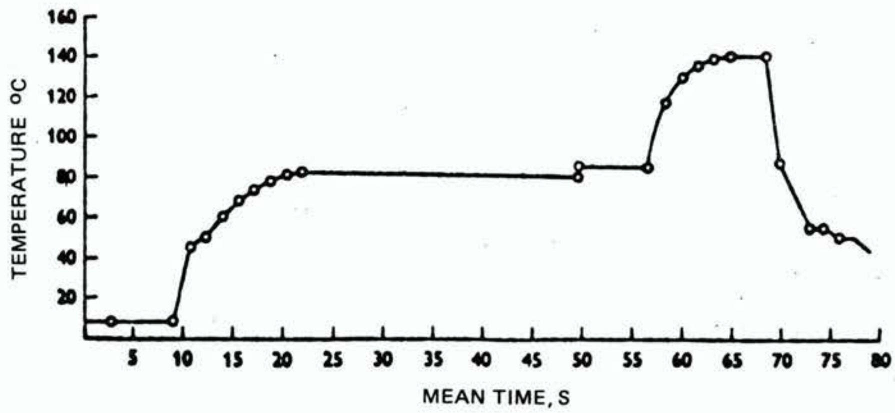


Fig. 4 – Flow diagram of plate-type UHT sterilizer.

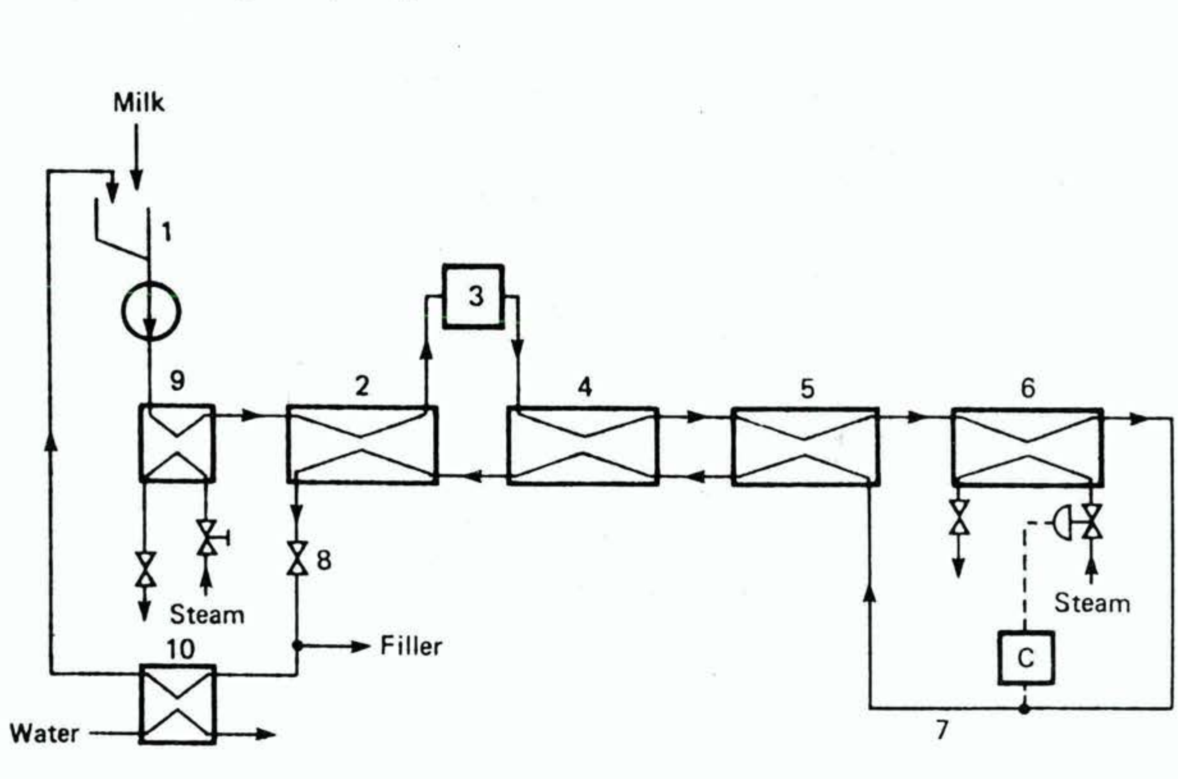


Fig. 5 – Flow diagram of plate-type UHT sterilizer with recirculated-water regeneration and final heating.

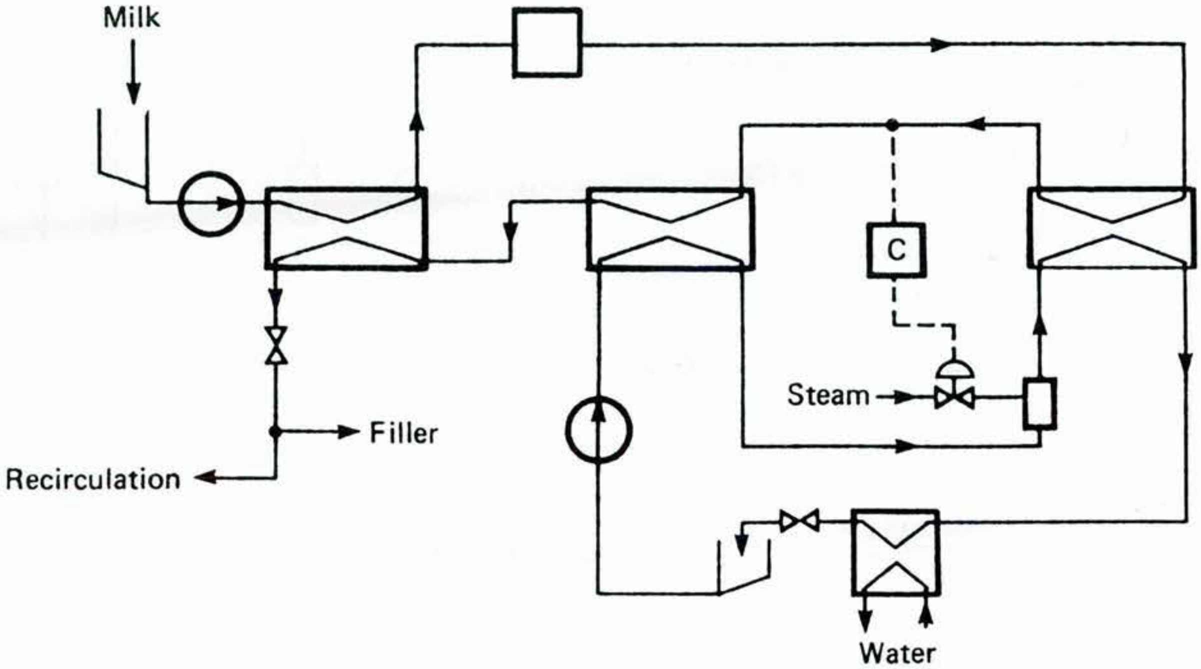


Fig. 6 – Flow diagram of tubular UHT sterilizer.

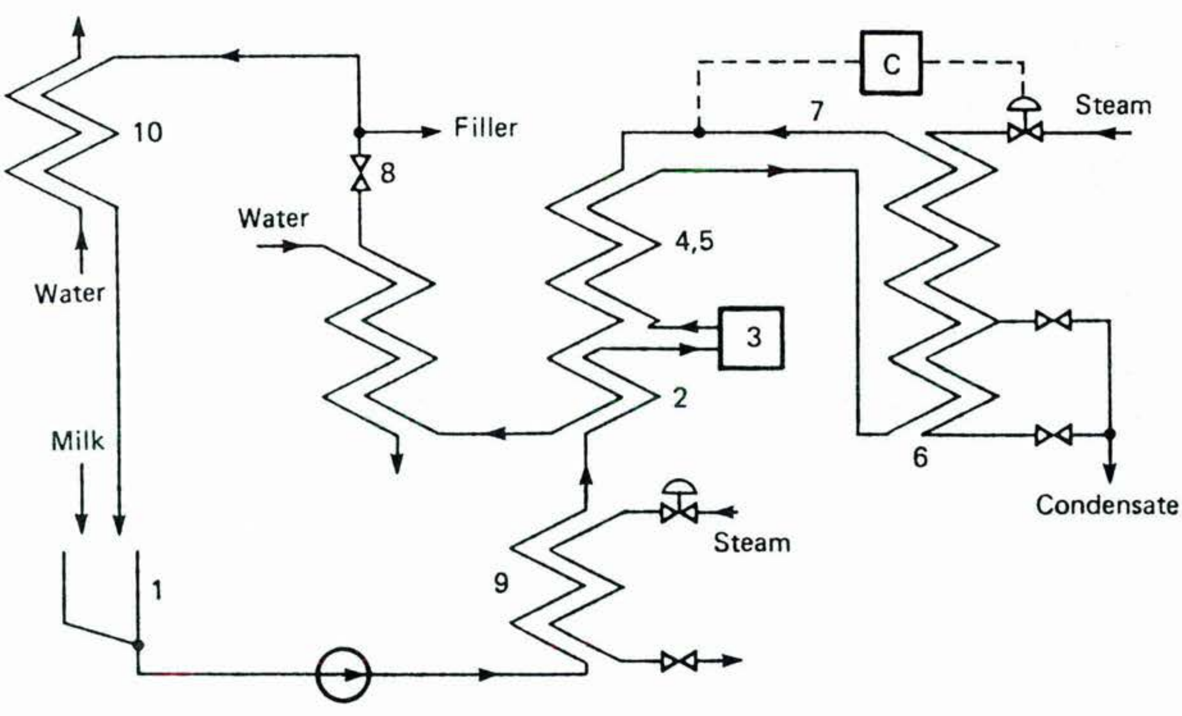


Fig. 7 – Flow diagram of steam-into-milk UHT sterilizer.

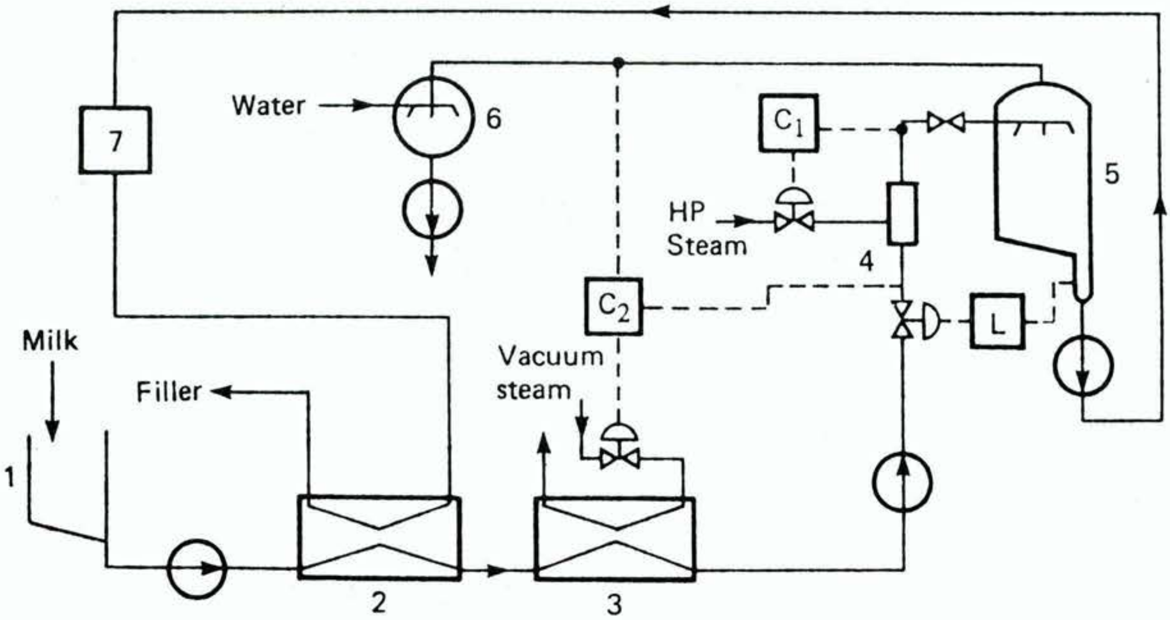
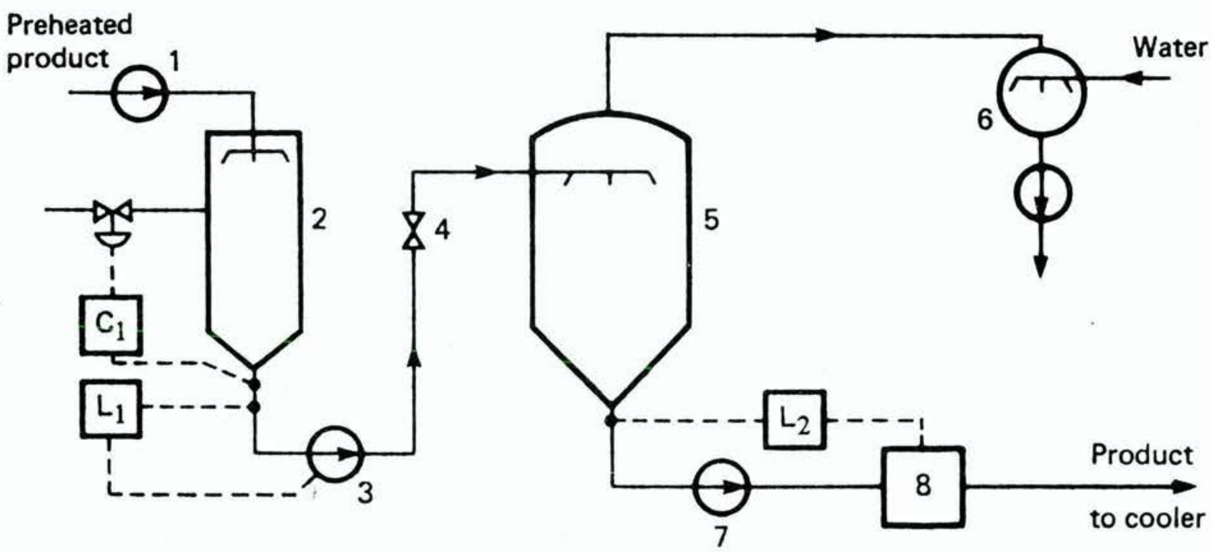


Fig. 8 – Schematic diagram of milk-into-steam heating and expansion cooling system.



CHAPTER 7

ASEPTIC PACKAGING

by Dr O. Cerf (France) – for sections I and II – and by Mr C.H. Brissenden (UK) for section III

I – PRINCIPLES

Asepsis, in the context of the milk packaging industry, means the reduction of microbial re-contamination of UHT-processed milk to a level which is sound commercially and economically. Such a definition may surprise some readers, and deserves further explanation.

A. REDUCTION OF THE MICROBIAL RE–CONTAMINATION LEVEL

We shall demonstrate in this section that statements like "the destruction of all microorganisms", "total destruction", etc. should be avoided.

1. The logarithmic order of thermal death and the risk of non-sterility

When a population of a given strain of microorganisms – vegetative cells or spores – is heated in given conditions of temperature, pH, etc..., a linear curve is generally obtained on a plot of the logarithm of the viable microorganism concentration versus the time on a linear scale (fig. 1). This is commonly known as a logarithmic order of death. To understand its implication, we shall give an example. Assume a food product containing an average of 100 heat resistant spores of a given strain per millilitre, distributed in 10 millilitre vials. After a certain time D of heating at a given temperature, there will remain an average of 10 surviving spores per ml. It is a property of the logarithmic order of death that after a further heating time D (total heating time being now 2 D) there will remain an average of 1 surviving spore per ml. Therefore D is called "decimal reduction time", and corresponds to the time necessary to destroy 90% of the population of microorganisms.

At the end of a total heating time of 3 D, the average concentration of surviving spores will be 0.1 per ml. At first sight, this fraction of a surviving spore seems meaningless. It should be understood that the numbers of survivors calculated so far must be considered as statistical averages: 0.1 per ml is equivalent to an average of 1 surviving spore per 10 ml and since the vials have a capacity of 10 ml, it is equivalent to 1 survivor per vial. In the same way, the 0.1 surviving spore per vial at the end of a total heating time of 4 D should be understood as 1 survivor per 10 vials. This reasoning is summarized in the following table.

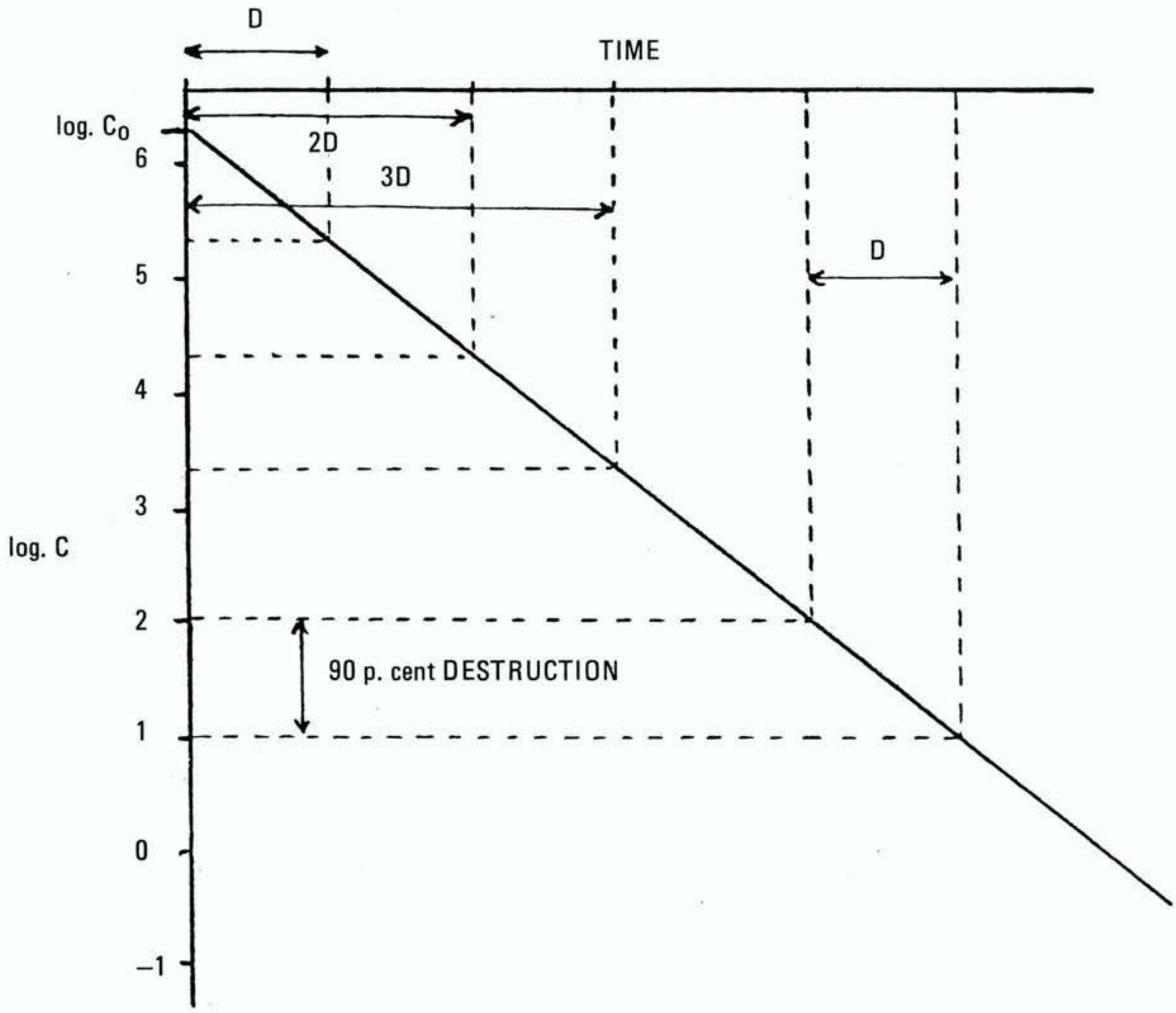


Figure 1.– Kinetics of killing of microorganisms by a lethal treatment (heat or chemical sterilization) called survival curve. On the ordinate 6 is the logarithm of 10^6 (1 million) microorganisms per unit volume 5 of 10^5 (100 000), etc.. The equation of the survival curve is

$$\log C = \log Co - \frac{t}{D} \text{ or } C = Co \times 10^{-\frac{t}{D}}$$

with Co, microorganism concentration at time zero, C, microorganisms concentration at time t, D, (reverse of the slope) "decimal reduction time", i.e. time necessary to destroy 90% of the population.

Heating time	Number of survivors		Vials containing 1 survivor	
	per ml	per vial	proportion	percentage
0	100	1 000	1	100
D	10	100	1	100
2 D	1	10	1	100
3 D	0.1	1	1	100
4 D	0.01	0.1	0.1	10
5 D	0.001	0.01	0.01	1
6 D	0.0001	0.001	0.001	0.1
etc.				

Table 1. Example of the effect of heating on the population of surviving microorganisms in 10 ml vials and on the proportion of vials containing survivors (initial population: 100 microorganisms per ml).

Vials containing 1 surviving spore or more are not sterile. Those which do not contain surviving spores are sterile. Thus the heating process produces sterile vials along with non-sterile ones. The aim of the industrial operation called sterilization is to minimize the proportion of non-sterile vials. But, a law of Nature, the logarithmic order of death, makes it impossible to destroy all microorganisms. There remains always a proportion of non-sterile items.

In other words, to each heat sterilization treatment is linked a "risk of non-sterility" R, expressed as a proportion of the vials which contain one or more surviving microorganisms, or as the probability for one container to be non-sterile. That risk can be calculated through the following equation:

$$R = Co \times V \times 10^{-\frac{t}{D}} \qquad (1)$$

where Co is the concentration of the most heat resistant microorganisms per ml of product before the process, V is the volume in millilitres of the unit container, t is the heating time and D the decimal reduction time of the most heat resistant microorganisms at the heating temperature. In the preceding example

Co = 100 spores per ml,
V = 10 ml.
If $t = 6\ D$: $R = 100 \times 10 \times 10^{-6} = 100 \times 10 \times 0.000001 = 0.001$

Many deviations from the logarithmic order of death have been noted (Cerf, 1977). But many of these may describe certain events other than microorganism death (Stumbo, 1973), and it is almost always possible to stay on the same basis of reasoning which has been developed above, by sligthly modifying the exponent in the equation of the risk (L'Haridon & Cerf, 1978).

A summary of the above paragraph 1 would be: the risk is strictly proportionnal to

- the initial contamination level,
- the volume of the unit container,

and depends on the efficiency of the lethal treatment.

2. Application to other lethal processes

Heat at > 135°C is used to sterilize the milk, and can also be used to sterilize some elements of the aseptic packaging machines. Nevertheless most packaging materials must be treated at lower temperatures, and chemical sterilization is used in several plants.

The sterilization by chemicals obeys the same rules which have been stated in the preceding paragraph. Volumes of product in the equation (1) may be replaced by surfaces of material:

$$R = Co \times S \times 10^{-\frac{t}{D}} \qquad (2)$$

where Co is the number of microorganisms per square centimetre and S is a surface in cm^2, the other symbols being the same as those of equation (1).

As for heat sterilization, deviations from the logarithmic order of death exist and can almost always be accounted for by a slight modification of the exponent.

3. Sources of re-contamination in packaging machines

Every object or substances with which the UHT milk comes into contact is a potential source of re-contamination:

- walls of tubes, tanks, valves and fittings (direct contact) or of the enclosed space where the filling operation takes place (indirect contact through a gas)
- gas used to raise the pressure in the filling space
- packaging, sealing and closure materials
- etc..

Therefore, aseptic packaging implies the sterilization of all those potential sources. The physical or chemical sterilization treatments which are employed will be reviewed later in this chapter. We must retain at the present moment that the equations (1) or (2) are applicable to these treatments: to each one is associated a risk of non-sterility.

4. Rule of the addition of risks

Whether the spoilage microorganisms come from a certain source or whether they come from another, they will not less adulterate the milk (Fig. 2). If the non-sterility occurs when one microorganism comes from the source 1 or from the source 2 ... or from the source n, the probability of sterility is the product of the probabilities of the absence of microorganisms coming from the n sources:

$$1 - R = (1 - R_1) . (1 - R_2) ..... (1 - R n)$$

R being the risk of non-sterility of the packaged milk, R_1 the risk associated to the sterilization of source 1, R_2 of source 2, ..., R n of source n; and if R_1, R_2 ....., R_n are small, which happens happily here, the preceding equation becomes:

$$R \simeq R_1 + R_2 + ... + R_n \qquad (3)$$

This is known in Boolean algebra as the Morgan theorem, and in aseptic packaging industry as the rule of the addition of risks.

The following example will show an important consequence of the rule. Suppose a machine with three risks:

$$R_1 = 10^{-3}$$
$$R_2 = 10^{-5}$$
$$R_3 = 10^{-6}$$

Then $R = 1.011 \times 10^{-3} \simeq 10^{-3}$

The consequence can be enunciated as follows: the risk of non-sterility of a machine is closely associated with the least efficient sterilization operation – the weakest link in the chain.

A second important consequence is: the more sterilization operations there are in an aseptic packaging plant, the greater the probable risk of non-sterility.

5. Mechanical failures

Mechanical failures such as leaks in valves, insufficient heating of gases, pin-holes in filters, etc..., may cause re-contamination of the milk. Here again, the milk will be non-sterile if a certain failure or if another occurs. Therefore, the rule of the addition of risks does apply also to mechanical failures, as do the 2 consequences of the rule.

A mechanical failure is worthy of a special mention: the leaks of the milk package. Very minute holes with a diameter as small as a few micrometers may let bacteria penetrate into the milk (Cerf, 1976), especially when condensation of water has appeared onto the pack (Michels & Schrank, 1979). Measures for avoiding that kind of failure must cease only at the moment where the consumer opens the pack to drink its content.

B. CHOICE OF REDUCTION LEVEL

1. Growth of microorganisms in milk

A great deal of microorganisms are capable of growth in milk, and some of them are pathogenic. Yet UHT milk is rightly considered as a safe product. The following reasons may be put forward:

– only food poisoning bacteria are concerned, namely enterococci, staphylococci, staphylococci, *Bacillus cereus, Clostridium perfringens* and *C. botulinum.*

– occurrence of the 2 first ones comes mainly from contact with infected human carriers, which is improbable due to a high mechanization.

– occurrence of *Clostridia* could be mainly with spores escaping UHT treatment: this is highly improbable, and survivors would not find appropriate anaerobic conditions.

– occurrence of *B. cereus* surviving the UHT treatment is equally improbable, but those bacteria are common in the dairy environment and are able to contaminate the milk through leaks. Fortunately, toxin production has been reported only occasionally in commercial UHT milk (Gilbert & Taylor, 1976) and anyway the growth of *B. cereus* is made visible by milk discoloration and/or cream flocculation.

Therefore the attention of aseptic packaging machine manufacturers as well as dairy men can be restricted to:

– the microorganisms which come from the sources enumerated in section A and which are the more resistant to the sterilizing processes: bacterial or fungal spores .

– the leaks which may let microorganisms enter the milk (Fig. 2).

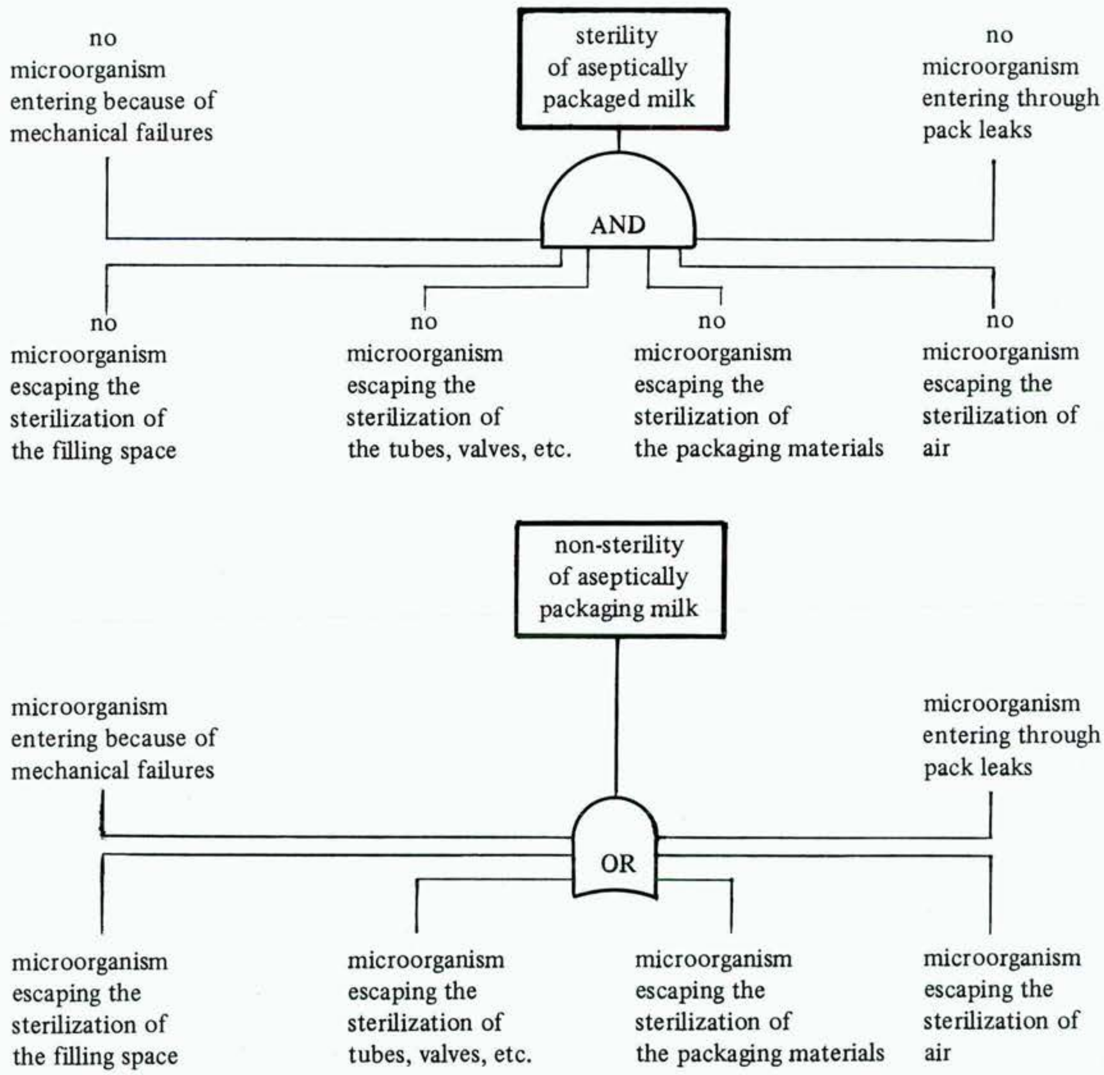


Figure 2. Fault trees of aseptic packaging machines, using the symbols of the System Approach. Only a few examples of causes of non-sterility are given.

The microorganisms which will enter the more probably are those which are found usually in the water stagnant on the floor of dairies (psychrotrophic *Pseudomonas*, micrococci, coryneform bacteria, enterococci, *Bacillus*, sometimes yeasts, etc...). In general these microorganisms do modify the milk visibly (coagulation, proteolysis, staining, flocculation) or produce a bad smell or flavour, or modify a measurable property of the milk (acidity, pH, heat or alcohol stability, redox potential, etc..). But, one of us (Cerf, 1980) has already quoted that about one fourth of bacteria contaminating UHT milk cannot attain a cell concentration higher than 10^5 per millilitre and must be detected by direct counts on nutritive media.

2. The 1 per 1,000 level

We should recall that the proportion of UHT milk containers containing at least one microorganism is the sum of what we called the risks of non sterility, arising from the logarithmic order of death of each sterilization process, and of the risks of re-contamination caused by mechanical failures, mainly by leaks. This total is known as the "fraction defective".

The reader should be convinced now of 3 facts:

– the fraction defective is never reduced to zero,

– it is possible to reduce the fraction defective by careful choice and control of efficient sterilizing processes taking into account the initial contamination levels and the volume and surface of unit containers and by a careful control of the mechanical failure sources.

– all causes of contamination must be considered with an equal care.

Consequently, one should be able to manage the plants in order to limit the fraction defective to a level which would be acceptable commercially. This level should not be higher than 1 defective per 1,000 container. Although Dr H. Burton denies its paternity, that level is generally attributed to him, and has received a wide acceptance. It corresponds to an average of one defective every about 3 years in a family consuming 1 UHT milk container per day.

C. CONTROL OF THE RISKS

It is shown in Chapter 9
that sterility checking of UHT products is of limited value in monitoring an industrial plant:

– the results are long to obtain since microorganisms must grow in the milk in sufficient amount to become detectable readily, one week being a delay which is considered in several countries as a good compromise.

– the path or pathes of re-contamination are difficult to trace, owing to the variety of microorganisms species capable of growth (see above).

Therefore, the risk sources have to be under control during the plant runs. A complete list of such controls would be irrealistic, but a short account could be useful here:

– physical controls: steam pressure, temperature and time of sterilization cycle, steam pressure in aseptic barriers, pressure drop of air through filters, intensity of UV radiations of UV lamps, electric intensity through resistances for heat sterilization of air or for drying of plastic material after its contact with a chemical sterilizing agent, leakproofness of sealings of plastic materials, temperature and moisture of packaging material storage, etc..

– chemical controls: concentration of sterilizing agents used for packaging materials or aseptic barriers, etc..

– preventive maintenance: periodic replacement of membranes and gaskets in aseptic valves and fittings, of filters, of heating elements, etc..

II – INDUSTRIALLY AVAILABLE MEANS

A. TYPES OF PACKAGING MATERIALS AND THEIR PROPERTIES

An extensive review on this subject can be found in the monograph: Technical Guide for the Packaging of Milk and Milk Products (IDF Document 92, published in 1976 – a new edition is in preparation).

1. Glass

Although prototypes of aseptic filling plants have been or are currently studied for glass bottles, no one has been developed industrially, and this material is only cited as a reminder. Problems of tightness between cap and bottle are well solved, glass offers a protection against oxygen, and against light provided it is filled with anti-actinic compounds.

2. Plastic

Principally non toxic polyethylene, polypropylene and polystyrene are used for the aseptic packaging of milk (Vanderpoorten, 1974) alone or in 2 or more ply laminate, sometimes with other substances like cardboard and/or aluminium sheets. It is generally agreed that the thickness of the plastic film must be superior to 13 μm (Ronsivalli et al., 1966) in order to be impervious to microorganisms. Practical experience shows that this thickness may be insufficient and 40 to 50 μm are more common with one layer packages. But it can be satisfactory with multi-ply materials where the superposition of holes is improbable.

Polyethylene and polypropylene are relatively permeable to oxygen and UV and visible radiations. Protection against oxygen can be afforded by coextrusion or coating with less permeable substances (polyvinylidene chloride, aluminium, etc..). Protection aginst ligth can be obtained in the same way, with aluminium, or a pigmented layer of plastic substances (Hansen et al., 1975, Hedrick & Glass, 1975, Coleman et al., 1976).

A major problem of plastics remains that of sealing, depending on the chemical state of the product, on pressure, temperature, etc.. of the jaws (Schricker, 1972; Stehle, 1974; Boujkow & Foissy, 1978), of physical constraints during the film unrolling, on humidity, temperature, etc.. in the dairy.

The overall fragility of plastic packages is also a great concern, and must be remembered all along the commercial circuit of UHT milk.

Plastic material can be sterilized when coming out of the extruder, but this is not always the case and should be checked for new formulations. In many plants, the material comes in contact with non sterile atmosphere even for very short time and has to be sterilized again before filling.

B. CHEMICAL STERILIZATION PROCESSES

A complete review on sterilization processes used for aseptic packaging can be found in Flückiger (1980).

1. Ethylene oxide $(CH_2)_2O$

This gas has a slow sporicidal action since more than 3 h are necessary in general, depending on temperature, relative humidity and type of plastic. In addition a time for desorption of several days must be provided (Chaigneau, 1977). Therefore ethylene oxide can be used as a pre-sterilization agent, for example to reduce the microbial contamination of packaging material, thus permitting a final sterilization in a shorter time or with a less efficient treatment. It can also be used as sterilization agent if the sterility conditions are not jeopardized until the filling operation.

2. Hydrogen peroxide H_2O_2

Hydrogen peroxide is a poor sporicide at ambient temperature, where the D value for *Bacillus* spores is a few minutes in 20% (m/m) H_2O_2. Its action is better at higher temperatures, the D value becoming of the order of a few seconds at 80°C. But 2 limitations arise:

– hydrogen peroxide becomes unstable, particularly in the presence of catalyst of decomposition (e.g. heavy metal ions).

– the presence of catalase (an enzyme decomposing H_2O_2) in *Bacillus* spores limits the practical sterilizing efficiency which can be attained by immersion in hot peroxide (Cerf & Metro, 1977).

Nevertheless an adequate effectiveness may be obtained if H_2O_2 is first deposited on the surface which must be sterilized and secondly evaporated at its boiling temperature slightly higher than 100°C (Swartling & Lindgren, 1962) heat being carried by warm air or irradiated by infra-red elements. This is the possibility of eliminating H_2O_2 which gives to that product its great success for aseptic packaging, to sterilize the filling space and/or the packaging material.

Use of hydrogen peroxide has also the following disadvantages:

– surface-active substances are often added to insure an even wetting. These substances are not evaporated with H_2O_2 and can be found in milk.

– the efficiency of evaporation must be checked routinely by titration of H_2O_2 in milk.

– vapor of H_2O_2 must be exhausted to avoid injuring the workers.

Sporicidal action of H_2O_2 was formerly attributed to the formation of nascent oxygen. There is no scientific reason to believe that the sporicidal activity could come from another molecule than H_2O_2 itself.

3. Other sterilizing agents

Very potent liquid sterilizers are the sodium hypochlorite and the peracetic acid. They act efficiently at ambient temperature or lower, but cannot be evaporated by heating: hypochlorite leaves residues of chloride, peracetic acid of acetic acid. Therefore they can be used only provided there is a sterilized water rinse.

Alcohols are good disinfectants but they preserve the bacterial spores, except at high temperatures where they act as sterilization adjuvants. Thus, glycols can be used at temperatures higher than 100°C at atmospheric pressure. Other sterilizers (formaldehyde, glutaraldehyde, betapropiolactone, etc..) are not well adapted to the temperature or duration needed by the industrial rythm of aseptic packaging.

C. PHYSICAL STERILIZATION PROCESSES

The review of Flückiger (1980) comprises some of the processes reported below.

1. Moist heat

Moist heat (saturated steam or hot water) is one of the most simple and reliable sterilizing processes. In aseptic filling machines, its use is restricted to the milk tubes, and to the aseptic barriers (see par. D).

2. Dry heat

Dry heat is currently used to sterilize the air injected in the closed space where the filling takes place, alone or in combination with filtration. It is generally agreed that air flowing in front of electric resistances should be heated at 300°C (basis of computation: sterilization cycle of 30 min at 170°C, $z = 33°C$ or $Q_{10} = 2$). Dry air is also used to sterilize milk tubes at 330-350°C during 30 min.

After cooling by water through tubular exchangers, sterilized air at 180-200°C can evaporate H_2O_2, and at 50°C or less pressurize the filling space.

3. Ultra-violet radiations

Effective sterilization by UV can be obtained only if strict conditions are obeyed:

- perpendicular incidence of rays on surface
- dry atmosphere
- smooth surface devoid of dust and dirt
- low density of microorganisms to avoid shadowing effect
- no visible light to avoid reactivation of microorganisms
- lamp irradiating effectively in the 200-280 nm range
- shields to protect the skin and eyes of operators.

Such requirements are difficult to apply, and they involve the plastic manufacturer as well as the dairy. Therefore, in the opinion of the authors, UV radiations should be employed only with materials which have been sterilized already, as a complement.

4. Ionizing radiations

High energy beams can be used only by especially trained people. Hence, they are useful as a preliminary sterilizing treatment for the packaging material, before delivery at the dairy.

5. Filtration

Membrane filters which have pore diameters inferior to the size of bacteria are not used to sterilize air, being too fragile and creating a too large pressure drop.

Depth filters, whose arrest efficiency is linked exponentially to their thickness are preferred. One may distinguish between mats of compressed glass or asbestos fibers, and sintered materials such as metal or ceramics. Depending on their composition, depth filters can be sterilized by fumigation or by dry air or steam heating. Their efficiency relies on their dryness and flow rate, and the flow must remain between high and low limits.

D. ASEPTIC BARRIERS

1. Principle

Each place where a contact between ambient unsterile atmosphere and sterilized milk could happen should be protected by means of an aseptic barrier, that is a space where a sterilizing agent (saturated steam or liquid sterilizer) is circulated.

2. Aseptic valves and fittings

Aseptic valves are of 2 types:

- those with a membrane, with the closure resulting from the pressing of the membrane against a protrusion of the opposite side,
- those where the valve is driven by a stem going outside in the atmosphere through a gasket.

Whenever the membrane of the first type is susceptible to become pierced, an aseptic barrier should be used. With the second type, an aseptic barrier is always necessary.

With fittings, aseptic barriers are preferable. They are necessary where the milk is at a pressure lower than atmospheric pressure.

E. CONTROL OF LEAKERS

In the great majority of cases the leaks happen at the seals and are too small to let the milk flow through them even when the pack is firmly compressed. Therefore packs must be sampled at regular time intervals, emptied, the inside of sealings made visible by cutting the parallelograms in the middle or the bottles at the neck, the traces of milk and rinse water dried. Then a dye having a strong wetting ability must be applied along the seals. Capillarity forces will drive the dye through the leaks, and an examination of the pack from outside will permit a diagnosis. Other methods have been suggested (electric conductivity measurement, etc..), but no one has the simplicity of the dye.

III – ASEPTIC PACKAGING SYSTEMS

The UHT treatment of milk was originally developed to improve the quality of the in-bottle sterilized product by destroying heat-resistant bacteria and their spores which could survive the time-temperature combinations in the in-bottle sterilizer and cause rapid spoilage – sweet curdling and 'bitty cream' – of the product. This process had already become well-established in Western Europe by the mid-1950's and it led to the reduction of holding times in continuous sterilizers and hence an increase in output for a machine of given size.

The next logical step in this development was to establish whether UHT-treated milk could be successfully filled and sealed into glass bottles without the need for the in-bottle sterilizing process. The argument which prompted this thinking was that, if the milk was sterile, the in-bottle sterilizing process was required only to destroy the organisms which gained access with the bottles and closures.

Trials were carried out in the UK in the 1950's in which UHT-treated milk was filled into conventional, sterilized milk bottles with crown closures. No attempt was made to provide a sterile environment for the filling and sealing operation but extra care had been taken in washing the bottles. Quite a high proportion of the filled bottles was found to have a long shelf life at ambient temperatures but in others the spoilage was very rapid and it was concluded that a truly aseptic bottling system, using pre-sterilized bottles and closures, was needed if the failure rate was to be reduced to an acceptable level. This led to a programme of research and development at the National Institute for Research in Dairying, Shinfield, which led to the successful demonstration of a prototype aseptic bottling and capping (omnia seal) machine by the Graham Enock Manufacturing Co in 1967. At the same time, the U.D. Manufacturing Company had been working independently on the development of an aseptic filling process for glass bottles with crown closures.

Meanwhile, in Japan, numerous UHT plants equipped with final cooling sections, reducing the temperature of the milk to 4°C had been installed to work in conjunction with locally-manufactured bottling systems incorporating washers with a heavily chlorinated final rinse and high-speed fillers dispensing the milk into 180 ml wide-necked glass bottles, closed with a cardboard disc and over-wrapped with a heat-sealed polyethylene film. The milk was mainly distributed through refrigerated outlets but it was claimed that milk in the unopened bottles would remain sweet for several days at ambient temperature. Subsequently, the manufacturing rights for the UDEC aseptic bottling system were sold to the Japanese company but, so far as is known, they have never been exploited.

A. Wander of Switzerland developed the SATCO aseptic bottling system in which sterile conditions were maintained by infra-red heat and filtered air, the bottles being closed with rigid aluminium 'Omnia' seals similar to those used on the Graham Enock machine, but the system did not progress beyond the prototype stage (2000 lph).

In general, although a great deal of effort has gone into research and development work, the aseptic filling of glass bottles has not proved commercially successful. It should not be forgotten however that the technology has been developed and that it could merit re-appraisal in the changed economic climate of the 1980's, and it is interesting to note that a system for the sterilization, aseptic filling and sealing of glass bottles has recently been described (28th May, 1980) by the French company, SERAC S.A.

In parallel with, but independently of, these developments, work was in progress in the USA on the aseptic canning of several different food products including milk. The originator of the aseptic can filler employing superheated steam sterilization was McKinley Martin and his results were first published in 1951. The system was further developed by the James Dole Engineering Company of San Francisco and in 1953, at the Konolfingen experimental station of the Bernese Alps Company in Switzerland, a Dole filler was linked to an Uperiser (direct steam injection UHT system) to produce a wide range of aseptically-packed milk products. Aseptic canning is now an established method of packaging for sterile evaporated milk and ice-cream mixes in cans ranging from 6 oz to 1 gallon, and it has been used on a limited scale for unconcentrated liquid milk.

MAKE OF ASEPTIC PACKAGING MACHINE	STERILISING SYSTEM			SEALING SYSTEM	BULK AND/OR OVERWRAP SYSTEM
	RAW MATERIALS	Packaging Material or Empty Package	Operating Atmosphere		
TETRA–PAK	Polythene-paper aluminium foil laminate	H_2O_2 bath followed by radiant heat	Hot H_2O_2 vapour and steam above carton forming & filling zone	Heat sealing below liquid level while carton is being formed	Hexagonal crates or cartons
TETRA–BRIK	”	”	”	” and folding & heat-sealing of flaps	Tetra-tray & Tetra-shrink overwrap
PURE–PAK (ex CELL-O NLL)	”	Pre-sterilized blanks sprayed with H_2O_2 after forming followed by hot air drying	Hot sterile air plus H_2O_2 vapour	Heat sealing after filling	
COMBIBLOC (PKL, PERGA)	Cardboard plastic & aluminium foil laminate	Blanks sprayed with H_2O_2 after forming followed by hot air drying	Gas-heated sterile air at 200°C	”	
THIMONNIER	"Saranex" polyethylene PVDC laminate	H_2O_2* bath followed by UV irradiation * previously alcohol	Bacto-filtered air	Heat sealing above liquid level to form pouch	Cartons holding 6-20 litres or stackable plastic boxes up to 20 L
PREPAC	Polyethylene polypropylene & Saran laminate	H_2O_2 bath followed by drying with bacto-filtered air	”	Heat sealing above liquid level to form pouch	Outer plastic bags holding 3/5 pouches packed into cardboard boxes holding 4 bags for pallet.
ROMMELAG (bottle-pack)	Polyethylene granules	Hot parison blown with sterile compressed air	Hot sterile air (milk filling line concentric with blowing nozzle)	Heat seal during formation of bottle neck & opening device after volumetric filling	Crates or cardboard cartons
REMY (TOTAL PAC)	Polyethylene granules and polyethylene coated aluminium strip	Empty bottle blow-moulded from hot parison with sterile compressed air & sealed	Sealed empty bottle opened, filled & sealed in isolated chamber pre-sterilized with high boiling point poly-alcohol solution. All access to chamber via hypo-chlorite solution seals	Polyethylene coated circular aluminium cap heat-sealed on to filled bottle	Crates or cardboard cartons
SIDEL (SIDERAC)	High density polyethylene granules & polyethylene coated aluminium strip	”	Sealed empty bottle opened, filled & capped in atmosphere of bacto-filtered air	Polyethylene coated square aluminium cap heat-sealed on to square opening on filled bottle	Cardboard carton packs holding 4 x 1 litre bottles or larger boxes
HOEFLIGER & KARG (BOSCH; SERVAC)	All thermoplastic mono- or multi-layer films or aluminium laminates	Base & lidding webs sprayed with H_2O_2/air mixture & dried with sterile air	Forming, filling & sealing operations under bacto-filtered air	Plastic-coated aluminium web heat-sealed on to vacuum-formed plastic cup	As required
PLASTIMECANIQUE (FORMSEAL)	Various plastic materials in roll form; web thickness up to 1.5 mm for cups. Lids usually of thermoplastic lacquered aluminium foil	Packaging material base and lid webs immersed in H_2O_2 and dried.	Operating atmosphere - all operations from forming to sealing carried out in sterile air tunnel at slightly above atmospheric pressure	Lacquered aluminium web heat-sealed on to vacuum-formed plastic cup (heat-sealed plastic lids and re-useable plastic lids covered by sealed aluminium foil also available)	
HAMBA	Plastic cups (ready-formed) aluminium & plastic laminate for reel caps	Cups & lids irradiated with UV	Cup irradiation & filling in sterile atmosphere	Plastic-coated aluminium web caps heat-sealed on to cups	”

NB: The above list describes the more commonly used systems and is not intended to be complete. Their listing is not intended to endorse any particular make. Numerous other aseptic filling systems for milk have been described and, in several instances, experimental installations have been demonstrated. Others have been abandoned after a relatively short periode of availability.

CONTAINER CAPACITY RANGE	SPEED RANGE	BASIC PRINCIPLE	SHAPE OF PACK	COUNTRY OF ORIGIN
15 ml to 1000 ml not inter-changeable		Form fill & seal from strip	Tetrahedron	Sweden
178 ml to 1000 ml not inter-changeable	3650 - 7500 cph for 500 ml & bigger: 4550 - 9300 cph for 250 ml & smaller	”	Rectangular brick 'Flat' top	Sweden
½ US pint to 1 US quart		Form carton from blank then fill & seal	Rectangular brick with gable top or 'flat' top	USA
0.2, 0.25, 0.5 & 1.0 litre	5000 to 10000 packs per hour	Form carton from centre-sealed blanks then fill & top seal	Rectangular with 'flat' top	Federal Germany
0.25, 0.5 & 1.0 litre; ¼, ½ & 1.0 US quart; ½, 1.0 & 2.0 imp pint	2000 to 3500 packs per hour	Form, fill & seal from strip	Cushion or pillow	France
0.25, 0.5 & 1.0 litre	Up to 4000 packs per hour	Form, fill & seal from strip	”	France
0.2, 0.25, 0.3 & 1.0 litre Recommended for milk but wider range is available	1200 to 6000 bottles per hour	Blow mould fill & seal. Milk filling line concentric with air blowing line	Bottle to customers' requirements	Switzerland
1.0 litre	5000 bottles per hour - possibly up to 6000	Blow mould empty, seal, cut off top & volumetrically fill in sterile atmos-phere, heat seal aluminium & plastic capsule	Rectangular bottle	France
0.25, 0.5, 1.0 1.5 & 2.0 litres	1000 to 1400 bottles per hour	Blow mould empty cut off top & gravimetrically fill in sterile atmosphere, heat-seal with alumi-nium plastic strip	Rectangular bottle	France
Governed by maximum forming depth of 100 mm	Dependent on container size and number per row	Cups vacuum formed from thermoplastic web. Filled, closed by heat-sealed plastic/aluminium web	Square or round cups to customers' requirements	Federal Germany
Up to 1 litre Governed by maximum forming depth of 100mm/125mm depending on material	Dependent on container size and number per row, eg, 15000 per hour for 500 ml or 21600 per hour for 125ml	Cups vacuum formed from plastic-coated web. Filled, closed by heat-sealed plastic-lacquered alu-minium web	To customers' requirements	France Fed. Germany
eg, 100 to 500ml	2000 to 36000 cups per hour depending on size	Ready-formed plastic cups filled & closed with diaphragm caps pressed from reel	”	Federal Germany

Konolfingen was also the site for the development of Tetra-Pak aseptic carton forming, filling and sealing machine which first became commercially available in 1961 and which, together with its sucessor, the aseptic Tetra-Brik, is now the most widely used packaging method for UHT milk. The Tetra-Pak was novel in many respects but its success as an aseptic packaging system was due mainly to the way in which the packages were continuously formed below the milk level from a strip of laminated paper, plastic and sluminium foil, which was continuously sterilized by hydrogen peroxide boiled off by radiant heat in the region immediately above the milk surface, thus giving a sterile atmosphere at the vital interface between the milk inlet and the packaging zone.

For many years, in spite of several attempts by other packaging machinery firms to launch aseptic versions of their equipment, the Tetra-Pak and Tetra-Brik were virtually the only packages in use for the distribution of UHT milk on a commercial scale. However, by the late 1970's a number of alternative systems for consumer packs had gained a foothold in the market; some of them are briefly described in the attached Schedule I which also gives similar details for the aseptic Tetra-Pak and Tetra-Brik systems.

During the early stages of its development, there was an almost universal tendency for aseptic packaging to be capable of protecting the contents from chemical change, as well as against microbial contamination, for prolonged periods of storage. Hence most aseptic packaging materials were designed to be opaque to light and practically impervious to oxygen and it was for these reasons that laminates incorporating aluminium foil were developed. Market experience has shown however that, in many countries, UHT milk is consumed quite soon after purchase and that there is little risk of serious chemical deterioration during its normal shelf life even if it is packed in a container which is not completely impervious to oxygen. Recently, therefore, manufacturers of aseptic packaging systems have offered alternative, cheaper materials for use in those markets where a comparatively short shelf life for UHT milk is acceptable.

In addition to those for small consumer packages, a number of systems have been developed for filling UHT milk aseptically into larger containers including drums (NO–BAC 55, USA), pails (DOLE, USA), and plastic film bags in fibreboard outer boxes (GAULIN, SCHOLLE, USA). It was also demonstrated by the Bernese Alps Company during their development of the Uperization UHT system that UHT milk could be successfully filled aseptically into a sterile stainless steel tank and transported over long distances for periods of several days at ambient temperature. A similar tank, developed by the Milk Marketing Board for England and Wales, has been in successful use since 1973.

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CHAPTER 8

UHT PROCESSING AND PACKAGING PLANT: BASIC REQUIREMENTS, SERVICES AND MAINTENANCE

by Mr C.H. Brissenden (United Kingdom)

1. The basic requirements which have to be established for a new UHT plant are in most respects the same as for other dairy process plant but there are some important differences which require careful attention particularly for installations which are remote from sources of supply.

   The principal points to be watched are:

   a) Availability of milk of desired quality and/or suitable ingredients (including water) and facilities for recombining.
   b) Frequency and continuity of supply of suitable packaging materials, including sterilants.
   c) Milk intake and storage facilities.
   d) The type and rated capacity of the UHT plant(s).
   e) The type, numbers and capacities of the packaging machinery.
   f) Alternative functions of the installation – e.g. processing other dairy products or fruit juices.
   g) Provision of space for the required test storage period for packed milk prior to dispatch.

2. **Considering these factors in more detail:**

i. Milk Supplies

The desirable qualities of raw milk for UHT processing have been dealt with in earlier Chapters but it must be recognized that, in practice, the ideal is not always attainable, especially where raw milk is refrigerated on the farms and bulked for transport to the processing dairy. It is also becoming increasingly common for the UHT processor to be supplied with milk which has already received some form of heat treatment elsewhere. It is, therefore, important to know the history of the milk supplied since this will to a considerable degree affect the quality of the UHT product – milk which has already been pasteurized is likely to give a more pronounced cooked flavour after UHT treatment than would be obtained from processing raw milk.

The quality of the milk fed to a UHT plant also influences the length of run and frequency of plant cleaning; longer runs can generally be achieved when the plant is fed with milk which has already been heat treated and some equipment manufacturers even recommend that milk intended for UHT processing should be pre-pasteurised.

In areas where seasonal fluctuations in milk production are sufficiently marked to affect supplies for the liquid market, facilities for preparing recombined milk, usually from skimmed milk powder and butteroil, should be provided. The availability of suitable ingredients should also be confirmed, bearing in mind that the choice of material is governed by the purpose for which it is to be used; milk powder manufacturers have accumulated a wealth of experience in the application of their products and, for example, the type of powder recommended for making a fully recombined milk would not necessarily be the same as that considered most suitable for recombination and blending with natural milk. The chemical and microbiological quality of water used for recombination is also very important and special treatment facilities may have to be installed.

Storage facilities for the recombined milk ingredients must also be provided, their size being determined largely by frequency of deliveries and the duration of seasonal fresh milk shortages.

ii. Packaging Materials

The most commonly used packaging systems for UHT milk demand special materials, usually composite laminates of paper, plastic and metal foil, which are produced on a very large scale in a small number of factories in industrialised countries and shipped to users all over the world. Any milk distribution system which is dependent on the availability of packaging materials from a distant source, probably in another country, must be vulnerable and it is therefore essential for the UHT milk processor to carry sufficient stocks of such materials to protect him from interruptions in their supply which may be outside his control.

Aseptic packaging systems often depend on the use of a chemical sterilant, e.g. hydrogen peroxide or alcohol, and it is essential to make sure that the law of the country permits their use and that steady supplies of the right quality are available.

iii. Milk Intake and Storage Facilities

The requirements are much the same as for any other milk processing plant but it must be recognised that any interruption in the supply of milk to a UHT plant linked with an aseptic packaging system can seriously upset the day's production – in this respect the UHT system is less flexible than pasteurization.

Consideration may also have to be given to providing pre-pasteurization as well as pre-cooling facilities if the recommendations of some UHT equipment suppliers are followed.

If provision is made for recombination, additional storage and pumping facilities will be required especially if recombined milk has to be blended with fresh milk.

iv. Type and capacity of UHT plant(s) and type, numbers and capacities of the packaging machinery

These 2 subjects are best considered together because the UHT process and the aseptic packaging system must of necessity be closely integrated. In the following comments, reference is made to the Tetra-Pak system but they would be equally valid for any other aseptic packaging system at present available.

The arrangement and flow system of any UHT plant are quite different from those of any other type of plant used for the production of packaged consumer milk. Unlike HTST pasteurization, or in-bottle sterilization, the processing and filling operations must be closely integrated to give a continuous uninterrupted flow sequence under completely sealed pressurized conditions.

For plants of relatively small capacities – e.g. 1,800 l/h – this means that the output of the processing plant must match that of the packaging unit(s), unless provision is made for a balance tank in the line between the heat treatment and the filling unit(s).

Installations in which the heat treatment plant is directly coupled with the filling unit(s) are often referred to as "directly linked". Those in which there is an aseptic balance tank between processing plant and filling unit(s) are often described as "indirectly linked".

A typical plant arrangement of the directly linked type is shown in figure 1. The main disadvantage in such installations is their lack of flexibility; output is fixed, and should there be any interruption in flow, the filling machine(s) and the processing plant must both be shut down and then cleaned and sterilized before production can be resumed. Greater flexibility is possible if the filling machine(s) are duplicated to provide a stand-by in case of emergency.

In installations with more than 2 filling machines in continuous operation it is advisable to include an aseptic balance tank. Such arrangements, if carefully planned, allow adequate flexibility for processing to continue in the event of a stoppage of one or more of the filling machines. Figures 2 and 3 show typical arrangements of multi-filling unit installations linked to a single processing unit.

Table 1 shows the minimum capacity required for a UHT plant linked to 2 Tetra Pak machines, and the surplus milk processed during 1 hour's run when only 1 filling machine is in operation. (In practice, a slight excess would be allowed on the throughput rate of the plant over the maximum demand of the 2 fillers working simultaneously). The 2 examples given are for installations where the 2 Tetra Pak machines are of the same and of different sizes.

The speed of output of any UHT plant is governed by that of the homogenizer, which is an integral unit of the system. Four types of plant are available:

a) Variable speed types, between certain minimum and maximum limits.
b) 3-speed types – i.e. set minimum and maximum limits, with a choice of one intermediate speed.
c) 2-speed types – usually maximum and half-speed.
d) Fixed speed types.

If flavour considerations are of little importance, the choice of plant is largely governed by capital and running costs and the question of whether it shall be of the direct or indirect heating type.

At the planning stage considerable care is necessary, especially if the plant is to be of the indirect heating type with an integral fixed speed homogenizer. On such plants the frequency of wash-through necessitated by deposit build-up, and hence pressure considerations, is of major importance.

Examples of the implications of this system are shown in Tables 2 and 3. Table 2 shows the capacity of UHT plant and aseptic tank required to keep one 1/2-litre Tetra Pak machine in constant operation if an intermediate 45 min clean is carried out after runs of 2, 4, 6 and 8 h respectively.

Table (2) illustrates the necessity to ascertain at what stage in the run an intermediate clean (under the most adverse conditions likely to be encountered) will be necessary, before a decision is reached on the plant capacity factor and the size of the aseptic storage tank which will be required.

Should it be decided that the size of the aseptic tank be limited to, say, a nominal 2000 litres, the corresponding plant capacity rates might be as shown in Table (3).

v. **Alternative Functions**

This monograph is concerned with UHT milk but it is becoming increasingly common for UHT processing and aseptic packaging installations to be designed for processing other products as well. If such alternative duties are likely to be required it is advisable to make the necessary provisions in the plant design at the outset. A UHT plant designed to work at a given hourly capacity on milk will have to work at a lower capacity on more viscous products such as creams or custards and the appropriate turn-down facility must be provided, especially in homogenizer rate.

Fruit juices are usually processed at lower temperatures than dairy products and they may be more corrosive, leading to the need for more resistant grades of stainless steel in some parts of the process plant.

vi. **Packed product storage space.**

It is generally recommended that the complete output of aseptically packed UHT milk should be held at ambient temperature for at least 48 h before it is released for distribution. The space necessary for this precautionary storage must therefore be allowed for when a UHT plant installation is being planned.

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3. Having established the basic requirements for the plant it is necessary to prepare a carefully co-ordinated plan covering steam, water, electricity, compressed air, refrigeration and in-place cleaning services as well as facilities for handling damaged and discarded or returned packs and for effluent disposal.

i. **Steam**

The choice of fuel supplies is usually governed by availability and cost, and will largely determine the type of steam-raising plant selected. As the temperature of UHT treatment is higher than that of pasteurization, the steam is usually generated at higher pressures; moreover, it is required in greater volume especially if the milk is to be pre-pasteurized on the same premises. When assessing the overall requirements it is important to include space heating and hot water services for cleaning and general purposes, and to make due allowances for the higher demands when the processing plant is started up and sterilized.

It is usual to instal 2 or more boilers of identical duties, each capable of producing and sustaining a 20% excess over the maximum likely demand.

For UHT plants of the direct injection type, the purity of the steam which is used may be controlled by legislation and a reboiler may be required to prevent any possibility of carry-over of contaminants from the primary generator to the milk itself; in other circumstances, where steam injection from the primary source is permitted, there may be restrictions on the substances used as boiler feed water additives.

ii. **Water**

Water will be needed for various purposes in addition to the requirements of the processing plant itself, and it is most important that the quality of the water is suitable for the purpose for which it is to be used. It may well be that certain chemical and/or bacteriological legal standards apply and that some conditioning and/or sterilizing treatment is necessary or strongly advisable to minimize the possibilities of damage to plant (e.g. by corrosion) or to avoid risk to health through product contamination. Particular attention must be given to the chemical and microbiological quality of water used for milk recombination. Softened water or condensate is recommended for the preparation of detergent solutions. Peak flow rates must be estimated at the planning stage.

iii. **Electricity**

Electricity will be required to run various items of the processing and filling plant, for other general equipment, and for sundry purposes – e.g. lighting and heating. As for steam and water requirements, estimates should be prepared of the peak load, and a diversity factor allowed when negotiating for a supply or deciding the size and type of generating plant required.

Where generating plant is necessary it is preferable to instal two or more units, in order to ensure continuity of supply when breakdowns occur and to allow shutdowns for maintenance. For instrument panels, etc. it is important that the supply be transformed to low voltage, for reasons of safety.

iv. **Compressed air**

In most UHT installations there will be a need for a compressed air supply for the actuation of automatic valves and the various control instruments on the processing plant, the filling units and mechanical handling systems which may be used. Air for control instruments must be free from dust and oil.

The advisability of installing centralized air compressors will depend largely on pressure considerations at the various points of usage. On such matters, it is advisable to consult the manufacturers of the various items of plant, to standardize where possible on the types of compressors used, and to ensure that standby units are available in case of breakdown or when units are serviced. For control instruments however an independent air supply from an oil-less compressor is strongly recommended.

v. Effluent disposal

The disposal of dairy waste water often presents serious difficulties. In the more industrialized countries legislation is being focussed increasingly on the disposal of wastes; in developing countries this problem is likely to command more attention in the future. The cost of treatment of dairy waste continues to increase and it is advisable to seek expert advice at a very early stage to ensure that an economic solution is found.

UHT milk is at present universally packed in one-way containers and all plants should have facilities for dealing with returned damaged or rejected packs of milk, including means for utilizing the milk itself and an efficient comminution or incineration system for the emptied containers. Proper arrangements of this kind make a very important contribution to solving the effluent disposal problem which, to a great extent, is caused by the unnecessary spillage and waste of milk.

vi. Refrigeration

The temperature to which UHT milk is cooled will normally lie within the range 15-20°C, when it is packed. Lower temperatures are unnecessary because microbial spoilage should not occur provided UHT treatment has been effective and asepsis maintained during packaging.

Only where the water supply is inadequate or is at a relatively high temperature will there be a need to use refrigeration for cooling the processed milk; even in such cases the refrigeration load will be low compared with that required for pasteurization. In temperate climates, therefore, the refrigeration requirements for a UHT plant will be limited. In warm climates the situation may be different and there may be some additional needs – e.g. for pre-cooling incoming supplies, possibly for cool or cold room storage of the finished product, and for air-conditioning. It should also be mentioned that there is a body of opinion, notably in the USA which maintains that even aseptically packed UHT milk should be chilled and distributed through refrigerated outlets in order to retard undesirable physico-chemical changes.

vii. In-place Cleaning

The denatured milk deposits which occur in UHT plants are not easily removed by detergent solutions of the strength and composition normally used for cleaning cold milk storage tanks and pipelines. UHT plants should not therefore be coupled to a central CIP system. They should be provided with a separate cleaning unit served with detergents of the appropriate composition and strength and preferably fully automated to ensure that the correct circulation temperatures and times are maintained. The same unit can serve the aseptic balance tank and pipelines from the UHT plant to the packaging machines.

Plant sterilizing procedures should also be independent of other process areas and automatically controlled.

In general, the services requirements of any UHT plant need to be carefully planned and it is recommended that load schedules should be assessed in overall terms and plotted graphically along the lines indicated in the FAO publication "Milk Plant Layout" (1).

4. Maintenance

A UHT process plant linked to an aseptic packaging line is a complex system incorporating several interdependent items of equipment operating under advanced automatic control. The maintenance of such a system must be the responsibility of skilled engineers and their work should consist of both general maintenance and a programme of preventive maintenance.

General maintenance involves carrying out any running repairs which may be necessary and includes the replacement of parts which may have developed faults or become damaged beyond repair. Such work is usually required as the result of unforeseen faults, mishaps or accidents, which are often unavoidable and must be considered inevitable even in well-run, efficiently managed plants. It could well be called "curative maintenance".

Preventive maintenance is intended to forestall the development of faults which are of an avoidable nature by instituting a system for the regular servicing and meticulous inspection of all parts of the plant, which is in complete contrast to the curative nature of general maintenance work.

In practice preventive maintenance is carried out as a set of routines in accordance with a prepared programme different routines being carried out at different intervals. These routines are established and the programme is prepared when the plant is being commissioned. The work consists of regular servicing, including lubrication, checking accuracy of instruments, checking actuation of valves, relays, etc. and generally ensuring that everything is in proper working order.

Details of the work from which the programme is prepared are drawn from maintenance manuals supplied by the equipment manufacturers, from advice given by the contractors responsible for installation and commissioning and from the past experience of the maintenance engineers.

A typical preventive maintenance scheme for a UHT process plant is shown in Table 4 from which it will be seen that some operations have to be carried out after every 10 running hours while other matters need attention once every 500 or 1000 running hours.

Tables 5 and 6 are extracts from a packaging machine maintenance manual, Table 5 listing some of the routines which should be carried out at intervals between 190 and 225 running hours and Table 6 those which should be attended to at intervals of 1000/1200 running hours. The forms have columns indicating:

1) The page of the manual on which detailed instructions are given, where necessary, for the particular operation.
2) Whether the activity should be carried out during production.
3) Whether a replacement part should be fitted.
4) Whether action has been taken and, if so, what kind of action.

The plant operators would normally keep a daily log which would include notes providing useful early warning systems for the general maintenance engineers and those responsible for execution of the preventive maintenance programme.

With such a planned maintenance scheme, urgent repairs and renovations should be required only very infrequently, provided that the programme has been conscientiously carried out. In time, as practical experience is accumulated, it becomes possible to forecast fairly accurately the life of expendable items such as gaskets, seals and diaphragm rubbers and to assess the likelihood of failure or deterioration rate of the more durable components. With the benefit of such experience, it should be possible to revise the original preventive maintenance programmes so that they are better suited to actual operating conditions and as economical as possible in time and materials.

TABLE 1

Tetra Pak machines running (carton capacity) 1	2	**Corresponding filling rates (litres/hour)** 1	2	**Total filling rate (litres/hour)**	**Processing plant rate (litres/hour)**	**Surplus milk processed (litres/hour)**
½ - litre	½ - litre	1,800	1,800	3,600	3,600	–
½ - litre	–	1,800	–	1,800	3,600	1,800
½ - litre	¼ - litre	1,800	1,125	2,925	2,925	–
½ - litre	–	1,800	–	1,800	2,925	1,125
–	¼ - litre	–	1,125	1,125	2,925	1,800

(Rated output of fillers: ½ - litre – 3,600 cartons per hour
¼ - litre – 4,500 cartons per hour)

TABLE 2

Length of run before start of intermediate 45 min. clean	**Plant Processing Rate L.P.H.**	**A Milk Processed during run L**	**B Milk Packaged during run L**	**(A–B) Surplus in Aseptic Tank at start of Clean L**	**C Milk required for packaging during 45 min Clean L**	**(A–B) – C Surplus in Aseptic tank at re-start after clean L**
2 hours	2,475	4,950	3,600	1,350	1,350	–
4 hours	2,475	9,900	7,200	2,700	1,350	1,350
6 hours	2,475	14,850	10,800	4,050	1,350	2,700
8 hours	2,475	19,800	14,400	5,400	1,350	4,050

TABLE 3

Length of run before start of intermediate 45 min. clean	Plant Processing Rate L.P.H.	A Milk Processed during run L	B Milk Packaged during run L	(A–B) Surplus in Aseptic Tank at start of Clean L	C Milk required for packaging during 45 min Clean L	(A–B) – C Surplus in Aseptic tank at re-start after clean L
2 hours	2,600	5,200	3,600	1,600	1,350	250
4 hours	2,200	8,800	7,200	1,600	1,350	250
6 hours	2,100	12,600	10,800	1,800	1,350	450
8 hours	2,000	16,000	14,400	1,600	1,350	250

TABLE 4

MAINTENANCE SCHEME FOR UHT PROCESS PLANT

Component	frequency in running hours					Operation
	10	50	200	500	1000	
HOMOGENIZER						
hydraulic tank unit	O					check oil level
high pressure pump	O					check oil level
homogenizing spindle	O					lubricate
gaskets		O				check/replace
U-packings		O				check/replace
Vee-belts				O		check/adjust
motor bearings					O	lubricate
REGULATING TRANSFORMER		O				check
THERMOCOUPLES		O				check
AIR–OPERATED VALVES						
gaskets		O				check/replace
U-packings		O				check/replace
PIPE FITTINGS						
pipe filters			O			clean
steam traps			O			clean
Strainer and air dampers of homogenizer	O					clean

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Action code: A = Satisfactory, B = Adjustment, C = Replacement

SPC-page	Action point ●=Carry out during production X=Replacement part		MS-page No.	Action Code	Action Done	Notes
		Peroxide bath - check gap between wetting roller and counter roller	185-11			
209200-1		Peroxide bath level guard - set	186-51			
209200-1		Peroxide system - check tightness	190-11			
35833-5		Tube heater - check el. connection and effect - Wattmeter	901-2			
		Sterile air - check temperature guards	166-12			
		Sterile air - check pressure guard	167-11			
37379-1		Jet deflector valve - check	170-11			
		Sterile air system - check tightness	175-11			
35910-3		Tube flushing, upper - check	177-11			
32998-2		Tube flushing, lower - check	178-11			
33069-2		Air knife - clean slot and check rollers	171-11			
35600-5		Product valve - overhaul	129-31			
35600-5		Sterile air valve - overhaul	130-31			
AB3: 228778-1 AB5: 228778-2		Ink unit - clean/check	147-11			
228779-1		Printing wheel - check	148-11			
37352-2		Lower filling tube - check	134-11			
		Peroxide bath - check position of packaging material on wetting roller	187-11			
	●	Package check	488-11			
	●	LS overlap - check	139-11			
	●	Pressure header - check for leakage	434-11			
31414-2	●	SA, strip guide - check	109-11			
	●	Peroxide bath - check even wetting	188-11			
	●	Printed design correction system - set	153-61			
	●	Pressure settings - check	255-11			
	●	Mist lubrication system - check	206-12			
228883-1	●	Cooling water system - check	215-11			
	●	Central lubrication unit - check pressure	201-51			
	●	Central lubrication unit - check automatics	201-61			
	●	Centr. lubr. final fold. unit - check	580-11			

TETRA PAK

TABLE 6

ASEPTIC BRIK (AB3, AB5)

From model 77, Issue 1

1000–1200 h

Action code: A = Satisfactory, B = Adjustment, C = Replacement

SPC-page	Action point ●=Carry out during production X=Replacement part		MS-page No.	Action Code	Action Done	Notes
23966-4 RF: 23966-3	X	Pressure unit - check	520-21			
23967-5		Pressure unit links and lever - check	521-11			
23966-4 RF: 23966-3		Pressure unit cam roller - check	522-11			
23966-4 RF: 23966-3		Pressure unit cam - check	523-11			
20748-1		Station chain - check	530-11			
30393-4		Discharger arm - check	535-11			
26535-2		Discharge slide carrier - check	540-11			
30393-4		Bevel gear - check	546-11			
30528-3		Side discharger - check	549-11			
		Discharger arm - set	535-51			
		Pressure unit, pressure plate - set	524-51			
		Pressure unit, pressure sides - set	525-51			
		BR, fixed knife/pressure roller - set	513-51			
		BR cutting - check	514-11			
		BR knives - replace	514-31			
20921-2	X	BR feed - check	510-41			
23612-2		Flap sealing element - set	504-51			
		Pressure block - check	526-12			
		Push-down device, slide plate - set	556-51			
31756-2		Push-down device - set	557-51			
		Damper - check	565-12			
		Synchronization main machine - - final folding unit	574-51			
36739-2		Safety coupling - check	577-11			
		Air system - check	583-11			
22427-1		SA, pressure and counter rollers - check	103-11			
7825-1		SA, guards and brake - check	105-11			
35833-5		Filling tube, pressure roller - check	136-11			
35910-3		Lower forming ring - check	137-11			
21394-6 33272-1		Tube supports and upper forming ring - check	140-11			

Figure 1 – Plant coupled direct to 1 Tetra Pak.

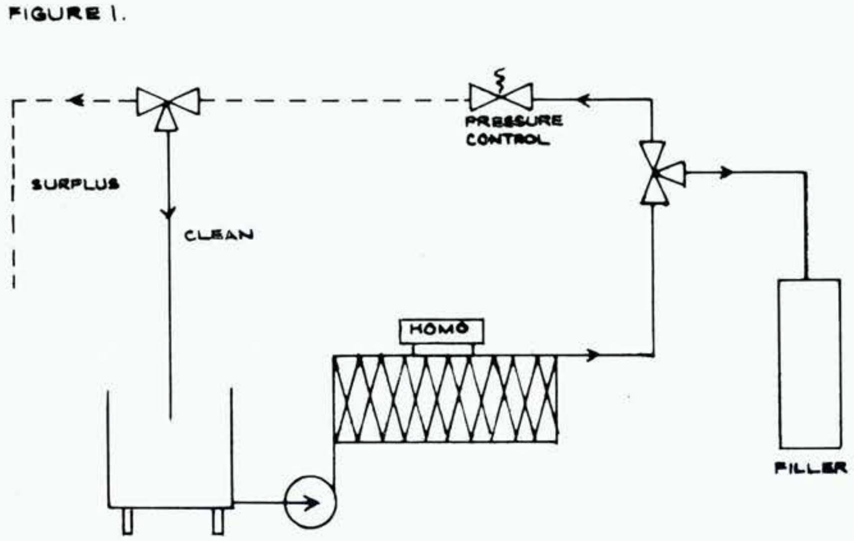


Figure 2 – Plant coupled to aseptic tank with 2 Tetra Paks.

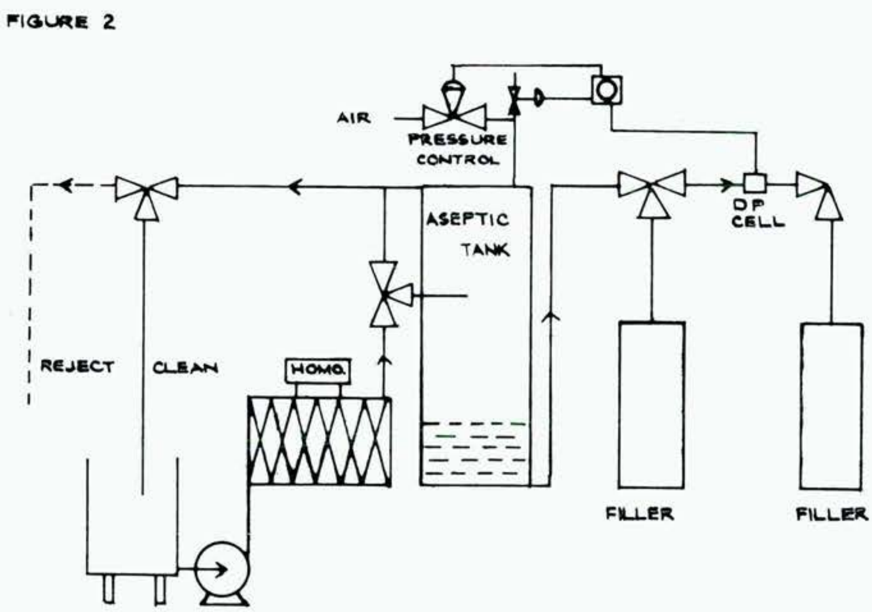
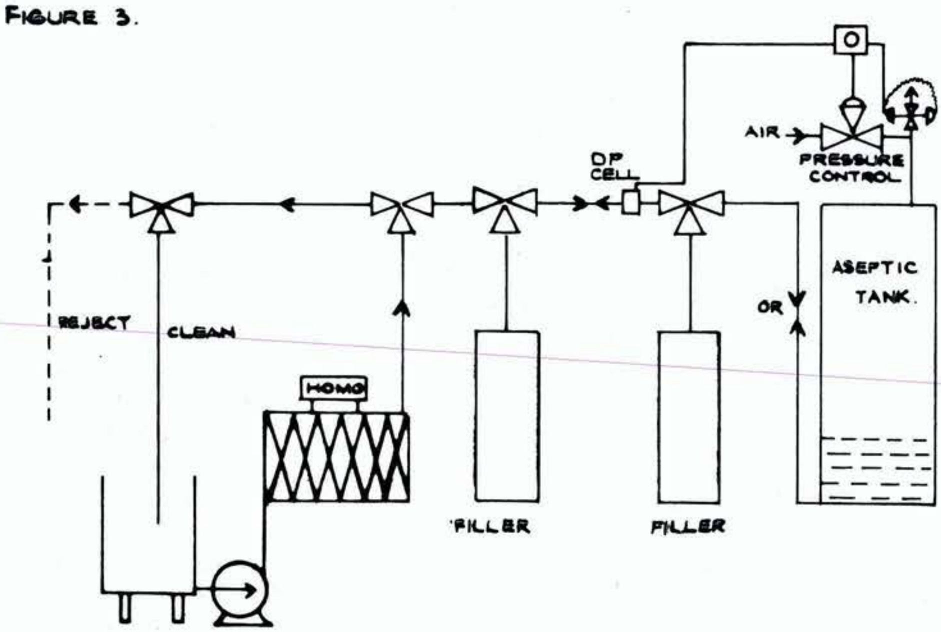


Figure 3 – Plant coupled direct to 2 Tetra Paks with surplus to aseptic tank for back feeding.



CHAPTER 9

TECHNICAL ASPECTS OF QUALITY ASSURANCE

Mr D.I. Shew (Australia)

INTRODUCTION

In the majority of UHT processing operations, it is the intention of the manufacturer to offer for sale a product resembling as closely as possible pasteurised homogenised milk, with the advantage that the product will retain its properties for many weeks without refrigeration. There may be some instances where the UHT treatment has been modified so that the product will more nearly resemble, particularly in flavour, in-container sterilised milk, but this is not the usual approach.

The objective of a quality assurance programme is to attain the required qualities regularly and uniformly and to retain them for a lengthy period during storage. Usually, as the qualities referred to will be those normally associated with pasteurised homogenised milk, it is these which should be established at the time of processing and packaging and maintained as long as possible, hence the term – Quality Assurance.

DEFINITION OF "STERILITY"

The essential feature of UHT milk is that it possesses not only a prolonged shelf life but contrary to pasteurised milk, is not dependent upon refrigeration and is usually stored and transported at ambient temperature. This vital characteristic depends upon the destruction of the microbial population of the raw milk by the heating process and the prevention of further microbial entry by ensuring aseptic conditions during post-heating handling and packaging.

Often it is stated that UHT milk must be sterile, but objections are frequently raised to the use of this term, on the grounds that it is not possible to prove that live micro-organisms are not present. It has been postulated that some may be heat shocked and unable to multiply in the product (Speck & Busta [1968]).

Furthermore, the destruction of micro-organisms by the UHT process is logarithmic and the extent of survival will depend upon the size of the initial population and their degree of heat resistance, so it is possible that even with adequate heat treatment a small proportion of packages of finished product may contain survivors.

The concept of "commercial sterility" has been discussed extensively elsewhere, notably by Lembke (1972), Von Bockelmann (1976), Burton (1970) and Speck & Busta (1968). Hence, if the terms "sterile" or "sterility" are used in other than absolute terms, it is necessary to define them. For the purposes of this Chapter, a package is said to be "sterile" when after being subjected to defined temperature and storage conditions the product fails to show any evidence of microbial growth.

EFFECT OF RAW MILK ON QUALITY

For any processed dairy product the quality of the raw milk is important. Should the milk contain flavours originating from fodder or weeds, or absorbed from the environment, then it is probable that such flavours will persist into UHT milk. If some vacuum treatment is given, as in direct heating methods, volatile flavours may be removed and the resulting product improved. In the case of weed taints which are intensified by heating, the UHT process may serve to render such flavours more pronounced. From the point of view of flavour, raw milk intended for UHT processing should be selected on the same basis as for pasteurisation, i.e. free from taints.

As for pasteurisation, milk with developed acidity will tend to coagulate on heating and is unsuitable for UHT processing. Any form of instability to heat is undesirable and should any doubt exist in this regard then the ethanol test should be used. Stability to ethanol, although it does not necessarily mean stability to heat, gives results which correlate closely with heat stability. An equal volume of ethanol and milk is mixed at room temperature and observed for signs of coagulation or flaking, the presence of which is regarded as a positive result.

IDF Standard No. 48 (1969) specifies 68% (V/V) alcohol. Using various strengths of ethanol over a range, the lowest at which some indication of precipitation occurs may be called the ethanol value. Pien (1972) suggests that for UHT purposes, raw milk should have an ethanol value in excess of 74%.

The type of microflora in raw milk may also have an influence upon the quality of the UHT product. For example, a high content of heat resistant spores renders survival of the occasional spore more likely. Also, it has been demonstrated that extra cellular proteases from certain spore-forming and psychrotrophic bacteria are not completely destroyed at 140 - 150°C and can produce proteolysis, bitterness and even gelation in UHT milk. These will be discussed in greater detail later in the Chapter.

It is thus desirable that the raw milk to be used for UHT processing should be of reasonably low count, should not possess a high level of heat resistant spores or certain psychrotrophic bacteria and should be stable to heat and to alcohol and free from taints.

PACKAGING MATERIALS

The primary function of packaging materials is the ability to be rendered free of micro-organisms (i.e. to be capable of being sterilised), to be filled aseptically and to maintain a condition of freedom from microbial entry as a completed package.

Secondary functions include the ability to withstand reasonably rough handling during transportation – both the package itself and its seal, and to form a barrier to the entry of oxygen and to the passage of water vapour (weight loss). Close inspection of packaging materials prior to use is an essential part of a quality assurance programme.

PROCESSING AND PACKAGING OPERATIONS

Probably no other dairy processing operation demands the same care and attention to detail as does the UHT process.

In the case of pasteurised milk, the effect of post-pasteurisation contamination is dependent upon the extent of that contamination. As an example, whereas one spoilage organisms in a litre carton would have a minimal effect on shelf life; with UHT milk, the effect of any such contamination would be to spoil the product in a very short time. Hence, the processing conditions must be such that will render the milk free from all spoilage organisms. The sterilisation procedure for the equipment, with steam or hot water, must ensure that all plates, pipes, valves, homogeniser (if downstream) and aseptic tank (if used) are effectively sterilised and maintained in that condition during processing. In most UHT plants the system of instrumentation and automation is such that the process once established is reproducible and free from human intervention and hence human error during both sterilisation and processing, ensuring that correct temperatures are maintained. For indirect plants requiring an intermediate clean without loss of sterility, an automated system is virtually essential.

Similarly, on the packaging side of the operation, the equipment must operate in a uniformly correct manner at all times since the results of any departure from normal can be disastrous.

The guiding principle for UHT plant procedure should be never to proceed if there is any suggestion of imperfect function of any part of the processing or packaging equipment. In other words, "if in doubt, STOP%".

For effective and efficient operation, the key is proper plant maintenance. Not only will poor maintenance produce too many stoppages and uneconomic operation, but lack of good maintenance could well lead to product failure – an even more important economic effect.

All valves and pipelines involved in handling of product subsequent to heating are a potential source of contamination and must be rendered sterile and maintained in that condition. Similarly where an aseptic tank is used the tank itself must be capable of effective sterilisation and the air which enters on cooling rendered free of micro-organisms by filtration, heating, or a combination of these processes.

With downstream homogenisation, the process must operate aseptically. Proper maintenance of the pistons and seals is essential to produce a sterile product.

It is probably no exaggeration to say that proper and effective maintenance is the most important single factor in determining the success of a UHT operation. Certainly its priority cannot be over-emphasised.

Areas of particular importance are those concerned with sterilisation of equipment and sealing of the package. When a UHT plant is in high production, there will be a temptation to reduce the time devoted to maintenance and this must be guarded against at all times. It has been referred to as "incremental degradation" by Roberts (1977). Where sterilisation of packaging material depends upon a combination of heat and hydrogen peroxide as with many of the laminates and plastics fillers, it is essential to maintain both the supply and the correct strength of the hydrogen peroxide.

With paper containing laminates, the exposed edge of the paper of the inside of the pack tends to absorb milk and any damage or rubbing of the pack externally may allow the paper to become infected and transfer the infection to the product in the pack. To prevent this occurring, it is customary to seal the exposed edge with a small strip of polyethylene. It is essential to ensure that this strip covers the exposed edge and is effectively sealed in the correct position. With laminates and plastic films where the seal is accomplished by a combination of heat and pressure, a uniform, effective seal is vital. Imperfect seals are often the most common source of product failure. Manufacturers of such filling equipment set out clearly the necessary steps for checking and also provide methods of testing seals, using dye solutions.

TRANSPORTATION AND STORAGE

Freedom from damage is vital – one leaking pack in a pallet load can cause havoc when growth of contaminants occurs in the leaked pack and may cause rejection of the whole pallet by the customer. The outer pack should protect the inner containers effectively and they must be packed firmly so that movement and chafing is avoided. avoided.

Storage is normally under ambient conditions and small variations within the range 15 - 25°C will have little effect within a period of say two months. However, higher temperatures, e.g. above 25°C for prolonged periods will hasten some of the physico-chemical changes such as the Maillard or browning reaction and lead to the early development of stale flavours. On the other hand, storage at lower temperatures, e.g. below 10°C will delay substantially the onset of off-flavour.

Undoubtedly milk with a high level of heat resistant protease enzyme will also deteriorate more rapidly at the higher temperatures and this was probably the basis of the suggestion of Lindqvist (1970) that 18°C should be regarded as the highest permissable storage temperature for UHT products. However, substantial quantities of UHT milk are marketed successfully in tropical and sub-tropical climates where the average ambient temperature would usually be well above 18°C.

The shelf life will depend to some degree upon the temperature of storage and if a product is to be stored for up to six months, then storage at a relatively low temperature will reduce the tendency to stale or oxidised flavours. It should be emphasised that judgment of the shelf life of UHT milk is subjective and will vary from consumer to consumer.

QUALITY PROBLEMS

These may be divided into two groups – those evident during production, and those which become manifest subsequent to production. The latter are usually more varied and more numerous.

IMMEDIATE PROBLEMS

At the commencement of packing, it is important that the first packs from each machine are examined immediately by taste and by smell to ensure that the product is normal at that stage and has not been overheated nor contains, for example, detergent or other extraneous residues. Several containers should be weighed to ensure that the correct quantity is being packed. These procedures are normally part of the Quality Assurance programme of any food packaging operation.

In the case of direct heating plants, this should include checking by solids determination, density or freezing point, to ensure that dilution has not occurred.

Several packages from each filling machine should be examined as discussed in the previous section to ensure correct sealing.

POST–PRODUCTION PROBLEMS

These may be assessed in three groups:

(i) microbial
(ii) physical
(iii) chemical or flavour

(i) Microbial Problems:

Micro-organisms occurring in UHT milk will almost invariably create some type of spoilage and if they are present, will either be survivors of the heat treatment or will have gained entry to the product subsequent to heat treatment. There is little evidence with modern UHT plants, using temperatures of 130 - 150°C, of survival of any of the raw milk flora (Cox, 1975). It may be that when the spore level is low, the very few survivors are virtually undetectable or that the heat stressed spores require a special medium in which to regenerate (Burton, 1969). Whatever the reason, in commercial practice, surviving spores appear to be a fairly rare cause of spoilage.

Furthermore, it appears that spore destruction in the UHT process proceeds at a greater rate than would be predicted from laboratory experiments (Davies, 1975). Although Leshina (1971) considered that a proportion of failures was due to heat resistant spores, Cox (1975) came to the conclusion that spore survival was very rare. It should be pointed out that although the presence of heat resistant spore-formers could indicate survival of the heating process, their resistance may enable them to enter the product as contaminants at the handling or packaging stage.

For some other dairy products, the additives used may have a protective effect and survivors may be encountered. An example is UHT chocolate milk prepared from cocoa with a substantial spore population which has been known to give considerable difficulty with lack of sterility, and spoiled packs have been shown to be due to surviving spore-formers from the original cocoa.

Faults due to micro-organisms may show up as "blowing", that is, the development of gas or by coagulation and proteolysis, or by bitterness and off-flavours. In the majority of cases, the organism has originated in the packaging system or subsequently due to faulty sealing or by external damage to the pack.

According to Davies (1975) "spoilage of UHT processed milk is more frequently due to filling and seaming faults in packaging than to resistant surviving spores". That would appear to be the general conclusion in commercial practice.

(ii) Physical Problems:

These include leakage of product due to faulty sealing or subsequent damage.

Milk with a normal fat content of 3 - 4% and effectively homogenised, will show no fat separation for some time; eventually some coalescence of fat globules will occur, forming a cream layer which may be redistributed by mixing. If the homogenisation has not been fully efficient and coalescence and aggregation occurs, the rise in fat globules may be excessive and the aggregated fat partly churned, giving the product an unsightly appearance.

Effective homogenisation, using total pressures of 3000 - 4000 psi.(*) will keep this problem to a minimum. Poor homogenisation may also arise from worn and damaged valves and the proper maintenance of these parts is essential. Perkin (1978) with direct heating, obtained better results with "downstream" homogenisation, that is, subsequent to heating. Damerow (1978) agreed that with indirect plants "downstream" homogenisation is more effective than "upstream" but concluded that the extra cost was probably not justified. Ellis (1977) found that even with efficient homogenisation, there was a tendency to re-grouping of fat globules and the formation of a cream plug in six to eight weeks.

Other physical characteristics which may develop on storage are the appearance of sediment from the milk constituents and thickening or gelation often accompanied by bitterness and even digestion of the coagulum. It must be stressed that these defects when they occur in the absence of any micro-organisms are not microbial, at least directly, in origin.

A considerable amount of work has been directed towards the problem of gelation, which may develop in less than three months (Zadow & Chituta, 1975), (Snoeren, van der Spek, Dekker & Both, 1979). The onset of gelation is influenced largely by storage temperature. Zadow & Chituta (1975) showed that storage at 2°C delayed gelation considerably as did storage at 40°C. The absence of gelation at 37°C has been reported by Samel, Weaver & Gammack (1971) and Keogh (1973). It appears that gelation is influenced also by the extent of heat treatment. Samel, Weaver & Gammack (1971) found that autoclaved milk did not coagulate on storage but the same milk treated by the UHT process showed gelation after a storage period. It seems that directly heated milk shows a greater tendency to gel formation than does milk which has been subjected to the indirect process, Zadow & Chituta (1975), Perkin, Henschel & Burton (1973) and Corradini & Bottazzi (1967). The use of higher temperatures and increased holding times will apparently delay the onset of gelation (Samel et al. 1971), (Hostettler, 1972), but will of course introduce flavour problems.

It has been found by the majority of workers that gelation occurs as the result of proteolysis and indeed proteolytic enzymes have been demonstrated to occur at a much higher level in coagulated milk (Corradini & Pecis, 1979). Earlier, it was postulated that gelation was a physico-chemical process but it now appears that it is enzymic due either to the survival of a natural heat resistant proteolytic enzyme in the milk (Ged & Alais, 1976), (Zadow & Chituta, 1975), or to enzymes from psychrotrophic bacteria, e.g. *Pseudomonas spp* (Richardson & Te Whaiti, 1978), (Adams, Barach & Speck, 1975), (Law, Andrews & Sharpe, 1977), or to both bacterial and natural enzymes (Snoeren & Evers, 1978), (Snoeren et al., 1979). Whereas most work with bacterial enzymes has implicated the heat resistant enzymes of *Pseudomonas spp* Harper, Hidalgo & Mikolajcik (1970) have found an enzyme produced by *Bacillus cereus* which lost only 50% of its activity at 140°C/3 s.

The tendency to gelation will thus be influenced by the level of heat resistant enzyme present in the raw milk, by the heat treatment and the time and temperature of storage. West, Adams & Speck (1978) found that the enzyme from a *Pseudomonas sp* could be largely inactivated by a low temperature treatment of 55°C for 1 h and UHT milk so treated showed considerably less proteolysis and no gelation upon storage.

** 3000 - 4000 psi ≅ 21 - 28 MPa or 210-280 bar*

Where gelation is a commercial problem, care should be taken to ensure that development of psychrotrophic bacteria in the raw milk is kept to a minimum and for prolonged storage the temperature kept as low as possible. Should the experience of West, Adams & Speck (1978) be substantiated elsewhere, the possibility of filling UHT milk at 55 - 60°C may overcome the gelation problem but could react adversely on flavour unless the temperature is subsequently reduced rather rapidly.

(iii) Chemical or Flavour Problems:

Due to the higher temperature employed UHT milk almost invariably possesses a slightly cooked flavour when compared with pasteurised milk. Immediately after production it possesses a strong "cabbage" flavour, due to sulphydryls; however, this flavour disappears in a few days, at a rate depending upon the oxygen level (Ashton, 1965). At higher levels of oxygen the sulphydryl groups responsible for "cabbagy" flavours are readily oxidised. Hence, indirectly processed milk, unless it has been de-aerated, loses this flavour at an earlier stage than does milk from the direct process (Burton, 1977).

Subsequently during storage, the milk will gradually develop flavours due to oxidation of the fat (enhanced at higher oxygen levels) and stale flavours, arising probably from condensation reactions between fat and protein. The rate of such changes will depend upon the initial oxygen level (Ashton, 1965) and the permeability of the container to oxygen (Flückiger, 1972), (Mehta & Bassette, 1978).

Generally, development of these flavours is accelerated by higher storage temperatures and hence is delayed at lower temperatures. Schmidt & Renner (1978a) found that flavour changes were less at a lower fat level. They considered that the development of free fatty acids and hydroxymethylfurfural was associated with flavour changes (Schmidt & Renner, 1978b).

SAMPLING SYSTEMS

Having produced a quantity of UHT milk spread over probably many thousand packages, and often from more than one filling machine, the next step is to ensure that the batch is free from micro-organisms and hence may be released for distribution.

The difficulty of prescribing a really effective sampling system has been well expressed by von Bockelmann (1974). Each package is an entity, although it will be uniform with others from the same batch with respect to fat content, globule size and other such characteristics. Hopefully, the whole batch will be uniform microbiologically, that is, it will be sterile and not one pack will contain a micro-organism capable of development in that pack. That, of course, is the ideal. How do we establish that the batch is completely sterile? The only certain way would be to incubate and then examine the contents of every container! Since that is clearly impossible, it is necessary to resort to a sampling rate of perhaps 1% or less, otherwise the cost becomes excessive. Wasserfall (1973) states "a lot of 3 000 - 8 000 packages where 0.1% defective ones are admitted requires random sampling of 300 individual packages". This would of course be quite uneconomic but it serves to illustrate the problem of sampling. Roberts (1977) gives details of a system where the sampling level is a little over 1%. Keogh (1973) suggests sampling for incubation purposes within the range 0.1 - 1% with greater attention to the start and finish of a run. Roberts (1977) suggests that likely areas of contamination, such as the paper splice should be more frequently sampled. Berry (1974) cites a failure rate of less than 1 per 10 000 packages after an examination of 50 000 containers. With this extremely low level, any sampling method would probably report the batch as being sterile.

It is necessary, then, to decide on a sampling level which will provide a reasonable assurance of the sterility of a batch and at the same time, not impose an excessive economic burden due to the cost of testing and destruction of product. One example would be to take one sample at start up, one every hour and one at the finish for each filler. Assuming a filling rate of 4 000 packs per hour and an 8 hour operation, this would amount to 9 packs from a production of 32 000 or 1 in 3 500 or 0.03%. If, more frequent samples are taken, two different incubation temperatures are employed for assessment, and several tests are made as well as samples set aside for later reference, the quantity of samples required could well rise to 1% or more of total production. No hard and fast rule should be laid down for the system will vary with the type of operation, the frequency of failures experienced and the complexity of the methods of testing employed. Essentially, it would appear that in any new operation, the amount of sampling and testing should be fairly intensive. As confidence in the methods used develops, then the number of samples (and tests) may be reduced to a level consistent with experience and the economy of the operation.

With a pasteurised milk operation where problems occur with post-pasteurisation contamination sampling of intermediate points may help to pinpoint the source. However, the aseptic nature of a UHT operation normally precludes any such sampling. Rather surprisingly, Burton (1977) advocates the use of intermediate sampling points; they would certainly increase the difficulty of maintaining sterility. If problems are encountered the usual procedure is to check thoroughly every aspect of the system before production of the next batch.

MICROBIOLOGICAL TESTING

Prior to testing, samples are incubated to develop any micro-organisms. Usually incubation is in the range of 30 - 37°C, although 45°C (Roberts, 1977) and 55°C (FIL/IDF: 48, 1969) are sometimes used for special purposes. The latter delineates control methods for sterilised milk which are often cited as the basis for testing UHT milk, and recommends incubation at 30°C for 14 days. In commercial practice, this would involve extreme delay if employed for batch clearance and generally much shorter incubation times of 2-7 days are used (e.g. Roberts, 1977). When tested by the colony count method, IDF Standard No. 48 recommends that not more than 10 colonies per 0.1 ml (100/ml) should be found. This is also specified in Milk (Special Designation – Amendment Regulations 1965 No. 1555) in the United Kingdom. Australian Standard AS 1095.2.7. (1971) states that no colonies should be found with a 0.01 ml inoculum after pre-incubation for 7 days at 30°C.

General experience has shown that with any of these techniques a positive result is indicated by a mass of microbial growth in the test, and a negative result by a complete absence of growth. The presence of one or two colonies can be attributed to atmospheric contamination when setting up the test.

IDF Standard No. 48 advocates incubation at 55°C in addition to 30°C "under conditions of tropical climates". Since the purpose of this temperature is to indicate obligate thermophiles and since UHT is unlikely to reach the vicinity of 55°C even "in the tropics" the necessity for use of this temperature is open to question, particularly as a mandatory test.

Whilst the above microbiological tests no doubt meet statutory requirements and produce objective results, they are time consuming and expensive as they require a further 2-3 days after the incubated sample is opened to obtain a result. With organoleptic testing, that is, examination of the contents of incubated samples by sight, taste and smell, the period of incubation for batch certification may be increased and a greater number of samples examined at a lower cost and usually great reliance is placed upon such results (Roberts, 1977), (Ashton, 1970).

It would appear that generally the demonstrated presence of micro-organisms in laboratory testing is accompanied by obvious organoleptic changes in the product. The further 2-3 days incubation with organoleptic testing renders this even more likely. For example, assuming that it is desirable to certify the sterility of a batch on the fifth day after production and incubation of the microbial test is for three days, then only two days is available for pre-incubation, whereas for organoleptic testing the samples may be incubated for five days and then examined

In support of organoleptic testing for quality control purposes, Ashton (1965) examined smears of 17 856 organoleptically normal cartons microscopically and none showed the presence of micro-organisms. On the other hand, Langeveld, Bolle & Cuperus (1978) with pure cultures found several organisms growing in milk up to 140×10^6/ml without showing any organoleptic change. With UHT milk Langeveld, Robbertsen & Stadhouders (1976) found that about 25% of non-sterile UHT packs showed no organoleptic change.

It is desirable that all failed packs be examined by microscopic examination or cultural methods to obtain some idea of the type or types of organisms involved. With experience such an examination may help to point to the source of contamination. If the organisms are of one type, this could indicate survival either of the heating process or the sterilising process during handling or packing. Mixed flora will more likely indicate gross deficiency in sterilisation or contamination subsequent to packing. The containers of any defective packs should be submitted to a careful examination to determine the possible source of any contamination attributable to the container.

One further word concerning IDF Standard No. 48; it relates to sterilised milk, that is, milk heated and sterilised in a container. Such product, like any canned food, is less likely to show variations between individual packs than does UHT milk, hence the provision to examine one pack before incubation and the other subsequent to incubation has not the same relevance, and it would appear preferable to incubate all UHT sample packs before testing, and in commercial practice, that is the procedure.

OTHER TESTS

Due to the difficulty and the cost of determining sterility by destructive methods, efforts have been directed towards developing a method which would permit the sterility to be determined without destruction of the container. von Bockelmann & von Bockelmann (1974) used slight surface temperature variation to select non-sterile packages. Moisio & Kreula (1973) measured changes in viscosity due to microbial activity.

Such methods could be useful where individual packs are available after incubation. In most commercial operations, containers are usually packed in bundles or outer cartons and then palletised for ease in handling and it would be very costly to apply such methods to the total production. However, any indirect method which could detect non-sterility without damaging the product would enable examination of a much greater proportion of the batch and would be extremely useful. Recently, Langeveld, Bolle & Cuperus (1978) described a method for the rapid determination of oxygen level and found that this gave a good correlation with lack of sterility and was cheaper and more rapid than microbiological testing.

On storage, the aggregation of fat globules may lead to separation of a quantity of fat at the surface and this may be regarded as a quality defect. Microscopic examination and measurement of the size of fat globules will assess the efficiency of homogenisation and the tendency of fat to rise and separate from the milk during storage. It is generally considered that satisfactory homogenisation is represented by 95% of fat globules being below 1 μm in diameter.

CONCLUSION

The production of UHT milk requires considerable care at all stages from selection of raw milk, through processing, packaging and storage. The successful operation in many countries throughout the world shows that care and attention to detail will enable many inherent difficulties to be overcome. As with all technical operations, care must be taken to ensure that familiarity with the operation does not lessen vigilance in the application of technical control – the most important factor being a rigid system of preventive maintenance.

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CHAPTER 10

LEGISLATIVE ASPECTS

by Mr P.F.J. Staal, Secretary General, IDF

1. BACKGROUND INFORMATION

A survey on statutory regulations in some 24 countries of IDF, in relation to UHT milk, was made in 1970 and the results, reflecting the situation at that time, were given as Chapter 10 of the 1972 IDF Monograph on UHT milk (IDF Document 68).

In January 1980, member countries, plus USA, were invited to comment on the following questions:

- Is UHT milk expressly mentioned in the legislation or statutory regulations in your country as a milk on its own, or is it covered by the legislation for UHT sterilized milk or pasteurized milk? Alternatively, is UHT milk covered by general food and dairy legislation?
- If regulations applicable to UHT milk exist, please supply a copy of these regulations with special reference to requirements regarding method of heating, time/temperature combinations, bacteriological/ chemical tests, maximum time between production and sale ("sell by date"), requirements on packaging and labelling, etc.

It can be inferred from the above that it was, in fact, attempted to obtain data on 2 main aspects: a) does UHT milk in individual countries enjoy a position of its own, distinct from pasteurized and sterilized milk? b) if so, how is UHT defined?

The following countries replied:

Australia, Norway, Denmark, Germany (F.R.), United Kingdom, Israel, USSR, Japan, Finland, France, Switzerland, Netherlands, Spain, USA, Poland, Sweden, Belgium, Italy, and a survey of the replies is given below. We wish to thank the Secretaries of National Committees of these countries for their cooperation.

Note.– Statutory regulations are mentioned in other chapters of this monograph too. Vide in particular, chapter 8.

2. REPLIES PER COUNTRY

2.1 Belgium

UHT milk is not expressly mentioned in existing milk regulations, at least not for the time being.

Firms using the UHT process were individually told to label the milk thus treated "pasteurized milk" with the facultative addition "UHT process". This was done in view of the flavour and nutritional characteristics of UHT milk.

The above-mentioned firms were also informed that, in respect of UHT milk, bacteriological characteristics would be checked on the following basis: "After 5 days of incubation in the original package, at 30°C ± 1, no deterioration should be noticeable and the number of viable germs should not exceed 100 per ml".

This requirement is likely to appear in future legislation and is already applied for school milk.

Except for the above, the general milk ordinance is equally applicable to UHT milk, requiring in particular that pasteurized milk should have a positive reaction to the turbidity test.

2.2 Sweden

The present Swedish regulations applicable to milk and milk products date back to 1972 and include standards for sterilized products as well as for UHT products. The wording of the standard does not include the term UHT but "hållbarhetsbehandlad", which, translated into English, would read "treated for prolonged keeping quality".

Translation of standard:

"Hållbarhetsbehandlad" milk and cream (milk and cream treated for prolonged keeping quality) are milk and cream which before aseptic packaging have been heat-treated so that remaining microorganisms and enzymes cannot make the product unfit for human consumption nor change the product in any marked way during maximum one year's storage.

"UHT milk and cream are not important on the Swedish market, which to more than 99% is a fresh milk market. Apart from the above-mentioned standard, there are no specific regulations for UHT products which have to be labelled and sold according to general requirements in Swedish food legislation. An exception for

UHT products is, however, made for the maximum temperature requirements which apply to fresh milk products during storage and transportation. The legislation clearly states that milk and cream treated for prolonged keeping quality are not subject to cold storage requirements valid for fresh milk products".

2.3 Poland

No UHT milk is produced in the country.

2.4 USA

The US Public Health Service/Food and Drug Administration Recommended Grade A Pasteurized Milk Ordinance is the basic standard used in the voluntary cooperative state – PHS program for certification of interstate milk shippers, a program participated in by 49 states. It is incorporated by reference and federal specifications for all milk and milk products; is used as a sanitary regulation for milk and milk products served on interstate carriers; and is recognized by the public health agencies, the milk industry and many others as a national standard for milk sanitation. A new ordinance, dated 1978, has just been published and will take effect on July 1, 1980.

The only reference to UHT is the definition for "ultra-pasteurized". This describes a dairy product that has been thermally processed at or above 138°C for at least 2 s, either before or after packaging, so as to produce a product which has an extended shelf life under refrigerated conditions.

At present, the Grade A label cannot be used on any milk that is stored without refrigeration. However, the USPHS/FDA has undertaken to prepare an amendment to the Grade A Ordinance that will permit the use of unrefrigerated products. This revision will have details involving processing, storage, packaging, equipment for pasteurization, sterilization and other important items.

At present all ultra-pasteurized products must meet the same requirements as are promulgated for pasteurized products. In other words, the individual producer for raw milk is allowed a maximum of 100,000 organisms per ml prior to commingling with other producer milk, and not to exceed 300,000 per ml as commingled milk prior to pasteurization.

Furthermore, there are a complete series of requirements for the maintenance of hygienic conditions on the farm, covering the animals' health, the construction of the barn and milking parlor, the cleanliness of the barn and cow yard, construction of the milk house and its cleanliness, the water supply, construction of the utensils and equipment and their cleaning and sanitizing, storage of all equipment used for various purposes, personnel health and cleanliness, vehicles used to transport the raw product, and insect and rodent control.

Sanitation requirements for the processing plant follow the same basic format, but in greater detail. Relative to pasteurization, relevant portions of the ordinance give the details for this process together with the appendices which have specific requirements for various types of equipment. This covers the method of heating, and both direct and indirect systems are permitted, provided that only culinary steam is used.

Chemical, bacteriological and temperature standards are also included in the ordinance; but there is nothing specific for UHT milk. At this time, UHT milk would have to meet the pasteurized standards of not more than 20,000 per ml.

There are no dating requirements and most of the states permit the milk plants to make their own determinations, but do require that they comply with the maximum bacterial count, regardless of the date of expiration given. There is a possibility that new legislation will require that a sell by date be incorporated into all packages of perishable foods.

At present, there are many plants throughout the country processing ultra-pasteurized refrigerated cream and flavored milk. Also, there are one or two plants processing UHT milk and milk products for sales overseas. The PHS/FDA has permitted one experimental installation in a very limited area where UHT milk, aseptically packaged and sold at ambient temperatures, will be allowed. This is being done to collect data and determine consumer opinion.

There is one other factor that is unique to the USA system; although the ordinance is recommended by the federal government, and has the effect of law, in many cases an individual state could permit plants within the state to sell UHT aseptically packaged, non-refrigerated products as long as the product does not cross state lines. This has not been done, but it is a possibility.

The PHS/FDA has prepared a draft ordinance to incorporate non-refrigerated sterilized milk and milk products into the Grade A Pasteurized Milk Ordinance.

They have defined the product as follows:

"Sterilized Milk and Milk Products – Sterilized milk and milk products are products hermetically sealed in a container and so thermally processed before or after sealing in accordance with Federal regulations and the Grade A Pasteurized Milk Ordinance so as to render the product free of microorganisms capable of reproducing in the product under normal non-refrigerated conditions of storage and distribution. The product shall be free of viable microorganisms (including spores) of public health significance".

However, the bacterial limits are "less than 10 per ml of incubated product".

2.5 Spain

UHT milk is considered in Spain as sterilized milk. However, if the UHT process if applied to evaporated milk, the latter product may be designated "aseptic evaporated milk".

The Spanish Committee pointed out that the present legislation might be revised especially in view of Spain entering the EEC and in the new legislation, a distinction is very likely to be made between traditional sterilization and UHT treatment. In this context, it is felt by the Committee that the designation "aseptic" referring to the mode of packaging, would be more appropriate for this type of milk than the abbreviation "UHT".

2.6 Switzerland

The following mention is made under article 7.3 (pasteurized milk) of the Food Ordinance:

"Milk subjected to an authorized process of heating at a very high temperature (UHT), for instance the uperization process, should be appropriately designated. Designations such as "UHT" referring to very high temperature heating, are not allowed if the UHT milk is subjected after packaging to a new sterilization or similar treatments, thus reducing the benefits to be derived from the UHT process. The UHT processes are characterized by the use of special equipment where the milk is heated for a few seconds to temperatures of 130 to 150°C, resulting in the destruction of germs, followed by immediate cooling. When filling is done aseptically, the storage time before sales to the consumer may reach a maximum of 30 days without cooling but with protection from light. If UHT milk is packaged in one way packages, hermetically sealed and impervious to light and gas, the shelf life can be extended to 4 months. The packages should mention the sell by date".

In addition, UHT milk should comply with article 73 bis (defining the size of one way packages such as Tetrapack, Zupack, etc.) and, if packaged in tins, with article 79 (defining requirements for milk preserves).

2.7 Netherlands

UHT-treated milk products are covered by the legislation concerning sterilized milk. There is one exception: UHT is only mentioned for different kinds of evaporated milk.

The regulation applicable to the UHT-treated kinds of evaporated milk is as follows:

The name "ultra hoog verhit" (ultra high temperature treated) or "UHV" (UHT) only may be, and must be used as the descriptive name for the following products: evaporated whole milk, evaporated semi-skimmed milk, evaporated milk with a high fat content, provided:

a. those products are subjected to a continuous flow heating process which ensures the destruction of any microorganisms
b. those products are aseptically packed in a packing reliably closed by a cap, which cannot be opened without breaking the cap on the spot.

Other requirements for these products are covered by the regulations for sterilized milk products. About 3% of the total liquid milk production (pasteurized and sterilized) is UHT treated.

2.8 France

UHT milk is expressly mentioned in the legislation as "UHT sterilized milk" and defined as a milk subjected to ultra high temperature treatment followed by aseptic packaging; the milk should be protected from light (light proof packages).

The heat treatment should be a continuous flow, direct or indirect, heating process applied once only for a very short time (at least 1 s), using a temperature of at least 140°C (140 - 150°C), with the resulting destruction or total inhibition of enzymes, and of microorganisms and their toxins, whose presence or proliferation could cause deterioration of the milk or make it unfit for human consumption.

The label should carry the following information in clear letters (from 1 May 1978):

- UHT sterilized milk, with the indication "whole", "partially skimmed" or "skimmed".
- the name or trade name of the person or firm responsible for the manufacture or sale.
- the registered number of the sterilization plant.

- the name of the country of origin, if its omission could create a confusion on the actual source of the milk.
- the volume, using a legal unit of measure.
- the indication: "after opening, keep in a cool place and use rapidly".
- sell by date.

For the rest, UHT sterilized milk should comply with the same requirements as those imposed on sterilized milk. It should remain stable after incubation at 31°C for 21 days (those conditions are suitable for mesophilic spore-forming germs) and at 55°C for 10 days (thermophilic spore-formers).

The future ordinance for UHT sterilized milk, now at the drafting stage, requires an incubation for 1 week at 30°C; one alcohol test to check the stability of the packaged milk; a bacteriological analysis on 10 samples per batch.

2.9 Finland

UHT milk products are expressly mentioned in the "decree on milk inspection" issued in 1975 by the Ministry of Agriculture and Forestry, and should comply with the following requirements:

Method of heating, time/temperature, quality of steam, etc.

- either indirect or direct heating by steam is allowed;
- steam heating (VTIS) is specified as 2-3 s to at least 135°C;
- the corresponding amount of water should be removed from the product (i.e. corresponding to the amount of steam injected);
- immediate cooling and aseptic packing into consumer packages is required;
- the water used for the steam must be of potable quality (as specified by the Law on National Health 469/65). Further, the plant should have this water analysed at an officially approved laboratory at least once annually, before end April.

Bacteriological requirements

After incubation at + 30°C for 14 days the UHT products should contain a maximum count of 100/ml. (This incubation, by the way, is performed on every single package of mother's milk substitutes produced).

Labelling

UHT treatment has to be indicated on the package. Since (about) 1971 no descriptive name as the former "Kestokerma", etc. (corresponding to e.g. German "H-milch") has been used. The product is now only labelled "Ultra-pasteurized half-cream" etc..

Other regulations are the same as for pasteurized products, except the last selling date, which should be marked in full: day, month, year.

Maximum time between production and sale

The sell-by date is 90 days from the date of heat-treatment and packing.

General remarks

UHT milk products are not a very big group on the Finnish market. Only 2 dairy plants cater for the needs of the whole country. The most important of the products is half-cream, and to some extent the mother's milk substitute, being the sole alternative in liquid form.

The products manufactured are:

Half-cream	(12 % fat)	0.2 ℓ	package
Whipping cream	(38 % fat)	0.2 ℓ	"
Low fat milk	(0.1% fat)	1.0 ℓ	"
Mother's milk substitute		0.2 ℓ	"
Vanilla custard		0.2 ℓ	"
Chocolate sauce		0.2 ℓ	"
Chocolate milk		0.2 ℓ	"

2.10 Japan

UHT milk is covered by general dairy legislation. The same conditions as for pasteurized milk apply to UHT milk.

2.11 USSR

No milk is produced in the USSR under the name UHT milk. However, some dairies produce milk in cartons according to certain requirements and the technology used is practically similar to that for UHT milk.

Milk is heated in continuous flow by steam injection to 140-142°C during 0.1 s and held at this temperature for 2-4 s. Sterilized milk is then filled into cartons of laminated material aseptically. The capacity of cartons is 0.25 and 0.5 litre.

Maximum time between production and sale is 10 days.

The following information should be marked on the carton either by stamping or by indelible dye:

- name of dairy
- commodity number
- name of product
- volume in litres
- date of production
- retail price
- time of distribution
- reference number of the standard

Each batch of sterilized milk is evaluated according to its physico-chemical characteristics and organoleptic properties to make sure that it satisfies the requirements of the standard.

Sterilized milk should meet the following physico-chemical requirements:

- fat content 2.5, 3.2 and 3.5%
- density not lower than 1.027 g/cm^3
- acidity not higher than 20°T
- temperature when delivered from a dairy not higher than 20°C.

For daily microbiological control 100 samples are taken per batch and kept at 37°C for 3 days and checked thereafter for organoleptic characteristics, acidity, under microscope and by cultivating on nutritive medium. Percentage of nonaseptic samples should not be higher than 0.25 per batch.

2.12 Australia

UHT milk is dealt with in Australia by general food and dairy regulations.

Uniform regulations do not exist.

However, a new draft regulation, produced in June 1979 by the National Health and Medical Research Council (Standard for milk) includes the following definitions for UHT milk:

"Ultra heat treated milk or UHT milk is milk which has been subjected to a temperature of not less than 133°C and aseptically packed in hermetically sealed containers".

Microbiological standards for UHT milk are as follows in this draft regulation:

Proceed as in Standards Association of Australia, Australian Standard AS 1095.2.7 except that for the purpose of this prescribed method when 3 sets of 5 containers of ultra heat treated milk or sterilized milk are examined as detailed the result shall be reported as showing no microbial growth when no microbial growth is detected in each of the following:

a. 5 out of 5 samples examined without incubation.
b. 5 out of 5 samples examined after 7 days incubation at 30 ± 1°C.
c. 5 out of 5 samples examined after 7 days incubation at 55 ± 2°C.

2.13 Norway

This country stated in April 1980 that the situation had not changed since 1972, when it was pointed out that there was no specific legislation on UHT milk in Norway.

2.14 Denmark

UHT treatment is mentioned as one of the alternative methods of heat treatment in the Danish regulations of 25th August 1976 on liquid milk for consumption and of 15th December 1977 on preserved milk. The method of heat treatment and the claims on the finished product are specified as follows:

"UHT treatment: A heat treatment of the liquid milk to not less than 135°C for not less than 1 s combined with packaging under sterile conditions in germ-tight packings. UHT treated products must be non-perishable to the extent that they should not change by storage for 14 days at 30°C or for 7 days at 55°C. Aschaffenburg's modified test of presence of non-denatured whey protein must be positive".

It is prescribed that the apparatus used for the UHT treatment, concerning type and setting up, must be passed by the Government Dairy Research Institute. Both direct and indirect steam heating are permitted.

Steam used directly in connection with the product must be produced from boiler-feed water which satisfies the requirements for potable water, and to which no chemicals have been added. In the steam pipe a filter must be inserted which efficiently detains particles from entering the boiler.

Consumer packings must be passed by the Government Dairy Research Institute before use.

By way of controlling that the above-mentioned claims on UHT treated milk products are satisfied, they are put to Aschaffenburg's test and after incubation as prescribed in the definition a sensory evaluation and a test on the bacteria content for aerobic and anaerobic culture as laid down by the standard No 59, 1965 of the Nordic Committee on Food Analysis are carried out.

It is prescribed that UHT treated milk products must be provided with (i) the description "UHT treated" and a statement of (ii) date of the heat treatment, (iii) last date of sale and/or last day of shelf life (these rules, however, will in all probability be modified according to EEC directive 79/112).

The producing company determines the distance between date of production and last date of sale/last date of shelf life.

UHT treated liquid milk for consumption is to be kept at 5°C or less at the dairy and in the retail shop.

2.15 Germany (F.R.)

In the German Dairy Legislation UHT milk *(H milch)* is milk heated in an authorized type of equipment and homogenized. Both direct and indirect heating are permitted. The use of direct heating should not result in changing the water content. The milk should be packaged under sterile conditions in sterile packages, protected from light, closed under sterile bacteria proof conditions. The milk should be able to keep at least 6 weeks in unopened packages, at room temperature.

Authorized UHT heating plants should be capable of heating the sterile milk to 135-150°C in short time.

2.16 Israel

UHT milk is not yet mentioned in the existing legislation in Israel. However, a recent draft of the official rules includes several paragraphs referring to UHT milk. The exact wording is still under consideration, but the principles will be as follows:

1. Both direct and indirect heating will be permitted. (At present one UHT plant is operating in Israel in one of the TNUVA Dairies, using direct steam injection).
2. The minimum time-temperature combination will be 130°C (min.) and at least 1 s.
3. The sterilization and aseptic filling should be done in a continuous process.
4. The sterility will be checked after incubation of samples at 35 and 55°C during 1 week. After this incubation the Standard Plate Count should not be higher than 5 per ml. The same rule applies to sterilized milk. (Israeli Standard S.I. 641).
5. UHT milk must be labelled (in Hebrew) as "Halav Ameed" which means "Keepable milk" (long-life milk). The sell-by date has to be marked, but there are no minimum or maximum time limits with regard to this date.
6. In addition all other labelling requirements are applicable: quantity, fat content (at least 2.8% as for pasteurized milk), name of the manufacturing dairy.
7. The draft rules include also paragraphs for UHT chocolate milk, UHT coffee-flavoured milk and UHT low fat milk (1%). These products are not yet manufactured in Israel.

2.17 United Kingdom

The marketing of UHT milk in the UK is covered by specific legislation (The Milk Regulations 1977) defining compositional quality, heat treatment, testing and labelling (see excerpts below):

- The milk shall be treated by the ultra high temperature method, that is to say retained at a temperature of not less than 132.2°C for not less than 1 s.
- UHT milk shall satisfy the colony count test described in Part V of the Regulations (incubation for 24 h at 30 to 37°C, followed by transfer (loop) on melted yeastrel milk agar medium, followed by incubation for 48 h at 30 to 37°C; the test shall be deemed to be satisfied by a sample if the number of colonies is found to be less than 10).
- UHT milk shall be put aseptically into airtight sterile containers.
- If direct heating is used, the contents of milkfat and of solids not fat should be "the same after that treatment as before it".
- The cap closing the containers shall be conspicuously and legibly labelled or marked with the words "Ultra heat treated milk" or "UHT milk" and shall also bear the name and address of the packer.

In the United Kingdom there is currently no legal requirement to label with a sell-by date, although it is expected that such legislation will be forthcoming. However, at the moment it is universally adopted by all manufacturers of UHT milk; in other words open-date-coding, usually a 'use-by' date, is in use in the United Kingdom for UHT milk.

2.18 Italy

UHT milk is not covered by specific legislation, but is practically covered by statutory regulations on pasteurized milk and sterilized milk ("indefinite shelf life") (R.D. 9.5.1929 No 994; D.P.R. 11.8.1963, No 1504).

As against this, UHT milk is expressly mentioned in the ordinance on Bacteriological Requirements for some Foods (11.10.1978) and in the more recent regulation No 12, dated 18 February 1980, concerning the labelling of different types of milk. In these ordinances, the modality and the number of sampling (5 containers/batch) and the bacteriological characteristics are laid down as follows:

- After 14 days incubation of UHT milk, in the original package, at 32 ± 1°C (aerobic bacteria) and after 7 days at 55 ± 1°C (for thermophylic bacteria), no deterioration should be noticeable and UHT milk shall satisfy the colony count test (no more than 110 colonies/ml).

  The shelf life of the UHT milk can be extended to 4 months in containers hermetically sealed and impervious to light and gas.

Legal requirements for labelling

- "UHT milk" or "medium shelf life" milk or "long shelf life UHT" milk, with the indication "whole", "partially skimmed" or "skimmed".
- The name or trade name of the "firm responsible for the manufacture".
- Address of the firm.
- Legal address of the manufacturer.
- The weight or volume.
- Sell by date (see ordinance 18.2.1980 No 12).

The following information is not legally required on the label:

Information regarding method of heating (direct or indirect), time/temperature combinations and the modality of preservation of UHT milk, before and after opening of the container (Ex. "after opening, keep in cool place and use as soon as possible").

3. SUMMING UP

Summarizing the situation in the first semester of 1980 in the 17 countries mentioned above, it appears that:

a) No specific legislation on UHT milk exists in Netherlands, Belgium, USA, Spain, Australia, Norway, USSR Japan, Israel, Italy. In some of these countries, however, such legislation is likely to be introduced shortly.

   UHT milk is assimilated to pasteurized milk (in e.g. Belgium, Japan) or to sterilized milk (e.g. USSR, Spain). USA coined the name "ultra-pasteurized".

b) UHT milk is expressly mentioned and described in the legislation in Sweden, Switzerland, France, Finland, Denmark, Germany (F.R.), United Kingdom.

When comparing the situation in 1972 with the current one, it is obvious that there was in 1972 some confusion about the nature of UHT milk. Indeed, several countries (e.g. USSR, Australia, Belgium) declared at that time that specific provisions referred to UHT milk in their legislation. The 1980 questionnaire more clearly asked countries to state whether in the legislation, UHT milk was considered as a milk on its own.

In countries with distinct regulations for UHT milk, provisions generally require the product to be designated UHT milk ("UHT sterilized milk" in France).

Time/temperature combinations vary (132.2°C for not less than 1 s in UK, 135-150°C for a "short time" in Germany, 135°C for not less than 1 s in Denmark, 135°C for 2-3 s in Finland, 140°C for at least 1 s in France, 130 to 150°C for a few seconds in Switzerland) and so do requirements as to the keeping quality.

As a general conclusion, it could be stated that the situation regarding legislation specific for UHT milk has not changed drastically from 1972 to 1980. This may well be linked to the fact that in several countries, UHT milk has not taken as considerable a share of the market as originally expected or is still not manufactured at all. Another reason is probably also the difficulty of tracing a sharp line between UHT milk on one hand and pasteurized and sterilized milk on the other.

This being said, it is significant that several countries (Belgium, Spain, Australia, Israel) envisage to issue regulations on UHT milk in the near future. The situation described above may, therefore, change significantly in, say, the next 5 years.

CHAPTER 11

UHT TREATMENT AND ASEPTIC PACKAGING OF MILK–PROBLEMS SPECIFIC TO WARM COUNTRIES

by Mr C.H. Brissenden (U.K.) & Dr P. Rosenfeld (Israel)

It is important to avoid generalisation when referring to the dairy industry of warm countries. Conditions vary so widely that the only factor which all these countries have in common is that, at some time of the year and in some regions, they experience higher temperatures than countries in temperate zones.

For example, the dairy industries of Israel and Venezuela are, in some regions, as advanced as those of any European country whilst, at the other end of the scale there are many countries in Asia and Africa where the general standards of milk production, processing and distribution are still very primitive.

Wide climatic variations may occur not only within a country, which may generally be considered as "warm", but also in the same place within a country. There may be wide fluctuations between minimum and maximum temperatures between summer and winter, raising altogether different sets of problems. For instance in Colombia, the milk producing area around Bogota is at an altitude of 2500 m with an average temperature of 16°C and yet within a few hundred kilometres, on the Caribbean coast, there is also a substantial dairy industry operating under very much hotter and less hygienic conditions. Contrast these conditions with those of New Delhi (India) where the temperature can fall to freezing point in the winter and rise to 46°C in the summer when strong winds whip up the dry soil into great clouds of dust which, despite all precautions, penetrates dairy buildings bringing its load of bacterial contamination.

The uses to which milk is put and local consumer preferences must also be taken into account and, with these factors in mind, consideration must be given to the most appropriate processing and distribution methods. For example, in areas such as the Middle East, where traditionally the most popular milk products are often fermented or soured in the home, is it possible to reproduce, even approximately, the desirable characteristics of such products from milk which has been UHT processed?

Population density is another important factor; a milk processing and distribution system which was successful in a country such as Kenya, where towns are comparatively small and far apart, would not necessarily be applicable in large cities such as Cairo or Calcutta.

When the first edition of this monograph was produced in 1973 the total number of UHT aseptic packaging installations in warm countries was between 50 and 60. Six years later the total has risen to nearly 300, the most important growth areas having been the Middle East, South East Asia and Latin America. In some countries especially in the Middle East, the advent of UHT treated recombined milk has created new markets where no liquid milk supply was previously available. The establishment of local recombining and UHT treatment plants has caused a decline in the export of aseptically packed UHT milk from Europe and Australia to the tropics and this trend is expected to continue.

It is clear that aseptically packed UHT milk is playing an increasingly important role in dairy development in warm countries where the introduction of the product has in many instances led to a general increase in milk consumption.

Such developments have often been stimulated by the introduction of government sponsored school feeding programmes. In countries where new dairy herds have been established it has often been possible to set up processing dairies in the milk production area, taking advantage of the fact that proximity to the consumer is not essential when the milk is UHT treated and aseptically packed.

RAW MILK SUPPLIES

In some countries transport facilities are unreliable and the time taken for milk to arrive at the processing centre may vary to such an extent that spoilage may be well advanced when the milk arrives, making it unsuitable for any form of heat treatment. For UHT treatment in particular, raw milk of good hygienic quality is essential.

In most warm countries there is a marked seasonal fluctuation in the volume of the raw milk supply and, if a steady output is required for the liquid milk market, recombination or reconstitution facilities are an essential feature of the processing dairy. They may also be required to cater for the surges in demand for milk which, in many countries, occur at times of religious feasts or fasts.

It is also common practice, in countries where the natural milk supply has a high fat content, to standardize or "tone" it by the addition of reconstituted skim milk.

Experience has shown that the stability and palatability of toned and recombined milks, whether pasteurized or UHT treated, are closely related to the physico-chemical properties of the milk powder, and butteroil used.

Microbiological quality is also important and it is therefore desirable that standards should be established for the critical properties of these basic raw materials, as well as for the water, employed in recombination and toning. There is a need for more fundamental information on the effect of UHT processing on the milk of tropical breeds of cattle and indeed of milk from other animals such as buffalo and goats. Information about the heat stability of such milks and seasonal variations in their compositional quality which could influence suitability for processing is of particular importance.

In this connection, reference may also be made to the possible influence of the natural bacteriostatic substances present in raw milk and in particular to the reportedly higher proportion of lactenins in raw buffalo milk, which may have to be taken into account in deciding processing procedures.

In addition to the seasonal effects of climatic conditions, variations in the types and qualities of feed and fodder on the properties of raw milk may influence its suitability for UHT processing and determine what pre-treatment or ancillary processing may be necessary.

PROCESSING CONDITIONS

Although safe time/temperature combinations have been established for UHT processing in temperate countries, it may be advisable to re-examine the suitability of these conditions for milk produced in the tropics where the naturally occurring contaminant flora may be different. For instance, spore forming, heat resistant Clostridia are more common in raw milk produced in some tropical South American countries than in other parts of the world.

The presence of pathogenic organisms in the raw milk supply is likely to be more common in warm countries and, whatever processing system is adopted, higher temperatures than those used for pasteurization in temperate climates are probably desirable. For the same reason, reliable safeguards to prevent recontamination of processed milk with raw milk are essential.

It is becoming increasingly common, to recommend that all raw milk should be pasteurized or "thermized" (*) immediately on arrival at the dairy whereas previously it was considered sufficient to pre-cool and store it prior to final processing: this change in practice is intended principally to inactivate psychrotrophic organisms and the enzymes which they produce and, in warm countries, it may well be desirable to adopt it, especially if the raw milk has been kept refrigerated before delivery to the processing dairy. All milk which is to be UHT treated should be cleaned by centrifugal clarification and coarse filtration may be also necessary before clarification if the milk contains a lot of solid dirt.

It may be necessary to modify homogenising temperatures and pressures to take account of the different fat globule size from tropical breeds of cow or buffalo.

The process plant may have to take into account some variation in heating and holding time in order to allow for local flavour preference. The temperature to which the UHT milk is ultimately cooled before packaging will depend on local ambient temperature conditions but should be sufficiently low to avoid affecting the packaging materials used.

It is essential that instrumentation and control on the processing plant should be as simple as possible, to ensure a reasonable compromise between moderate capital cost and trouble-free operation. Operating conditions which need special attention in warm countries are:

(i) Suitability of water for plant cleaning
(ii) Quality of water for steam raising where direct steam injection is used for UHT processing.
(iii) Reliability of electricity supply.
(iv) Bird, rodent and insect control.
(v) Effluent disposal.
(vi) Availability of skilled operators and maintenance engineers.
(vii) Availability of vital spare parts.

* *Thermization is a system of heat treatment. It is carried out under continuous flow conditions and consists of heating to 63-65 °C, holding for 15-20 sec and then cooling, with the result that psychrotrophic bacteria are almost completely destroyed, while for the greater part the milk enzymes are unaffected. Although thermization has a negligible influence on milk properties compared to pasteurization, in some countries thermization combined with pasteurization is considered to be a double heat treatment and is prohibited. (Note from the General Secretariat).*

(viii) Adequate supplies of butteroil and skim milk powder of the correct qualities.
(ix) Adequate supplies of packaging materials.
(x) Adequate supplies of detergents and sterilants including hydrogen peroxide for the aseptic packaging process.

PACKAGING

Many of the points in Chapter 7 (Aseptic Packaging) are relevant to the requirements of warm countries but the following paragraphs underline some of the special problems.

The Aseptic Tetra Pak and Tetra Brik are still the most widely used packages for the retail distribution of UHT milk but other systems have been introduced in some countries, notably the American Pure-Pak and the German PKL both of which use paper/aluminium foil/plastic laminates as the basic container material. The promise of reliable aseptically filled cheap plastic film pouches has yet to be fulfilled although there have been reports of isolated successes.

Aseptic canning and bag-in-box systems have not played a significant role in the development of the UHT milk market. Polystyrene pots made by the vacuum forming process followed by aseptic filling and closure with a heat-sealed diaphragm lid have been used for milk and dairy products to a limited extent but not, so far as is known, in warm countries.

Until quite recently the materials required for aseptic packaging have been available only from the developed industrialised countries but it is possible that laminates suitable for relatively short shelf life UHT products will soon be produced in India.

While paper appears at present to be the basic material for aseptic packages its widespread introduction could in some cases, impose a severe strain on limited forest wealth. Such use of paper therefore in some developing countries might have a lower order of priority on limited forest resources than, say, education. There is therefore an urgent need for research into alternative packaging materials for UHT milk.

In countries like India, where milk is boiled at home, it may be feasible to market UHT milk in bulk. For this to be practical and economic it would be necessary to develop a system by which UHT milk could be stored for about 24 h without expensive refrigeration equipment in suitable bulk containers under aseptic conditions for retail sale. If such a system could be evolved, it would certainly result in considerable savings in transportation and allied marketing costs and make available wholesome fluid milk to poorer sections of the population. It may therefore be desirable to investigate in depth the technical feasibility of such an approach. Proper control over retail distribution, especially in the rotation of stocks, is most important and may present a serious problem where the individuals responsible for retailing are no part of the company or organisation responsible for processing and packaging. A most important point to remember is that, even though aseptically packed UHT milk does not suffer microbial spoilage, it undergoes chemical changes which are accelerated as the storage temperature is increased so that, even if refrigeration is not available at the distribution points, the milk should be kept as cool as possible.

ECONOMICS

A processing and packaging system has yet to be developed which enables the dairyman, even in Europe, to offer aseptically packed UHT milk at the same price as pasteurized and it is therefore debateable whether in many warm countries UHT milk will be within the purchasing power of more than a privilieged few.

It would perhaps be of considerable importance to determine the comparative costs of aseptically packed UHT milk produced and processed in a primary rural centre and marketed directly in an urban area as against the production and pre-processing in a primary rural centre, its transportation in a chilled condition and re-processing in a city dairy for sale in traditional milk bottles through a specialised net-work of distribution centres. It is conceivable that such a comparison might reveal the superiority of the UHT process and sterile packaging system, in economic terms; it might also serve to show other ancillary benefits.

Depending upon the outcome of such a study, it may be necessary to undertake a study of the problem involved in long distance transportation, handling, etc. of UHT milk packages.

There is a need for careful comparison between the economics of aseptically packed UHT milk and the processing and manufacture of other types of milk and milk products if advice is to be available on the best methods of utilisation and means of making milk available to the greatest number of people in warm countries.

NUTRITIONAL ASPECTS

Provided that it is technically and economically viable, there is no doubt that aseptically packed UHT milk can be an excellent source of nutrition in warm countries, as will be evident from the facts presented in Chapter 4 on "the nutritive value of UHT milk".

CHAPTER 12 *

HISTORY OF THE DEVELOPMENT OF UHT PROCESSES

Prof. Dr H. Hostettler (Switzerland)

1. EARLY INVESTIGATIONS

The production of sterile milk of long keeping quality by means of a continuous flow process at a high temperature for a short time followed by aseptic packaging has been extensively studied during the last twenty years, and for the last fifteen years has become increasingly accepted as a suitable method of treatment for milk for consumption.

However, the concept is not new and the problem has been investigated for more than 100 years. The failures and phases of stagnation experienced by the earlier workers were mainly due to the dairy engineering problems encountered, but advances in this field since 1930 stimulated further research which has culminated in the present successful processes. The works of Stohmann (1), Winkler (3), Schulz (4) give an extensive summary of the early history. Whilst studying these one is surprised to find that apparently modern ideas can have been held for such a long time.

There is no doubt that the development of the sterilization of milk in closed containers at high temperatures and by continuous flow heating processes, leading to the modern UHT processes, took place side by side. The basic study of the sterilization of milk is due to Pasteur (5), who stated for the first time that the boiling of milk for several minutes was not sufficient to prevent spoilage of the milk by bacterial growth on subsequent storage at 30°C.

Only by heating to 110-112°C under a pressure of 1.5 atmospheres was further development of micro-organisms suppressed. In the following decades sterilization apparatus of various designs was developed, allowing heating to still higher temperatures. As early as 1893 a continuous flow-heating apparatus with hourly ouputs of 1000 - 5000 ℓ was constructed, allowing the milk to be heated to 125°C with holding time at this temperature of 6 min. After 1894 numerous patents (2) for sterilizing equipment were registered, especially from Berlin and Luebeck, in which sterilization in bottles, as well as continuous flow-heating, were described. In order to avoid the burning-on of milk in the indirect continuous flow heaters attention was also paid to the bactericidal effects of direct steam injection by which temperatures of over 100°C were obtained.

O. Lobeck, in the period 1909 to 1914, registered a number of patents (2) concerned with the method of spraying the milk with a jet of hot gas, air or steam. Under increased pressure the milk was treated by a jet of steam spraying vertically on to it or by means of a pressure nozzle. However, the process found no industrial use and the various patents became extinct because of non-payment of fees. Apart from direct heating with steam, attempts were made to improve the continuous flow heaters using indirect heating.

J. Nielsen, in 1909, constructed a tube for continuous flow heating and Toedt, in 1912, obtained a patent for a heater enabling temperatures of 130-140°C to be obtained. Whilst developing this process the objective was to render milk sterile by heating it suddenly but only for a short time to high temperatures to prevent alteration in the chemical characteristics of the milk.

The unsolved difficulty of filling the milk without recontamination into containers suitable for transport caused interest in the continuous flow heaters to wane, so that sterilization of the milk in closed containers (bottles and cans) in autoclaves retained its importance.

From 1932 automated "in-bottle" sterilization of milk pre-heated by a continuous process came into use, and sterilized milk became popular with consumers with a considerable expansion in its sales.

2. DIRECT UHT HEATING

In the USA George Grindrod, in 1927, again took up the idea of direct heating by steam injection and developed the Grindrod Impact Sterilizer (USP, 1,819,23/1927, USP, 1,798,120/1928). It was extensively described by G.J. & Alice M. Hucker (6). The process consisted of heating the milk to a temperature of 110°C by injection into it of steam at 2 atmospheres pressure through a nozzle. Subsequently the milk entered an expansion chamber which allowed the removal of the condensed steam. It was established that a holding time of 1-2 min was sufficient to destroy the non-thermophilic micro-organisms, but that destruction of thermophilic spore-forming bacteria required a somewhat higher temperature or a correspondingly longer holding time. The process was recommended for sterilization of milk which was to be further processed for condensed milk or milk powder, as well as for liquid milk for consumption in tropical and sub-tropical regions.

* *This chapter is reproduced from the original 1972 monograph.*

Later the steam injection process received many modifications and improvements in the USA, protected by patents (7 - 17).

These processes were adopted by the milk industry under trade names such as Rotojet, Torpedo, Vacreator, Califactor, and were used especially for UHT sterilization of unsweetened milk concentrates (18). According to information given by Brown et al. (19), temperatures approaching 150°C (300°F) were used with holding periods as low as 0.5 s. These UHT treatments produced almost sterile products, but with milk concentrates the undesirable secondary effects of "age thickening" and "gelation" were experienced. Deysher, Webb & Holm (20) as well as Ball, Curran & Evans (21) reported this for the first time in 1944.

Based on these experiences of the milk industry in the USA, the Swiss firms Alpura Ltd., Berne, and Sulzer Bros. Ltd., Winterthur, in collaboration with Bernese Alps Milk Ltd., Konolfingen, developed the Uperisation®- process (22) based on the injection of steam into milk. The perfected process involved the following innovations: fully automatic regulation and recording to ensure maintenance of specific gravity and thus the total solids content of the original milk, fully automatic regulation and recording of Uperisation temperature, the development of standards for the equipment, the installation of safety devices, engineering improvements of specific parts of the plant. The process uses a heat treatment of 150°C with a holding time of 2.4 s. The Uperisation process has been extensively documented. The aseptic filling into cans was carried out with the Martin-Aseptic Canning plant of the James Dole Engineering Co., San Francisco, California, USA. In this manner the marketing of Uperized milk in cans became possible in Switzerland in 1953. The steam injection processes VTIS of Alfa-Laval (1961) and the Cherry-Burrel process (1962) developed later are referred to in Chapter 6 of this monograph.

Uperisation depends on dry saturated steam being injected into the milk, but in the Laguilharre-process, developed at the same time, the UHT heating is carried out by spraying milk into an atmosphere of steam. The process was described in the French Patent No 1,075,502 and No 1,125,190 (Ciboit, 23) and by Hermier & Mocquot (24) and Peylet (25). The Laguilharre process was employed in the milk industry, partly under a different description, e.g. "Palarisator" (Paasch & Silkeborg), "Thermovac" (Breil & Martel).

3. INDIRECT UHT HEATING

Following the work of 80 years earlier, the continuous flow heating to high temperatures, based on indirect heat exchange, has received much attention in modern times. New heaters were developed which were used for various purposes in the milk industry and which were soon accepted for the production of sterile milk. As preheaters for the manufacture of milk concentrates in the USA the Mallory heater and the BDI-tubular heater were extensively used (Hunziker, 26). The Mallory heater enables heating to 140-149°C for 1.5 - 3 s, the BDI to 149°C for 0.87 s at an output of about 500 ℓ/h.

A number of continuous flow heaters of new construction were described by Schulz (4) (See also Chapter 6).

4. ASEPTIC FILLING

The technique of manufacturing sterile milk in the continuous flow heating process only reached its full importance when it became possible to achieve filling into sales packs while excluding all contamination. The present stage of aseptic filling is dealt with in Chapter 7, "Aseptic Packaging". Historically the first aseptic filling process on an industrial scale was the Martin Aseptic Canning System of the James Dole Engineering Co., San Francisco, California, USA, developed by W. Mc King Martin, Redwood City, Calif. (27). Its mode of operation consists in the sterilization of the cans and lids with superheated steam (250°C) whilst the filling of the sterilized and cooled milk also occurs under such a steam atmosphere. By the use of superheated steam, working under pressure can be avoided. After passing a sterilizing jet the lid is placed on the can and while at this temperature it is seamed. The process proved to be unsuitable for bottles because the glass cannot stand the momentary heating to such high temperatures.

In 1951, J. Meyer (28) described a process for manufacturing UHT milk and aseptically filling it into cans by the Martin Canning process. The milk has very little cooked flavour. Bloomberg & Hessey (29) also produced UHT sterilized milk which was prepared by heating to 140.5°C for 8 s in a tubular continuous flow heater, cooled and aseptically filled into cans. A keeping quality of 4-6 months without refrigeration was claimed for the milk. As stated earlier Uperised milk, aseptically filled into cans by the Martin Canning system, was marketed in Switzerland in 1953. In more recent times several milk packs have been developed suitable for aseptic packaging of UHT milk. That developed and marketed by Tetra Pak, Lund, Sweden, similar in form to a tetrahedron, turned out to be particularly suitable. As the result of collaboration between Alpura Ltd., Berne and AB Tetra Pak, Lund, it was possible to devise a satisfactory aseptic process for filling UHT milk into this container. This has been in use on a commercial scale since the 1st May, 1961 (30, 31). Further developments have occurred since that date, and aseptic filling of UHT milk into other packages is dealt with under "Aseptic Packaging" Chapter 7 of this monograph.

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APPENDIX

THE MARKET FOR UHT MILK IN THE FED. REP. OF GERMANY FROM THE POINT OF VUE OF MARKETING POLICY AND COSTS

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The sale of milk, heated to an ultra-high temperature (UHT milk) (1) has in recent years increased considerably in some countries, the Federal Republic of Germany amongst them, while the sale of pasteurized milk has decreased. With no other milk product have there been such drastic changes in consumption. It must be of great interest to discover the reasons for this development because one can then deduce whether this trend is likely to continue and how it can be influenced by marketing policy. The purpose of this study was to carry out such an analysis which should help the industry to come to the right decisions.

The amount of UHT milk sold varies from country to country even within Europe. In some countries almost 50% of the total milk consumed is UHT milk, while in others the consumption of UHT milk is only a few per cent above zero. This fact alone shows that the factors affecting the sale of UHT milk must exert their influence to very differing degrees in the various countries. An analysis of the factors responsible for UHT milk consumption in one country – in this case the Federal Republic of Germany – can provide explanations for the differences in the amounts of milk of this type consumed in other countries, provided it is known to what extent these factors operate in other countries. Thus this analysis, which is confined to the Federal Republic of Germany, can provide information on the development of the UHT milk market in other countries.

1. THE SITUATION WITH REGARD TO CONSUMPTION

UHT milk was produced in Germany for the first time in 1963 when it was offered for sale on a limited scale. Under a set of special licences permitting trial marketing, 10 dairies produced in 1967 about 24,000 t of UHT milk which corresponded to about 0.9% of the total liquid milk for consumption (2). In 1968 the sale of UHT milk was generally permitted by law. The number of producers rose within one year to 21 and the volume of production reached 67,000 t in 1969. The expansion of the UHT milk market had started. The consumption of UHT milk continued to rise at the expense of that of pasteurized milk: thus the sale of UHT milk increased by 1.39 million t annually (in 1979), while the sale of pasteurized milk decreased by 0.88 million t to 2.0 million t (1968 → 1979). When the consumption by the milk producer himself and the direct sale from the farm is included in this comparison then the reduction in the consumption of pasteurized milk becomes even greater than the increase in the consumption of UHT milk. There was therefore a slight reduction in the total consumption of milk (see Fig. 1). The per capita consumption decreased continually from about 85 kg per annum in 1968 to about 70 kg per annum in 1978/79. Only in the last two years (1978 and 1979) has there been a slight increase in consumption again. The rate at which pasteurized milk is being replaced by UHT milk in a year has also decreased considerably. Since 1978 the sale of UHT milk has risen only very slowly and the consumption of pasteurized milk has fallen very little. In 1979 the ratio of the sale of pasteurized milk by the dairies to that of UHT milk was around 58 : 42.

The fact that an increase in the consumption of UHT milk has coincided with a decrease in the total consumption of milk does not mean that there is a causal connection between the two observations. It is equally possible, for instance, that the availability of UHT milk has prevented an even greater reduction in the consumption of milk.

Neither does a comparison of regional cross-sections point to a connection between the consumption of pasteurized milk and the total consumption of pasteurized and UHT milk (see Fig. 2). In some regions a decrease in the consumption of pasteurized milk over a period of time was paralleled by a decrease in the total consumption of milk by the households, while in other regions there was an increase in the total consumption of milk over the same period of time. The information available here is therefore not sufficient to reach a conclusion regarding the influence of the increase in UHT milk consumption on the trend in total milk consumption.

What seems certain is, that the expansion of UHT milk consumption has taken place largely at the expense of the consumption of pasteurized milk. One type of milk has almost certainly been replaced by another. The following analysis is solely concerned with the reasons for this substitution and with its consequences.

Another trend in the pattern of consumption of milk should be pointed out here. It is the large increase in the consumption of low fat milk at the expense of whole milk. Until 1970 almost all milk sold for consumption was whole milk, but since then partially skimmed (1.5 - 1.8% fat) and fully skimmed milk have gained a considerable share of the market (Table 1).

That the low fat milk consumed in increasing quantities was mostly in the form of UHT milk was not due to the fact that UHT milk was offered for the first time as a special product, although this took place at about the same time. It reflects rather a general trend towards the consumption of low fat milk which can also be observed in other countries, such as Denmark, in which UHT milk has no significant share of the market. The sale of low fat liquid milk for consumption in the Federal Republic of Germany was only possible after a change in the regulation governing the types of liquid milk for consumption and these regulations applied to pasteurized as well as to UHT milk. The reasons why low fat milk was consumed in increasing quantities in the form of UHT milk and not of pasteurized milk should also be investigated.

2. THE REASONS FOR THE CHANGES IN CONSUMPTION OF UHT MILK AND PASTEURIZED MILK

2.1 Flavour, convenience and other image properties of UHT milk compared to pasteurized milk.

The measurement of the attitude of the consumer – in this case with respect to the products UHT and pasteurized milk – presents a considerable methodological problem because the consumer is not always able or willing to disclose his attitude. A number of psychological tests have therefore been developed. Not all have the same validity and reliability (3). Generally the least satisfactory method is the simplest one, namely, to ask the consumer directly for his opinion and to provide him with the criteria by which to judge the product. Statements reflecting the real opinion of the consumer can only be expected if the consumer is familiar with the criteria as they relate to the product and, furthermore, if the criteria are not such that the questioned person feels embarrassed if he gives an honest opinion.

Figs 3a and 3b give two ratings which are the result of such a direct questioning (data by Kess). In the first place it is noteworthy that the assessment by the regular buyers of pasteurized milk (Fig. 3a) and the regular users of UHT milk (Fig. 3b) are not qualitatively but only quantitatively different. This result is interesting particularly with respect to flavour. On average, even the "only UHT milk users" rate the flavour of pasteurized milk as better than that of UHT milk (4).

This finding cannot be taken as conclusive proof that the "habituation" hypothesis is invalid. According to this hypothesis, the consumer gets used to the taste of UHT milk if he has drunk it for long enough and then likes it equally well or even prefers it to that of pasteurized milk. But a sizeable group of UHT milk users rate the taste of UHT milk as equal to or even better than that of pasteurized milk. These results show, however, that caution is necessary when applying this hypothesis more generally.

Figs 3a and 3b show that UHT milk and pasteurized milk are rated differently with respect to the following properties:

In favour of pasteurized milk:
1. good flavour
2. health-giving, nutritious, rich in vitamins and proteins
3. fresh

In favour of UHT milk:
1. long storage life, suitable for storing
2. low in fat, low in calories
3. cheaper than pasteurized milk.

The dominant advantage of pasteurized milk is its better flavour. From this the customer concludes that pasteurized milk is better for health and has better nutritional properties, although no significant differences can be found objectively (5).

These advantages of pasteurized milk are acknowledged also by UHT milk users, but their arguments in favour of UHT milk are that it keeps longer than pasteurized milk and can therefore be stored. The question now arises whether this consideration is the real reason for the increase in UHT milk consumption at the expense of that of pasteurized milk, or whether it is an argument with which the questioned consumer readily agrees because it is of a general nature, i.e. the question is whether the weight given to this argument might not be due to the method of questioning. It is striking that the one advantage which the longer storage life of UHT milk has for the housewife, namely, that she can buy her milk less often and can buy larger quantities for storage, is hardly made use of.

According to Kess, only about a quarter of the regular buyers of UHT milk make use in their shopping habits of the long storage life of this milk and generally buy a 12-litre pack at one purchase.

The amount of UHT milk in storage in almost half of the households that used UHT milk at all was only one litre and in a further 34% of households only 2 or 3 litres. In half of the households questioned the UHT milk purchased was used within one week and in a further 29% within two weeks. The shopping habits of households with respect to UHT milk are therefore not significantly different from those with regard to pasteurized milk, although UHT milk has a guaranteed storage life of 6 weeks. The argument that UHT milk keeps longer is therefore no convincing reason – at least for a market share of more than 25% – for the growing preference of consumers for UHT milk in spite of its flavour disadvantages.

A further argument in favour of UHT milk is that it is low in fat and in calories. This argument seems equally insufficient to account for the shift in consumption from pasteurized to UHT milk. It should, first of all, be pointed out that a considerable portion of UHT milk, namely about 40%, is sold as whole milk (table 1), and that the only grade of UHT milk sold in the largest discount store until 1978 was a 3.5% fat milk.

Furthermore, partially skimmed milk which constitutes the largest proportion of UHT milk on the market is also offered in the form of pasteurized milk. However, there are fewer retail trade outlets for partially skimmed pasteurized milk than for UHT milk (table 2). This means that a large number of shops do not stock low fat pasteurized milk. The fact that low fat milk is available in the retail trade only in the form of UHT milk could explain why consumers buy UHT milk. But the question why partially skimmed pasteurized milk is not being distributed as widely by the retail trade as partially separated UHT milk has still to be answered. There is no convincing evidence that the partial explanation that partially separated UHT milk is preferred because the unpleasant taste of low fat milk is overshadowed by the flavour imparted by the ultra-high heat treatment, is correct.

The arguments of longer storage life and low fat content of UHT milk do therefore seem not to be a sufficient explanation for the change in consumer preference. It remains therefore to look at the price as the last reason. According to Kess, consumers did not consider the lower price of UHT milk compared to pasteurized milk as important.

But the argument of price is not suitable for inclusion in a questionnaire because it is known that a customer, when asked directly, will avoid naming the price as determining his choice and will rather put forward all sorts of other reasons which accord better with his desired social standing. This result therefore provides no information on the real influence of price on the relative amounts of UHT milk and pasteurized milk consumed. Other methods of enquiry have given results which, although they do not constitute definite proof, nevertheless suggest that the lower price of UHT milk of all fat grades is the reason for the shift in consumption.

2.2 The relation between the price of pasteurized milk and UHT milk

The pro- and contra-arguments set out in section 2.1 do not give an incontrovertible explanation for the shift in consumption from pasteurized milk to UHT milk, at least not as far as a market share of more than about 25 - 30% is concerned. The reason for this shift is therefore thought to be the price of UHT milk which is on average lower than that of pasteurized milk. This supposition is supported by the observation that the increase in UHT milk consumption was greatest in the case of partially separated milk where the difference in price between UHT and pasteurized milk was greatest (table 3). A further fact supporting the argument of price is that UHT milk is bought mainly and to a much larger extent than pasteurized milk in discount stores and supermarkets, i.e. in stores to which the customer goes mainly for the cut-price offers (Fig. 4). It is, furthermore, noteworthy that in the Scandinavian countries in which the price of UHT milk is higher than that of pasteurized milk the consumption of UHT milk has remained at a very low level.

The difference in price between UHT and pasteurized milk has steadily increased over the last 10 years (table 3). In 1968/69, when UHT milk was first marketed, it was more expensive than pasteurized milk, but already in 1973, UHT milk, especially the 1.5% fat grade, was markedly cheaper than pasteurized milk in cartons. In the following years the price of pasteurized milk increased steadily in line with the annual increase in the producer prices of the EEC. The price of UHT milk, on the other hand, hardly changed so that the price difference between pasteurized and UHT milk became increasingly larger. At the time of the price increase in 1979, the arithmetic average price of pasteurized milk of 3.5% fat in the cheapest form of packaging (tubular film bag) was exactly the same as that of UHT whole milk. Because the volume of UHT milk sold in discount stores and supermarkets is higher than average (Fig. 4) and because these stores sell UHT milk at specially low prices (table 4), the average price based on volume of UHT milk sold would be even lower than the arithmetic average and the difference in price between UHT and pasteurized milk would become considerably greater than that which can be calculated from table 3 which gives the arithmetic average prices.

What are the reasons for this trend in prices and, in particular, why is UHT milk sold more cheaply than pasteurized milk? The analysis of the possible reasons – costs in section 3 and the situation with regard to competition in section 4 – will show that if costs were the only factor pasteurized milk would be cheaper than UHT milk. The reason why the prices are as they are is that the competitive conditions in the pasteurized milk and UHT milk market are different.

3. COSTS AS ONE REASON FOR CONSUMER PRICES

This part deals with the costs of producing UHT milk.

The investigation presented here makes it possible to carry out a costing for UHT milk in the local currency because the indicated expenditure can be valued by applying the local input price. The input prices for the German Federal Republic used in this study are those of 1 January 1980. The costs were found by means of model calculations, the data for which were gathered in extensive analyses in the field (6). The basis of the calculation is a special form of component cost calculation. The products are costed by adding the cost of a single product, which is proportional to the quantity made, the fixed annual, daily and, if appropriate, batch costs of the department. As far as energy is concerned only the part proportional to quantity is taken into account. In this model calculation, the individual costs of the section supplying energy and the costs of other cost-incurring departments which are used are, however, not added to the costs of the department or of the product respectively.

3.1 Costs in the dairy

3.1.1 Contents and demarcation of the UHT department (7).

The following calculations are based on a UHT plant of the type "Sterideal" produced by the firm Stork, Amsterdam. The system "Tetrabrik" was used for the cost analysis. This system had a market share of 89.4% in the German Federal Republic in 1977 (8). Only the 1 litre pack has been examined here because in 1977 its market share was 84.7%. The choice of the UHT processing method Sterideal and the aseptic packaging system Tetrabrik does not imply that these systems are considered to be more economic means of processing and packing than other ones.

It should also be pointed out that in this study the losses of milk caused by leakages, etc. were not taken into account. To make model making easier the whole production process was divided into 3 sub-sections:

1. UHT heat treatment
2. Aseptic packing
3. UHT milk storage and dispatch

A complete calculation was performed for each of the 3 sub-sections. The analysis starts with the passage of the milk from the milk storage tank into the sub-section "UHT heat treatment". In every fully automatically controlled UHT plant a sterile buffer tank is placed after the heat treatment section. In this the UHT treated milk is held until it is packed aseptically. The capacity of the UHT plant is determined by the number of aseptic filling machines connected to the heat treatment part. An automated cleaning system is used for cleaning the UHT plant and the sterile tank.

The sub-section "aseptic packaging" consists mainly of the filling machines. Outer wrapping is done manually in half cartons each containing 12 packages which are then stacked on Europalettes of 720 units.

It was assumed that the palettes would be used 3 times. The fillers were cleaned mostly by means of the cleaning circuit of the UHT plant. The UHT milk warehouse was equipped with roller shelves and was large enough to accommodate the production of 7 days. This large storage capacity is necessary because the milk has to be kept for 5 days for reasons of safety and because a reserve capacity is required to ensure uniformity of production in case of short term fluctuations in demand.

In addition, UHT milk storage facilities with capacities suitable for varying amounts of product were studied, namely those which had been designed to store the production of a maximum of 1.5 and 3 working shifts.

Extensive investigations of the relation between storage capacity and amount of UHT milk produced were not carried out as they were beyond the scope of this study.

The calculation ends with the dispatch of the milk which includes the loading of the filled UHT milk palettes (720 E/palette) to the vehicles used for distribution.

3.1.2 Model specific parameters

For the cost analysis 3 models, each with a different hourly output of its units were produced. Extensive investigations were carried out in a number of dairies in order to determine the hourly wage rate, the energy consumption, the losses in packaging material, the space requirements, etc. The purchase costs of packaging material, of the UHT plant and the packaging plant were based on the list prices of the manufacturers. Any special agreements which the manufacturers might have made with individual dairies were not considered. Firms who seek guidance from the calculations presented here (e.g. for investment decisions) should therefore insert into their calculations the prices which have actually been quoted to them by their suppliers (e.g. individual manufacturer's prices for packaging material).

Details of the capacities of plant and equipment are given in the list of parameters in table 6. This table lists the buildings and machinery and their capital costs in January 1980 as well as the period of usefulness and the repair quota. The capital costs of the buildings of the sub-section "UHT heat treatment" and "aseptic packaging" are based on the building costs of a reinforced concrete building, while for the "UHT milk storage" the costs of a structure covered with concrete slabs were used in the calculation.

An exact quantification and differentiation of the maintenance and repair costs respectively is very difficult because these costs cannot be separated from the calculated depreciation. The costs calculated for these items are based on experience at this Institute and on estimates. The difference between maintenance and repair costs is that the fixed annual costs are taken as maintenance costs and those which are accounted for as proportional to the quantity of product are called repair costs. This division of costs is only performed for plant and equipment but not for buildings. The calculated interest rate is 8% of half of the investment costs of plant and equipment.

As mentioned before, the individual models were based on the assumption that the capacities of the UHT milk storage facilities were adapted to varying volumes of production. The facilities differ in the following pieces of equipment: roller shelves, palettes and buildings. If the UHT milk store is designed to take the production of 7 days when the daily working time varies from more than 1.5 to 3 shifts, then the capital cost of model 1 is increased by 355,415 DM, that of model 2 by 702,121 DM and that of model 3 by 1,037,228 DM.

Table 7 shows the factor prices and the amounts used in the UHT milk section, arranged according to type of costs and cost dependence. The consumption proportional to quantity refers to 1000 units of production, which here means "1 litre packs". For instance, the number 1022 in the line "carton, aluminium foil laminated" means that 1022 packs are necessary to produce 1000 1-litre packs. This corresponds to a quantity-dependent loss of about 2.2%. A fixed daily loss of 140 blanks is allowed for in the starting and stopping of each packaging plant.

As regards the cost of personnel, the following is to be noted:

It has been assumed for the purpose of calculation that the personnel in the individual sub-sections is employed in production, the preparatory and final work and the intermediate cleaning of the UHT plant. If there are no full shifts in the UHT section the labour is used in other sections.

An exception is the Head of the section. His personnel cost is regarded as a fixed annual amount. For simplicity sake these costs are put entirely to the account of sub-section "aseptic packaging". However, the Head of the section is responsible for the operation of the entire UHT milk department.

In the sub-section "UHT heating" each of the 3 models contain one machine supervisor. In model 3, with its 2 UHT plants, he has, in addition, the assistance of a skilled worker. The UHT plant is assumed to have an operating time of 7 hours, so that one intermediate cleaning is required for a 2 shift operation, and 2 cleanings for a 3 shift one. The intermediate cleaning is carried out within a period of 20 min using the high temperature short time process.

In the sub-section "aseptic packaging" each plant has one machine supervisor, one packer and one person responsible for the palettes. The volume or weight control required by law are also the responsibility of the machine supervisor. The regular maintenance of the aseptic packaging plant is carried out on Saturdays when there is no production and, apart from the plant personnel, the machine supervisor also takes part for 5 h. This working time is distributed over the fixed daily working time of the machine supervisor so that the fixed daily working time of the sub-section "aseptic packaging" is one hour more than of the sub-section "UHT heating". The costs of the plant personnel are allocated to the maintenance costs. The packers and palletizers are assumed to have a break of 30 min in each shift. But as production is not interrupted, costs for additional personnel have to be allocated. An exception is model 1 in which the driver of the fork lift truck of the UHT milk store is available for the necessary relief work.

In the sub-section "UHT milk storage and dispatch" all 3 models employ one fork-lift-truck driver continuously during production, although the daily working time is different in each model. The dispatch clerk is however only accounted for in relation to the time that he is occupied. For each UHT plant and each aseptic packaging plant one machine supervisor whose job is the careful operation and strict supervision of the plants, has been allowed for.

3.1.3 Variations in production

The capacity of the UHT milk section is determined by the output of the aseptic packaging plant as this has a lower actual hourly output than the UHT plant. A 3 shift production on 252 days per year is taken as a 100 per cent utilization of the capacity of the plant. The 3 shift operation is defined as follows:

A total of 24 h of work per day minus 2.5 h of work for preparation and at shut-down makes a net production time of 21.5 h per day.

This comes to 5,418 production hours in a year. Therefore the maximum annual amounts of UHT milk in 1 litre packs that can be produced in the 3 models are as follows:

model 1	17,879,400
model 2	35,758,800
model 3	53,638,200

Table 8 shows the effect of different degrees of utilization of capacity on the costs per unit of UHT milk in 1 litre packs for models 1, 2 and 3. 11 variations, differing in the degree to which capacity was utilized and the number of days of production in a year (252/180/126) were selected for each of the 3 models. The degree of utilization of capacity can be defined in various ways: thus a 44.2% utilization is obtained by a production on 252 days for 9.5 hours per day, or a 180 days' production for 13.3 hours or a 126 days' production for 19 hours per day. Where the variations involved intermediate cleaning the costs for this were allocated to the sub-section "UHT heating" and were regarded as batch fixed costs.

3.1.4 Discussion of the results

The results obtained by means of the model calculations are presented in the tables and are, in addition, illustrated by means of graphs. The starting point for the discussion is table 8 which summarises the effect of differing degrees of utilization of capacity on the unit costs of UHT milk in 1 litre packs. The degree of utilization varies between the upper and lower limits of utilization, namely, 21.5 hours of production per day (100% utilization) and 3.5 hours of production per day (16.3% utilization). For these extreme degrees of utilization the unit costs in the UHT milk section are: for model 1, 22.97 and 35.72 Pf/1-litre pack, for model 2, 21.90 and 31.41 Pf/1-litre pack, and for model 3, 21.91 and 30.77 Pf/1-litre pack. There is only very little difference from the costs in model 2. It is clear that the unit costs in all 3 models are lower when the plant is fully utilized than when it is incompletely utilized. The differences between full and incomplete utilization are: 12.75 / 9.51 / 8.86 Pf/1-litre pack. In addition, variations in the number of days of production in the 3 models lead to differences in unit costs of up to 0.59 / 0.49 / 0.50 Pf/1-litre pack.

Table 9 shows the composition of the unit costs of the UHT milk section arranged according to type/group of costs and cost dependence when the 3 models were operated at 100% utilization (3 shift operation), 62.8% utilization (2 shift operation) and 25.6% utilization (1 shift operation) on 252 days. The difference in cost between model 1 and 2 is 1.07 Pf per pack for a 3 shift operation, but this is increased to 1.47 Pf per pack for a 2 shift operation and rises to 3.27 Pf per pack for a 1 shift operation. There is no significant difference in costs between model 2 and 3 in the 3 variations. The table shows clearly that the same trend, namely, a great reduction in costs on going from model 1 to 2 and almost the same costs in models 2 and 3, exists for all degrees of utilization of capacity. One of the main reasons for this is that a change from model 1 to 2 involves an increase in the size of the section and a larger section operates more productive machinery and makes considerably more effective use of personnel (see also table 6). In changing from model 2 to model 3 these advantages are partially lost again.

The largest part of the costs in all 3 variations is that of the packaging material. This accounts for 70 - 73% of the total costs in a 3 shift operation, for 66 - 69% in a 2 shift one and for 56 - 60% in a 1 shift one, when production fees are included. The difference in costs of packaging material in models 1 and 2 in a one shift operation (packaging 0.50 Pf/unit, over-wrapping 0.16 Pf/unit) arises from the fact that the price of packaging material varies with the quantity ordered. The differences in fees and dues are also due to a quantity related graduation of production fees to be paid to the firm Tetra Pak. Next to the costs of the packaging material the costs of personnel and plant (depreciation, interest charges, maintenance) have an influence on the costs of UHT milk, which is not to be underestimated. Energy costs, accounting for about 6% of the total costs in all variations are a relatively small fraction of the total costs.

Table 10 shows the composition of the unit costs of the UHT milk section, arranged according to type of costs, group of costs and sub-sections, for production conditions which are the same as in table 9. The sub-section "aseptic packaging" accounts for by far the largest fraction of the total unit costs, namely, for about 77 - 86% (depending on the degree of utilization). This is due chiefly to the costs of packaging material and of personnel. The sub-sections "UHT heating" and "UHT storage and dispatch" contribute relatively little to the costs.

Fig. 5 shows the effect of varying the number of days of production (252, 180, 126) while keeping the volume of production constant. The data for this Figure are taken from table 8. The differences in the unit costs which arise from such a variation are a maximum of 0.96 Pf/1-litre pack of UHT milk in model 1 when the degree of utilization is 25.6%. However, in model 2, at a degree of utilization of 44.2%, the reduction in cost is only 0.49 Pf/1-litre pack. These results show that, at a relatively low degree of plant utilization, quite considerable reductions in unit costs can be achieved by reducing the number of production days in a year. When the degree of plant utilization is greater this effect becomes considerably smaller due to the greater volume of production. It should finally be mentioned that unit costs are determined by 2 factors acting in opposite directions:

1. the number of production days
2. the number of intermediate cleanings

The number of intermediate cleanings has only a small effect on the unit costs (see also table 9).

Table 11 is derived from the data in table 9. It gives the percentage composition of the unit costs for models 1 and 2 and for a 3–/2–/1– shift operation with equal number of days of production.

When the number of days of production is kept constant the fraction of the total cost represented by the fixed annual costs increases most rapidly with decreasing utilization of capacity; it increases by about 12-14% on going from a 3 to a 1 shift production, while the percentage share of the fixed daily costs increases by about 4% under the same conditions. Model 3 is not included in the above discussion of Fig. 5 and table 11 because the unit costs of models 2 and 3 are almost identical.

Fig. 6 illustrates the changes in unit costs in the UHT milk department as a function of the capacity and utilization of capacity on 252 days of production per year.

The data for this are taken from table 8. The unit cost functions of the 3 models investigated do not intersect. Operating under the stated conditions there is therefore no volume of production for any of the models where it would be economically more advantageous to change from one model to the other below the utilization of capacity. For this reason production should always be carried out with the smallest possible model provided it gives a sufficient annual processing capacity. The ideal of a 100% utilization of capacity is realizable in practice because UHT milk storage facilities sufficient to deal with short term fluctuations in demand is taken into account.

At a degree of utilization of 44.2% (a 1.5 shift operation) there is a single adjustment of the UHT milk stores of all 3 models to the 7-days production volume of each model (see table 6). This adjustment causes a break in the curves of unit costs. The values in the absence of this adjustment are represented by the broken line continuation of the curves. The adjustment is responsible for a cost advantage of 0.61 / 0.63 / 0.63 Pf/1-litre pack.

A production of 17.9 million 1-litre packs per year exhausts the capacity of model 1. The unit costs are 22.97 Pf/pack. The annual production in model 2 has to reach 24.7 million packs before the unit costs fall to the value which is obtained in model 1 at an annual production of 17.9 million packs. It is therefore not economical to produce quantities between 17.9 and 24.7 million 1-litre packs per year. It is advisable to put up a plant of double capacity in the form of model 2 only when the "critical amount" of 24.7 million 1-litre packs/year is exceeded.

Model 3 has 1.5 times the capacity of model 2. When the degree of utilization of these 2 models is the same the unit costs are also about equal (table 8). As far as the volume of production is concerned there is no region in model 3 in which the unit costs are lower than in model 2, although model 3 produces 1.5 times as much as model 2. A very small decrease in unit costs is obtained at a degree of utilization of 25.6%. The explanation for this is that in model 3 costs decrease a little in the sub-section "aseptic packaging" and "UHT milk storage and dispatch", but there is an increase in costs in the sub-section "UHT heating" due to higher personnel and capital costs (table 10). These data show clearly that the only reasons for installing model 3 could be marketing policy and possibly other cost factors which have not been considered in this study (concerned with product ranges, etc.).

3.2 Differences in costs between pasteurized and ultra-high temperature heated milk in the dairy

The costs of the UHT milk department have been presented above in detail. The costs of the pasteurized milk department are taken from an actualized study (costs of January 1980) which was also undertaken to determine the optimum capacity and degree of utilization of capacity (9). The costs of storage for the finished product and the dispatch, which are included in the work on UHT-milk, were calculated separately for pasteurized milk (10) because they are not included in the costs of the section producing milk for consumption (9).

To make the comparison easier the costs of UHT milk and pasteurized milk are based on equal production capacities and degrees of utilization of capacity (table 12). The annual volumes of production differ slightly from each other which is due to the method of model making. The difference in costs between the 2 systems is 10.19 Pf/unit.

Table 13 shows the difference in the composition of the unit costs of pasteurized and UHT milk arranged according to type and group of costs and cost dependence. The fixed annual costs of UHT milk are 2.57 Pf/unit and are therefore by 1.55 Pf/unit higher than those of pasteurized milk. These higher costs are mainly due to the calculated depreciation, interest and maintenance costs. The fixed daily costs are about the same in both systems. The higher costs of personnel in the pasteurized milk section are due to the larger number of staff in the dispatch section. Fixed batch costs do not occur in the production of pasteurized milk. The greatest differences are shown by the costs which are proportional to the volume of production. Packaging alone is responsible for a difference of 4.14 Pf/unit and overwrapping for a further difference of 2.01 Pf/unit.

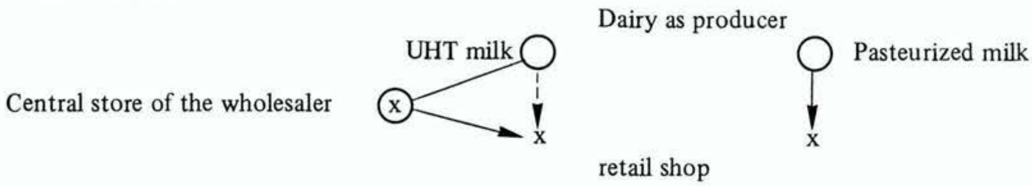
These two items alone give pasteurized milk an advantage over UHT milk of 6.15 Pf/unit. This amounts to 60% of the total cost difference. The difference in costs of about 10 Pf per 1-litre pack quoted above applies only for the model conditions stated. Savings can be made in UHT processing which reduce this difference in costs to about 7 Pf/unit of 1 litre. These savings can be brought about by omitting the sterile tank, by simpler overwrapping (shrink film instead of cartons), by omitting the roller shelves and by financial measures.

In the cost comparison presented here the pasteurized milk was packed in rigid cardboard packages. But pasteurized milk can also be packed in 1 litre tubular film bags made of plastics. According to actualized standard calculations (9) the production costs of milk packed in tubular film bags are lower by about 5 Pf/litre than those of milk packed in cardboard cartons. Thus the tubular film packed pasteurized milk is by another 5 Pf/litre cheaper than UHT milk. The total difference in costs between pasteurized milk in tubular film bags and UHT milk is therefore 12 - 15 Pf/litre unit.

3.3 Difference in distribution costs between pasteurized and UHT milk.

The area of sales extends from the distribution platform of the dairy to the arrival at the retail shop.

As a rule pasteurized milk is sent directly from the dairy to the retail shops, i.e. there is no intermediate central store. On the other hand, only a small part of UHT milk is delivered directly to the shops. In such cases, the number of which is small, there are no significant differences in distribution costs between UHT and pasteurized milk because the quantities and the frequency of distribution of the 2 types of milk are approximately the same. The situation is different in the case of the predominant method of distributing UHT milk which involves an interruption of transport and reloading via the wholesale trade. If the consignments are not less than 20 t and the distance not more than 300 km the dairy does not pay any freight charges from the wholesale store to the customer. Its costs will, in such a case, be lower than if it delivered the milk directly to the retail trade.



The distribution costs which the wholesaler has to bear in delivering to the retail trade are difficult to assess. The reason is that it is impossible to find out which of the costs of goods in the wholesale trade are to be attributed to the UHT milk. It seems, however, reasonable to assume that distribution via a central store is more costly than direct delivery because of the interruption of transport and the additional reloading necessary. The cost of the predominant method of distribution of UHT milk is estimated to be about 3 Pf/litre-unit higher than that of the direct distribution of pasteurized milk.

3.4 Differences in costs in the retail trade

It is not usual in the retail trade to make an itemised cost calculation of goods because almost all costs – with the exception of the actual cost price of the goods – are common costs covering all the goods sold. For this reason it is not possible to ascertain the precise difference in costs between pasteurized and UHT milk. The sale of pasteurized milk brings with it considerably higher costs than that of UHT milk because more personnel is required to place the milk packs on to the shelves of the low temperature cabinet, to replace the milk when it is sold out and to clean the cold cabinets when a package has leaked. UHT milk on the other hand, can simply be placed on palettes next to the cold cabinet in the shop and needs therefore very little personnel.

Supposing, for instance, that the daily sale of pasteurized milk of all grades and size of packs from the cold cabinet is 200 litres and that the personnel costs for the extra work are 6.00 DM daily, then this alone means additional costs of about 3 Pf/litre (10). These additional costs of pasteurized milk compared to UHT milk of about 3 Pf/litre are thought to be typical. In small retail shops with a small turnover the costs of UHT milk could be as high as those of pasteurized milk because it is not possible there to display the UHT milk on their palettes.

The higher material costs of the cold cabinets, in the form of electricity and interest on capital, which are only necessary for pasteurized milk, are insignificant and can be neglected. It is questionable whether the savings in cooling costs in the case of UHT milk are even an advantage because the cold cabinet for dairy products has a great attraction for the customer because the products offered in it present the image of freshness. This is also the reason that the cold cabinet in the dairy product section is one of the most profitable sales areas in a retail shop (11). UHT milk, particularly the 0.5 litre packs are sometimes sold from cold cabinets. This must be regarded as a concession to the habits of the customer. As a rough guide, the cost advantage of UHT milk over pasteurized milk in the retail trade is estimated to be about 3 Pf/litre pack.

3.5 Differences in total costs: Dairy – distribution – retail trade.

As described in sections 3.2 - 3.4 the following cost differences between UHT and pasteurized milk are typical: (+) = higher cost, (–) = lower cost:

a. in the dairy:

a1.	compared to pasteurized milk packed in cartons	+	7 - 10 Pf/ℓ
a2.	compared to pasteurized milk in tubular film bags	+	12 - 15 Pf/ℓ

b. in distribution (interrupted freight) about + 3 Pf/ℓ

c. in the retail trade about – 3 Pf/ℓ

d. total –

d1.	compared to pasteurized milk packed in cartons	+	7 - 10 Pf/ℓ
d2.	compared to pasteurized milk in tubular bags	+	12 - 15 Pf/ℓ

When these differences in cost are compared with the relation in retail prices shown in table 3 (December 1979) it is evident that there is no correspondence between the former and the latter. In the case of whole milk the price of UHT milk is not higher, as would be expected from the higher costs, but lower than that of pasteurized milk, at least that packed in cartons. In discount stores such as Penny and Aldi, which have the greatest turnover of UHT milk, the price of whole UHT milk is 87 Pf/ℓ (table 4) which is considerably lower than that of pasteurized milk. The discrepancy is even greater in the case of partially separated milk. As regards the arithmetic average values, UHT milk is by 8 Pf/ℓ cheaper than pasteurized milk in tubular bags and by 12 Pf/ℓ cheaper than pasteurized milk in cartons. The minimum price of UHT milk of the 1.5% fat grade is almost the same as its higher costs. The relationship of the prices is not only qualitatively but also quantitatively the exact opposite of that of the costs. The explanation for this seemingly paradoxical situation is provided by the differing competitive conditions in the UHT and pasteurized milk market.

4. THE COMPETITIVE SITUATION IN THE PASTEURIZED MILK AND UHT MILK MARKET AS THE REASON FOR THE PRICE STRUCTURE.

In the UHT milk market a large number of dairies supply an almost uniform product while in the case of pasteurized milk the milk is obtained from a few suppliers. It follows from this that the retail trade is, in the case of UHT milk, in a much stronger position when buying from the dairies and can therefore enforce considerably lower purchasing prices than in the case of pasteurized milk. This state of affairs arises as follows: In the case of pasteurized milk the local dairy has the advantage of being near. This advantage outweights the differences in transport costs to the nearest dairy of the comptetition. Because pasteurized milk has the character of fresh milk it is still regarded as necessary that the dairies deliver the milk directly to the retail shops. The necessary delivery service which deals specially with milk for consumption and to some extent with pasteurized milk products, constitutes a costly investment. It becomes more economical if the network of the retail traders served is very dense. This favours the state of affairs in which each town obtains its supplies from one manufacturer – that is generally from the local dairy – rather than from several suppliers for instance, the wholesalers supplying the retail trade. Such a concentration of the milk delivery system on one supplier means that it is difficult for other suppliers of pasteurized milk to enter the market ant it limits the freedom of the retail trade to look for alternative suppliers. It explains the fact that an average of almost 90% of the pasteurized milk in the Federal Republic is distributed to the retail trade from local dairies.

It is almost impossible to establish by means of cost calculations to what extent the local milk supplier can gain a price advantage from the fact that he is on the spot. What determines the upper limit of prices is the point above which it is more advantageous for a group of retail traders to deal with a non-local supplier of pasteurized milk, or to use a delivery system managed by themselves or by the wholesale trade.

The market situation with regard to UHT milk is radically different. Because the product has a long storage life, a uniform quality in spite of different origins and the deliveries are carried out under the management of the retailer and via their own central stores, the retail trade has the whole Federal Republic and, beyond that, the neighbouring EEC countries at its disposal for buying. The number of UHT milk producers and therefore the number of firms offering UHT milk has increased steadily. In 1973 there were about 35 in the German Federal Republic and now there are about 60. The retail trade is therefore able to make full use of its concentrated buying capacity. In view of the existing ample and further expanding production capacity, it is assumed that the selling prices, at least of the more distant dairies which have to bear freight costs, represent a net use of the milk which is not higher than would be obtained if the milk were converted into butter and separated milk powder at Government intervention prices (12). Only dairies which are close to their markets and which utilize their capacity fully can achieve a net use of UHT milk which is considerably more favourable (13).

The individual dairy is unable to free itself by its own efforts from the unfavourable competitive position in the UHT milk market which is the same for all dairies. The prices are so low and will remain as low as they are at present as long as there is a multitude of suppliers facing a retail trade which is concentrated into a few groups.

In the case of pasteurized milk it is likely, on the other hand, that the dairies will, because of their favourable competitive situation, enforce relatively high prices even in the future. The situation would only change if the storage life of pasteurized milk were to be increased, and it would therefore be possible to sell it over a wider area and if the retail trade would take the delivery to the shops under its own management. But the dairies will not be able to maintain these high prices for pasteurized milk which do not reflect the true cost relationship. Prices are going to be reduced – if behaviour is rational – when the percentage increase in sales of pasteurized milk caused by the price reduction becomes greater than the percentage price reduction. (Price-sales elasticity <-1). Because increased sales of pasteurized milk due to (relative) price reductions can, in the main, only be achieved at the expense of UHT milk, the chances of such an increase in sales, compensating for the reduction in price would increase with an increase in the market share of UHT milk (12). If this chance is used, one can expect that the market share of UHT milk will not rise significantly above its current level of roughly 50%. The chances that such a price strategy, aimed at stabilising or even reversing the trend in pasteurized milk sales, will succeed will be greater if certain marketing measures are adopted, particularly if UHT and pasteurized milk are more easily distinguishable by their packages.

5. SUMMARY

The fraction of the total liquid milk sales (pasteurized milk, buttermilk products, sterilized milk, UHT milk) represented by UHT milk has risen since it entered the market in 1968 to about 41% in 1979. The total consumption of liquid milk has fallen slightly over the years and the increase in consumption of UHT milk has been mainly at the expense of pasteurized milk. An analysis of the reasons for this change in the pattern of consumption has shown that the longer storage life of UHT milk and the fact that it is sold mainly as the low fat grade are not the real reasons. The main reason seems to be that UHT milk is, on the average, and particularly in discount stores, cheaper. The average retail price of pasteurized milk of all fat grades, but particularly of the low fat grade, is currently higher than that of UHT milk. The higher price – particularly of the low fat milk – is also the reason that not all retail shops, and especially discount stores, stock pasteurized milk.

To establish the reason for the difference in price between UHT milk and pasteurized milk, the costs of production and distribution and the competitive position were analysed. The cost analysis showed that the costs of UHT milk were, depending on type of package and other cost dependent factors, 7-15 Pf per 1-litre unit higher than those of pasteurized milk. Considering costs alone one would expect the price of UHT milk to be higher than that of pasteurized milk and not lower.

The only reason that the price difference is the opposite of the cost difference is the radically different competitive situation in the pasteurized milk and UHT milk market. In the case of pasteurized milk a few dairies supply the retail trade whose buying power is concentrated, while in the case of UHT milk there is a large number of suppliers. The dairies are going to reduce the higher prices for pasteurized milk which they maintain because of their advantageous competitive position when, with UHT milk having a relatively high share of the market, the chance increases that a reduction in the price of pasteurized milk would increase its percentage share of the market at the expense of UHT milk. It is therefore thought that the market share of UHT milk in the German Federal Republic will not be much higher than 50% in the future.

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Table 1. Changes in the market share of milk for consumption of different fat grades in the form of pasteurized milk and UHT milk.

	(percentage of the total production of pasteurized milk and UHT milk)					
	1971		1975		1979	
	pasteurized milk	UHT milk	pasteurized milk	UHT milk	pasteurized milk	UHT milk
Whole milk (3.5% fat)	90.0	5.0	61.7	10.3	51.6	16.9
Partially separated milk (1.5 - 1.8% fat)	1.7	0.1	7.1	17.8	4.7	24.4
Separated milk, (0.3% fat max.)	2.3	0.0	0.3	2.8	0.3	2.1
Total	100		100		100	

Source: statistical annual and monthly reports of the Ministry of Food, Agriculture and Forestry, Bonn.

Table 2. Changes in the average distribution in the retail trade (% of all shops) of pasteurized milk and UHT milk in 1-litre units, different packaging and fat content.

Period of investigation	Area of investigation	Number of shops	Pasteurized milk				UHT milk in cartons		
			3.5% fat		1.5 - 1.8% fat		3.5% fat	1.5-1.8% fat	up to 0.3% fat
			tubular film bags	cartons	tubular film bags	cartons			
March 1973	Federal territory	77	44	68	–	–	27	21	5
July 1975	Northern Germany	20	65	65	–	40	45	60	15
December 1976	Federal territory	38	58	66	32	39	53	82	58
December 1979	Federal territory	43	37	91	16	46	77	95	53

Source: Own investigations

Table 3. Changes in the average [a] retail price of pasteurized milk and UHT milk in different types of packages and of different fat contents (in DM per 1-litre pack).

Period of investigation	Area of investigation	Number of shops	Pasteurized milk				UHT milk packed in cartons		
			3.5% fat		1.5-1.8% fat		3.5% fat	1.5-1.8% fat	up to 0.3% fat
			tubular film bags	cartons	tubular film bags	cartons			
March, 1973	Federal territory	77	0.78	0.87	–	–	1.00	0.84	0.67
July, 1975	Northern Germany	20	0.91	1.00	–	0.90	1.01	0.80	0.71
December, 1976	Federal territory	38	0.96	1.05	0.86	0.94	1.00	0.82	0.72
December, 1979	Federal territory	43	1.01	1.05	0.88	0.93	1.01	0.81	0.71

[a] The average is the arithmetic mean of the prices in all shops. The greater weight of the discount stores whose prices for UHT milk vary considerably would become more evident if weighting would be according to turnover (see, however, table 4).

Source: Own investigations

Table 4. Retail prices of milk consumption in 1-litre packs in December, 1979. Data obtained by a short enquiry in 43 stores or groups of stores respectively. (DM per 1-litre pack).

Store	Pasteurized milk for consumption				UHT-milk		
	3.5% fat		1.5 - 1.8% fat		3.5% fat	1.5-1.8% fat	up to 0.3% fat
	Tubular film bag	Rigid pack	Tubular film bag	Rigid pack			
1. Munich							
Penny-markets	-	0.99	-	0.83	0.89	0.69	-
Tengelmann-branch	0.99	1.19	-	0.83	-	0.89	0.79
Dt.supermarket	1.00	1.24	-	0.83	0.99	0.79	-
Co-op branch	0.99	1.14	-	0.88	0.89	0.79	0.69
Krone-market	-	1.19	-	0.88	0.99	0.79	0.69
Total:							
a)No.of articles	3	5	-	5	4	5	3
b)Ø-price	0.99	1.15	-	0.85	0.94	0.79	0.72
2. Karlsruhe							
Kolossa	-	0.99	-	-	0.99	-	-
Wertkauf	-	0.99	-	0.89	1.09	0.79	0.65
Schneider	-	1.09	-	1.05	1.19	0.89	-
Total:							
a)No.of articles	-	3	-	2	3	2	1
b)Ø-price	-	1.02	-	0.97	1.09	0.84	0.65
3. Herford							
Marktkauf	-	0.92	-	0.82	0.85	0.69	0.59
Basar	1.02	1.02	-	0.82	0.89	0.69	0.59
Kaufhof	-	0.99	-	0.82	1.19	0.89	-
Hill	-	0.96	-	0.76	-	0.77	0.67
Minipreis	-	0.95/ 0.99	-	-	-	0.69	-
Total:							
a)No.of articles	1	6	-	4	3	5	3
b)Ø-price	1.02	0.97	-	0.81	0.98	0.75	0.62
4.Hagen							
bilka	-	0.99	-	-	0.99	0.79	0.69
Kaufhof	-	0.99/ 1.18	-	1.09	-	0.99	-
Horten	-	0.99	0.89	0.89	0.99	0.89	0.79
Kaufhalle	0.79	1.12	-	-	1.09	0.79	0.69
Dt.supermarket	-	0.99	0.80	-	-	0.80	0.70
Rewe	-	0.99	0.89	-	1.05	0.82	0.69
Total:							
a)No.of articles	1	7	3	2	4	6	5
b)Ø-price	0.79	1.04	0.86	0.99	1.03	0.85	0.71
5. Cologne/Bonn							
Hertie	-	0.98/ 1.08	-	1.08	1.09	0.89	-
Stüssgen	-	0.99	0.79	-	0.99	-	0.79
Dt.supermarket	1.19	-	0.79	1.09	1.00	0.80	0.69
Kaufhalle	-	1.15	0.99	1.09	1.09	0.79/ 0.95	0.69
Karstadt	-	1.08	0.98	0.98	0.98	0.78	-
Total:							
a)No.of articles	1	5	4	4	5	5	3
b)average price	1.19	1.06	0.89	1.06	1.03	0.84	0.72
6. Hamburg							
Spar	-	0.99	-	-	1.09	0.79	0.89
Comet-market	0.99	-	-	-	-	0.72	-
Karstadt	-	1.15	-	-	1.10	0.89	-
Pro-Market	1.09	1.19	-	-	0.99	0.79	-
Horten	1.09	1.15	-	-	1.10	1.00/ 1.24	-
Kaufhalle	1.09	1.09	-	-	1.09	0.79	0.79
Safeway	1.09	1.19	-	-	-	0.89	-
plus-Market	-	0.98	-	0.89	-	0.69	-
Spar,Vetersen	-	0.95	-	-	0.79	0.79	0.79
HL,Vetersen	-	0.99	-	-	0.94	0.74	-
Hertie,Elmshorn	-	0.89	-	-	1.15	0.99	0.78
Pro/Co-op,Tornesch	0.99	-	-	-	0.99	0.79	-
Penny, Tornesch	-	0.99	-	-	0.87	0.69	-
Total:							
a)No.of articles	6	11	-	1	10	14	4
b)Ø price	1.06	1.05	-	0.89	1.01	0.84	0.81
7. Kiel							
Co-op	-	0.96	-	-	-	0.79	-
Dt.Supermarket	0.99	1.19	-	-	1.00	0.80	0.78
Kaisers	-	1.00/ 1.14	-	0.94	0.99	0.79	0.69
Edeka	0.99	1.02	-	-	-	0.69	0.79
Aldi	-	-	-	-	0.87	0.69	-
Eno	0.95	1.02	-	0.93	0.98	0.69	0.67
Total:							
a)No.of articles	3	6	-	2	4	6	4
b)average price	0.98	1.06	-	0.94	0.96	0.74	0.73
8. Total of all towns							
a)No.of articles	15	43	7	20	33	43	23
b)Ø price	1.01	1.05	0.88	0.93	1.01	0.81	0.71

Table 5. **Construction of models**

	Unit	Model 1	Model 2	Model 3
UHT – plant		1 plant 4000 B	1 plant 8000 B	1 plant 4000 B 1 plant 8000 B
Nominal output of the UHT treatment plant	ℓ/h	4,000	8,000	12,000
Aseptic packaging plant		1 plant AB 1000	2 plants AB 1000	3 plants AB 1000
Nominal output of the aseptic packaging plant	1 - ℓ - packs/h	3,600	7,200	10,800
Actual output of the aseptic packaging plant	1 - ℓ - packs/h	3,300	6,600	9,900

Table 6. **List of parameters of plant and equipment in the UHT milk section**

Plant and equipment	Model 1		Model 2		Model 3		Period of useful-ness. (years)	Repair quota %
	Capacity	Capital costs DM	Capacity	Capital costs DM	Capacity	Capital costs DM		
1. UHT-heat treatment								
UHT-plant	4,000 l/h	353,000	8,000 l/h	432,000	4,000 + 8,000 l/h	785,000	10	1.37
Sterile tank	6,000 l	155,850	10,000 l	165,400	6,000 + 10,000 l	321,250	15	1.00
Tank cleaning plant		41,510		41,510		41,510	10	1.50
Assembly		23,290		23,290		34,995	10	1.37
Piping, electrical installations, assembly		102,210		134,670		182,580	20	0.50
Buildings	459 m³	113,436	567 m³	140,128	981 m³	242,443	60	1.50
		789,296		936,998		1,607,778		
2. Aseptic packaging								
Basic fee AB 1000	1 h/3600 P/h	349,440	2 h/7200 P/h	698,880	3 h/10800 P/h	1,048,320	8	7.00
Transport costs		1,086		2,172		3,258	8	1.50
Freight & assembly		9,170		17,135		25,100	8	0.50
Piping, electrical installations, assembly		77,690		132,885		164,404	20	0.50
Packing table	1 h.	905	2 h.	1,810	3 h.	2,715	10	0.50
Roller conveyor		724		1,930		3,137	10	1.50
Scales		1,593		1,593		1,593	8	0.62
Buildings	576 m³	142,352	936 m³	231,322	1,296 m³	320,292	60	1.50
		582,960		1,087,727		1,568,819		

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Table 6 continued

Plant and equipment	Model 1 Capacity	Model 1 Capital costs DM	Model 2 Capacity	Model 2 Capital costs DM	Model 3 Capacity	Model 3 Capital costs DM	Period of useful-ness. (years)	Repair quota %
3. UHT milk store and dispatch								
a) Prod. <1.5 shift operation								
Fork lift		41,150		41,150	2 h.	82,300	10	1.00
Lift truck		1,195		1,195		1,195	10	2.50
Brake rollers shelves store		174,975		343,917		506,825	15	1.75
Palettes	915 h.	22,469	1.830 h.	44,940	2.750 h.	67,532	3	0.50
Buildings	1,406 m^3	128,012	2,264 m^3	206,131	3,122 m^3	284,250	40	3.00
		367,801		637,333		942,102		
b) Prod. > 1.5 shift operation <3.0 shift operation								
Fork lift	1 h.	41,150	1 h.	41,150	2 h.	82,300	10	1.00
Lift truck		1,195		1,195		1,195	10	2.50
Brake rollers shelves store		386,153		760,238		1,134,320	15	1.75
Palettes	2,070 h.	50,833	4,140 h.	101,665	6,210 h.	152,499	3	0.50
Buildings	2,459 m^3	223,885	4,780 m^3	435,206	6,689 m^3	609,016	40	3.00
		703,216		1,339,454		1,979,330		
4. Total sum invested								
a) Prod. <1.5 shift operation		1,740,057		2,662,058		4,118,699		
b) Prod. > 1.5 shift operation <3.0 shift operation		2,075,472		3,364,179		5,155,927		

Table 7. List of factor prices and quantities used in the UHT-milk section.

Type of costs	Factor unit	Factor price Pf/unit	Quantities of factors used: fixed annual use			fixed daily use			fixed batch use**			use proportional to quantity, per 1000 1 - 1 packs		
			Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
1. UHT-heat treatment														
Machine supervisor	h	2,039.00				2.5	2.5	2.5	0.25	0.25	0.25	0.296	0.148	0.099
Skilled labourer	h	1,825.00						2.5			0.25			0.099
Electric power (not own)	kWh	12.05				65.2	82	128	17.3	29.9	45.2	16	13.8	13.9
Water (not own) + effluent	m^3	200.37				16.2	27.6	43.3	2	4	6	2	2	2
Steam (own)	t	4,884.00				1.089	1.676	2.718	0.113	0.227	0.34	0.085	0.085	0.085
Caustic soda	kg	65.00				10.6	20.6	31.2	5.4	10.6	16			
Horolith	kg	123.00				5.2	10.2	15.4	1.4	2.7	4			
P_3 - tin resistant	kg	169.00				4	4	6						
Machine oil	l	509.00				0.5	0.5	1						
2. Aseptic packaging														
Department head	h	2,658.00	2.229	2.229	2.229									
Machine supervisor	h	2,039.00				3.5	7	10.5				0.303	0.303	0.303
Labourer (heavy work)	h	1,624.00				1.5	3	4.5				0.606	0.648	0.648
Electric power (not own)	kWh	12.05				90	174	258				10.6	10.6	10.6
Water (not own) + effluent	m^3	200.37				2	3	4				0.218	0.218	0.218
Aluminium foil laminated carton	St.	12.40-13.265*				140	280	420				1.022	1.022	1.022
Carton (outer wrapping)	St.	28.47-30.20*										83.4	83.4	83.4
Adhesive tape	m	2.53										6	6	6
P_3-tin resistant	kg	169.00				4	6	8						
Machine oil	l	509.00				5	10	15						
Hydrogen peroxide	l	161.00				10	20	30						
Basic fee	1/4 year	195,000.00	4	8	12									
Production fee		0.60-0.88*										1.000	1.000	1.000
3. UHT-milk store and dispatch.														
Skilled labourer	h	1,825.00										0.1	0.1	0.1
Labourer (heavy work)	h	1,624.00				1	1.75	2.5				0.303	0.152	0.101
Electric current (not own)	kWh	12.05				27	42	57				0.85	0.85	0.85
Water (not own) + effluent	m^3	200.37				2	4	6						

* staggered according to quantities sold or produced

** the costs of intermediate cleaning were regarded as fixed batch costs in the UHT-heat treatment section.

Table 8.

The effect of different degrees of utilization of capacity on the unit costs of UHT milk in 1 - ℓ - packs

Degree of utilization of capacity	No. of days of production per year	No. of intermediate cleanings per year	No. of hours of production per day	Working shifts per day	Model 1		Model 2		Model 3	
					Actual hourly output 3,300 1 - ℓ - packs		Actual hourly output 6,600 1 - ℓ - packs		Actual hourly output 9,900 1 - ℓ - packs	
					1 000 units per year	Pf/1 - ℓ pack	1 000 units per year	Pf/1 - ℓ pack	1 000 units per year	Pf/1 - ℓ pack
100.00	252	504	21.5	3.00	17,879.4	22.97	35,758.8	21.90	53,638.2	21.91
81.4	252	504	17.5	2.50	14,553.0	23.57	29,106.0	22.38	43,659.0	22.40
62.8	252	252	13.5	2.00	11,226.6	24.57	22,453.2	23.10	33,679.8	23.11
62.8	180	360	18.9	2.68	11,226.6	24.35	22,453.2	22.92	33,679.8	22.93
44.2	252	252	9.5	1.50	7,900.2	25,69	15,800.4	23.86	23,700.6	23.88
44.2	180	180	13.3	1.98	7,900.2	25.33	15,800.4	23.56	23,700.6	23.58
44.2	126	252	19.0	2.69	7,900.2	25.10	15,800.4	23.37	23,700.6	23.38
25.6	252	–	5.5	1.00	4,573.8	30.06	9,147.6	26.79	13,721.4	26.73
25.6	180	90	7.7	1.28	4,573.8	29.52	9,147.6	26.35	13,721.4	26.28
25.6	126	126	11.0	1.69	4,573.8	29.10	9,147.6	26.00	13,721.4	25.92
16.3	252	–	3.5	0.75	2,910.6	35.72	5,821.2	31.41	8,711.8	30.77

Table 9. Composition of the unit costs of the UHT-milk section, Pf/1 - ℓ pack, – arranged according to type and group of costs and cost dependence.

Type and group of costs \ Cost dependence	Fixed annual costs			Fixed daily costs			Fixed batch costs			Costs proportional to quantity			Total costs			%		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
3.0 shift operation 252 days of production 100% utilization 17,879.4/35,758.8/53,638.2 thousands 1-l packs																		
Personnel costs	0.27	0.14	0.09	0.23	0.19	0.20	0.02	0.01	0.01	2.88	2.40	2.40	3.40	2.74	2.70	14.8	12.5	12.3
Energy				0.16	0.13	0.14	0.03	0.03	0.03	1.19	1.17	1.17	1.39	1.33	1.33	6.0	6.1	6.1
Packaging				0.03	0.01	0.01				12.67	12,67	12.67	12.70	12.68	12.68	55.3	57.9	57.9
Outer wrapping										2.65	2.65	2.65	2.65	2.65	2.65	11.5	12.1	12.1
Various fuels				0.10	0.09	0.09	0.01	0.01	0.01				0.11	0.11	0.11	0.5	0.5	0.5
Dues, fees	0.04	0.04	0.04							0.60	0.60	0.60	0.64	0.64	0.64	2.8	2.9	2.9
Repairs										0.37	0.32	0.33	0.37	0.32	0.33	1.6	1.5	1.5
Depreciation	0.94	0.78	0.81										0.94	0.78	0.81	4.1	3.5	3.7
Interest charges	0.48	0.39	0.40										0.48	0.39	0.40	2.1	1.8	1.8
Maintenance	0.29	0.26	0.26										0.29	0.26	0.26	1.3	1.2	1.2
Total	2.03	1.61	1.60	0.52	0.43	0.44	0.06	0.05	0.05	20.36	19.81	19.82	22.97	21.90	21.91	100.0	100.0	100.0
2.0 shift operation 252 days of production 62.8% utilization 11,226.6/22,453.2/33,679.8 thousands 1-l packs																		
Personnel costs	0.43	0.22	0.14	0.37	0.30	0.32	0.01	0.01	0.01	2.88	2.40	2.40	3.69	2.93	2.87	15.0	12.7	12.4
Energy				0.26	0.21	0.22	0.03	0.02	0.02	1.19	1.17	1.17	1.48	1.40	1.41	6.0	6.0	6.1
Packaging				0.04	0.02	0.01				12.67	12.67	12.67	12.71	12.69	12.68	51.8	54.9	54.9
Outer wrapping										2.65	2.65	2.65	2.65	2.65	2.65	10.8	11.5	11.5
Various fuels				0.16	0.15	0.15	0.01	0.01	0.01				0.17	0.16	0.16	0.7	0.7	0.7
Dues, fees	0.07	0.07	0.07							0.69	0.60	0.60	0.76	0.67	0.67	3.1	2.9	2.9
Repairs										0.37	0.32	0.33	0.37	0.32	0.33	1.5	1.4	1.4
Depreciation	1.50	1.24	1.28										1.50	1.24	1.28	6.1	5.4	5.6
Interest charges	0.77	0.62	0.64										0.77	0.62	0.64	3.1	2.7	2,7
Maintenance	0.47	0.42	0.42										0.47	0.42	0.42	1.9	1.8	1.8
Total	3.24	2.57	2.55	0.83	0.68	0.70	0.05	0.04	0.04	20.45	19.81	19.82	24.57	23.10	23.11	100.0	100.0	100.0
1.0 shift operation 252 days of production 25.6% utilization 4,573.8/ 9,247.6/13,721.4 thousands 1-l packs																		
Personnel costs	1.06	0.53	0.35	0.90	0.75	0.78				2.88	2.40	2.40	4.84	3.68	3.53	16.1	13.7	13.2
Energy				0.64	0.51	0.54				1.19	1.17	1.17	1.83	1.68	1.71	6.1	6.3	6.4
Packaging				0.10	0.05	0.03				13.12	12.67	12.67	13.22	12.72	12.70	44.0	47.5	47.5
Outer wrapping										2.81	2.65	2.65	2.81	2.65	2.65	9.3	9.9	9.9
Various fuels				0.40	0.37	0.37							0.40	0.37	0.37	1.3	1.4	1.4
Dues, fees	0.17	0.17	0.17							0.76	0.69	0.60	0.93	0.86	0.77	3.1	3.2	2.9
Repairs										0.37	0.32	0.33	0.37	0.32	0.33	1.2	1.2	1.2
Depreciation	3.09	2.44	2.55										3.09	2.44	2.55	10.3	9.1	9.5
Interest charges	1.58	1.21	1.25										1.58	1.21	1.25	5.3	4.5	4.7
Maintenance	0.99	0.86	0.87										0.99	0.86	0.87	3.3	3.2	3.3
Total	6.89	5.21	5.19	2.04	1.68	1.72				21.13	19.90	19.82	30.06	26.79	26.73	100.0	100.0	100.0

Table 10. Composition of the unit costs of the UHT-milk section, Pf/1 - ℓ packs, – arranged according to type and group of costs and sub-sections.

Type and group of costs \ Sub-sections	UHT-heat treatment			Aseptic packaging			UHT-milk store and dispatch			Total costs		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
3.0 shift operation 252 days of production 100% utilization 17,894/35,758.8/53,638.2 thousands 1-l packs												
Personnel costs	0.69	0.34	0.44	2.01	1.95	1.90	0.70	0.45	0.36	3.40	2.74	2.70
Energy	1.17	1.12	1.13	0.20	0.19	0.19	0.02	0.02	0.02	1.39	1.33	1.33
Packaging				12.70	12.68	12.68				12.70	12.68	12.68
Outer wrapping				2.65	2.65	2.65				2.65	2.65	2.65
Various fuels	0.05	0.04	0.04	0.06	0.07	0.07				0.11	0.11	0.11
Dues, fees				0.64	0.64	0.64				0.64	0.64	0.64
Repairs	0.11	0.06	0.08	0.17	0.17	0.16	0.09	0.09	0.09	0.37	0.32	0.33
Depreciation	0.34	0.21	0.23	0.29	0.28	0.28	0.31	0.29	0.29	0.94	0.78	0.81
Interest charges	0.18	0.11	0.12	0.14	0.12	0.12	0.16	0.16	0.16	0.48	0.39	0.40
Maintenance	0.06	0.03	0.04	0.15	0.15	0.15	0.08	0.08	0.07	0.29	0.26	0.26
Total	2.60	1.91	2.08	19.01	18.90	18.84	1.36	1.09	0.99	22.97	21.90	21.91
2.0 shift operation 252 days of production 62.8% utilization 11,226.6 /22,453.2/33,679.8 thousands 1 - 1 packs												
Personnel costs	0.73	0.37	0.46	2.25	2.10	2.03	0.71	0.46	0.38	3.69	2.93	2.87
Energy	1.25	1.18	1.19	0.20	0.20	0.20	0.03	0.02	0.02	1.48	1.40	1.41
Packaging				12.71	12.69	12.68				12.71	12.69	12.68
Outer wrapping				2.65	2.65	2.65				2.65	2.65	2.65
Various fuels	0.06	0.05	0.05	0.11	0.11	0.11				0.17	0.16	0.16
Dues, fees				0.76	0.67	0.67				0.76	0.67	0.67
Repairs	0.11	0.06	0.08	0.17	0.17	0.16	0.09	0.09	0.09	0.37	0.32	0.33
Depreciation	0.55	0.33	0.37	0.46	0.45	0.45	0.49	0.46	0.46	1.50	1.24	1.28
Interest charges	0.29	0.17	0.20	0.22	0.20	0.19	0.26	0.25	0.25	0.77	0.62	0.64
Maintenance	0.09	0.05	0.06	0.25	0.24	0.24	0.13	0.13	0.12	0.47	0.42	0.42
Total	3.08	2.21	2.41	19.78	19.48	19.38	1.71	1.41	1.32	24.57	23.10	23.11
1.0 shift operation 252 days of production 25.6% utilization 4,573.8/9,147.6/13,721.4 thousands 1 - 1 packs												
Personnel costs	0.89	0.44	0.56	3.19	2.73	2.55	0.76	0.51	0.42	4.84	3.68	3.53
Energy	1.53	1.39	1.41	0.25	0.24	0.25	0.05	0.05	0.04	1.83	1.68	1.71
Packaging				13.22	12.72	12.70				13.22	12.72	12.70
Outer wrapping				2.81	2.65	2.65				2.81	2.65	2.65
Various fuels	0.12	0.10	0.10	0.28	0.27	0.27				0.40	0.37	0.37
Dues, fees				0.93	0.86	0.77				0.93	0.86	0.77
Repairs	0.11	0.07	0.08	0.17	0.17	0.16	0.09	0.09	0.09	0.37	0.32	0.33
Depreciation	1.34	0.79	0.92	1.14	1.11	1.09	0.61	0.54	0.55	3.09	2.44	2.55
Interest charges	0.72	0.43	0.49	0.52	0.48	0.47	0.34	0.29	0.29	1.58	1.21	1.25
Maintenance	0.22	0.13	0.15	0.60	0.59	0.58	0.17	0.14	0.14	0.99	0.86	0.87
Total	4.93	3.35	3.71	23.11	21.82	21.49	2.02	1.62	1.53	30.06	26.79	26.73

Table 11. Percentage composition of the unit costs according to cost dependence.

	Model 1			Model 2		
cost dependence	3 shifts	2 shifts	1 shift	3 shifts	2 shifts	1 shift
fixed annual costs	8.8	13.2	22.9	7.4	11.1	19.4
fixed daily costs	2.3	3.4	6.8	2.0	2.9	6.3
fixed batch costs	0.3	0.2	–	0.2	0.2	–
cost proportional to quantity	88.6	83.2	70.3	90.4	85.8	74.3
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table 12. Comparison of the systems for producing pasteurized and ultra-high temperature heat treated milk for consumption

	Past. milk 1-litre units	UHT milk 1-litre units
Type of packaging plant	Tetrabrik B 1000	Tetrabrik AB 1000
Number of packaging plants	2	2
Actual output of packaging plants	2 x 3300 units/h	2 x 3300 units/h
Annual production	22,275,000 units	22,453,200 units
Days of production/year	300	252
Utilization of capacity	50%	62.8%
Costs, Pf/ℓ-litre unit, inclusive of storage, dispatch and cooling costs	12.91	23.10
Difference in costs, Pf/unit	10.19	

Table 13. Costs of the production section, including costs of cold store, cooling and dispatch, for pasteurized and ultra-high temperature heat treated milk for consumption in 1-litre units.

(Number of days of production per year and annual degree of utilization as given in table 7).

Type of costs	Fixed annual costs		fixed daily costs		fixed batch costs		costs proportional to quantity		total costs		%	
	past. milk Pf/unit	UHT milk Pf/unit	past. milk Pf/unit	UHT milk Pf/unit	past. milk Pf/unit	UHT milk Pf/unit	past. milk Pf/unit	UHT milk Pf/unit	past. milk Pf/unit	UHT milk Pf/unit	past. milk Pf/unit	UHT milk Pf/unit
Personnel costs		0.22	0.57	0.30		0.01	1.07	2.40	1.64	2.93	12.7	12.7
Energy			0.06	0.21		0.02	0.36	1.17	0.42	1.40	3.3	6.0
Packaging			0.01	0.02			8.53	12.67	8.54	12.69	66.2	54.9
Outer wrapping							0.64	2.65	0.64	2.65	4.9	11.5
Various fuels			0.03	0.15		0.01			0.03	0.16	0.2	0.7
Dues, fees	0.04	0.07					0.47	0.60	0.51	0.67	3.9	2.9
Repairs							0.15	0.32	0.15	0.32	1.2	1.4
Depreciation	0.53	1.24							0.53	1.24	4.1	5.4
Interest charges	0.30	0.62							0.30	0.62	2.3	2.7
Maintenance	0.15	0.42							0.15	0.42	1.2	1.8
Total	1.02	2.57	0.67	0.68		0.04	11.22	19.81	12.91	23.10	100.0	100.0

Figure 1.

Changes in sales of milk for consumption in the German Federal Republic between 1968 and 1979.

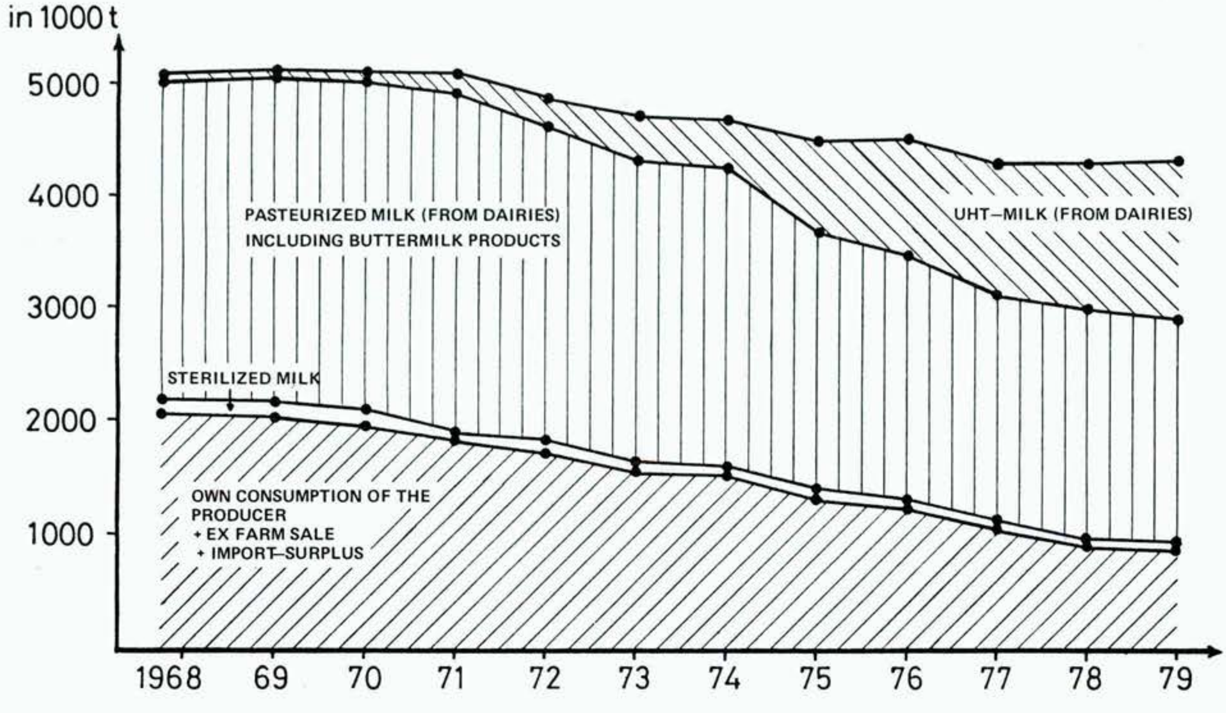


Figure 2

Market share of pasteurized milk and total consumption of pasteurized and UHT milk in the Federal States (FS), percent of average in the Federal Republic.

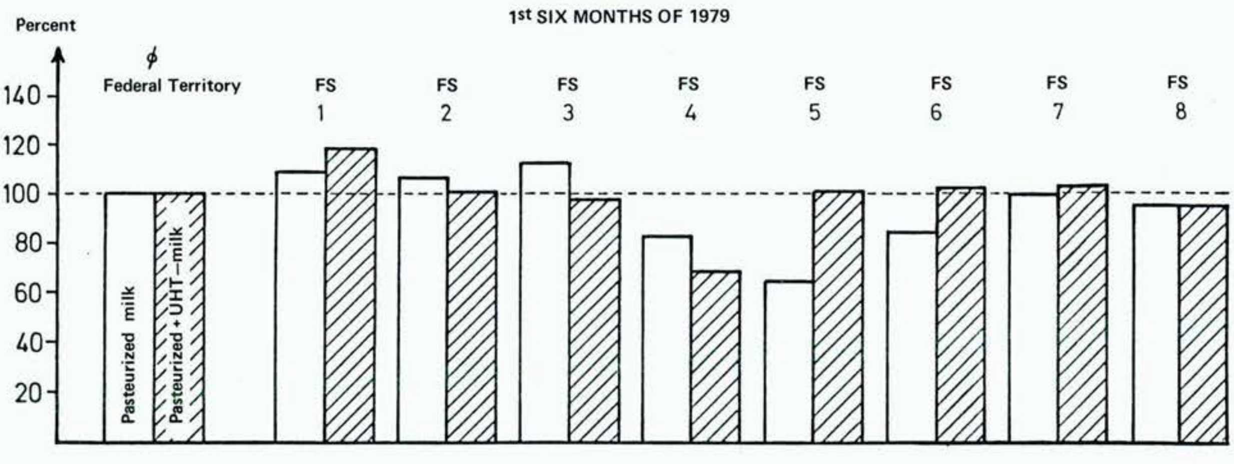


Figure 3a.

Profile of the properties of UHT and pasteurized milk obtained from the assessment of regular buyers of pasteurized milk who know UHT milk from their own experience but do not use it.

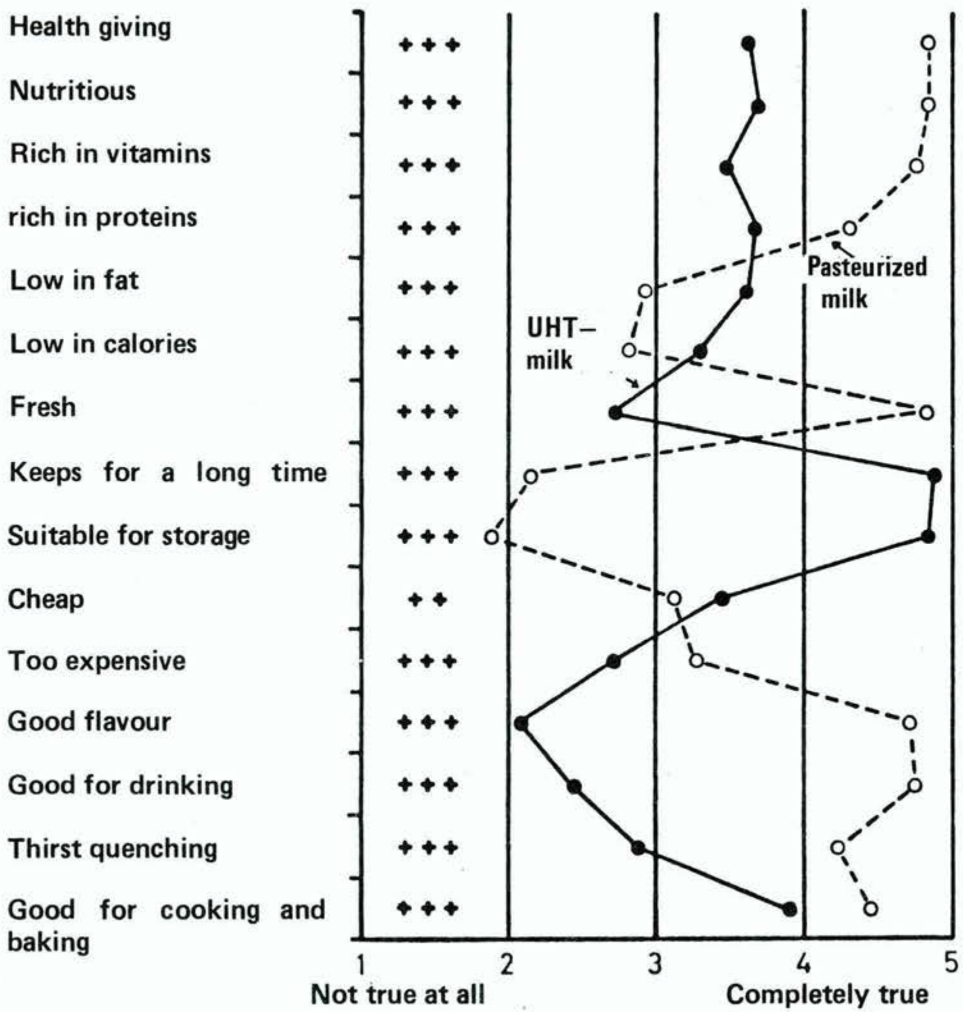


Figure 3b.

Profile of the properties of UHT milk and pasteurized milk obtained from the assessment of those milk users who use only UHT milk in their homes.

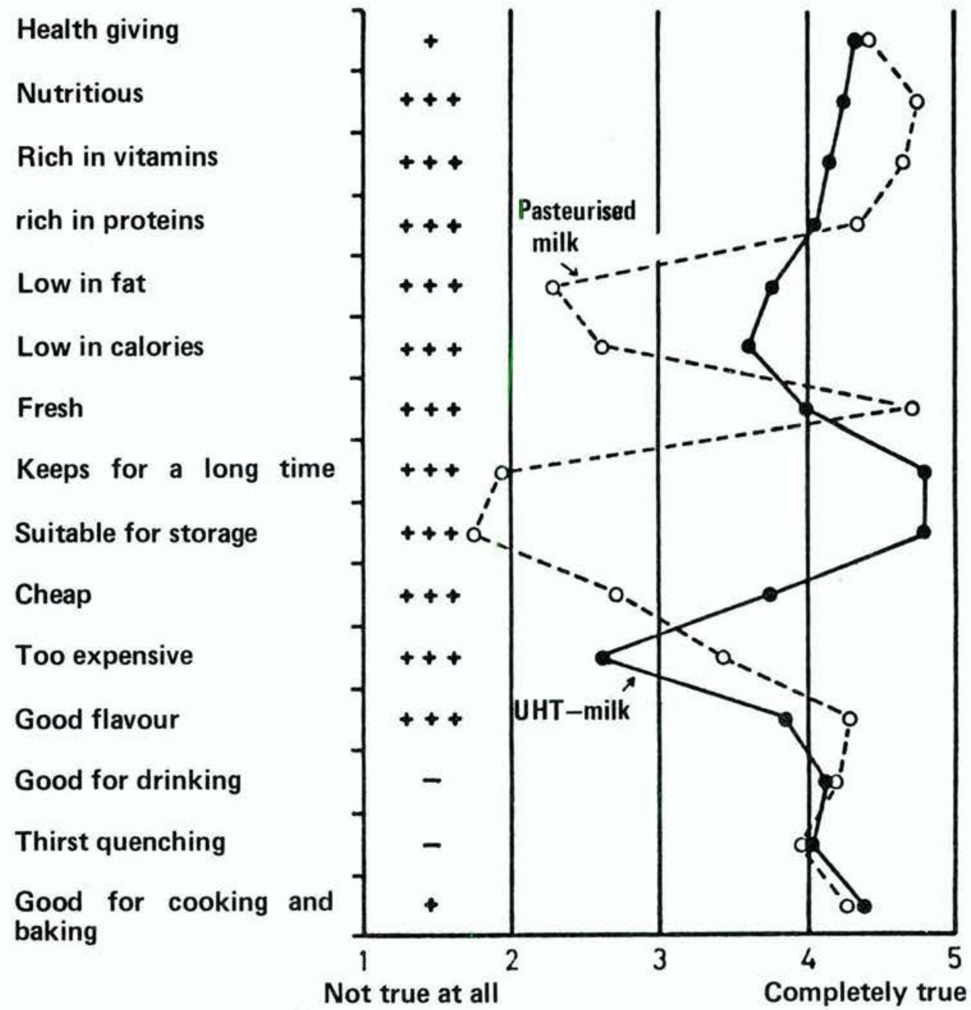


Figure 4.

The structure of the sales outlets for pasteurized milk (including raw milk) and UHT milk in the German Federal Republic in 1978.

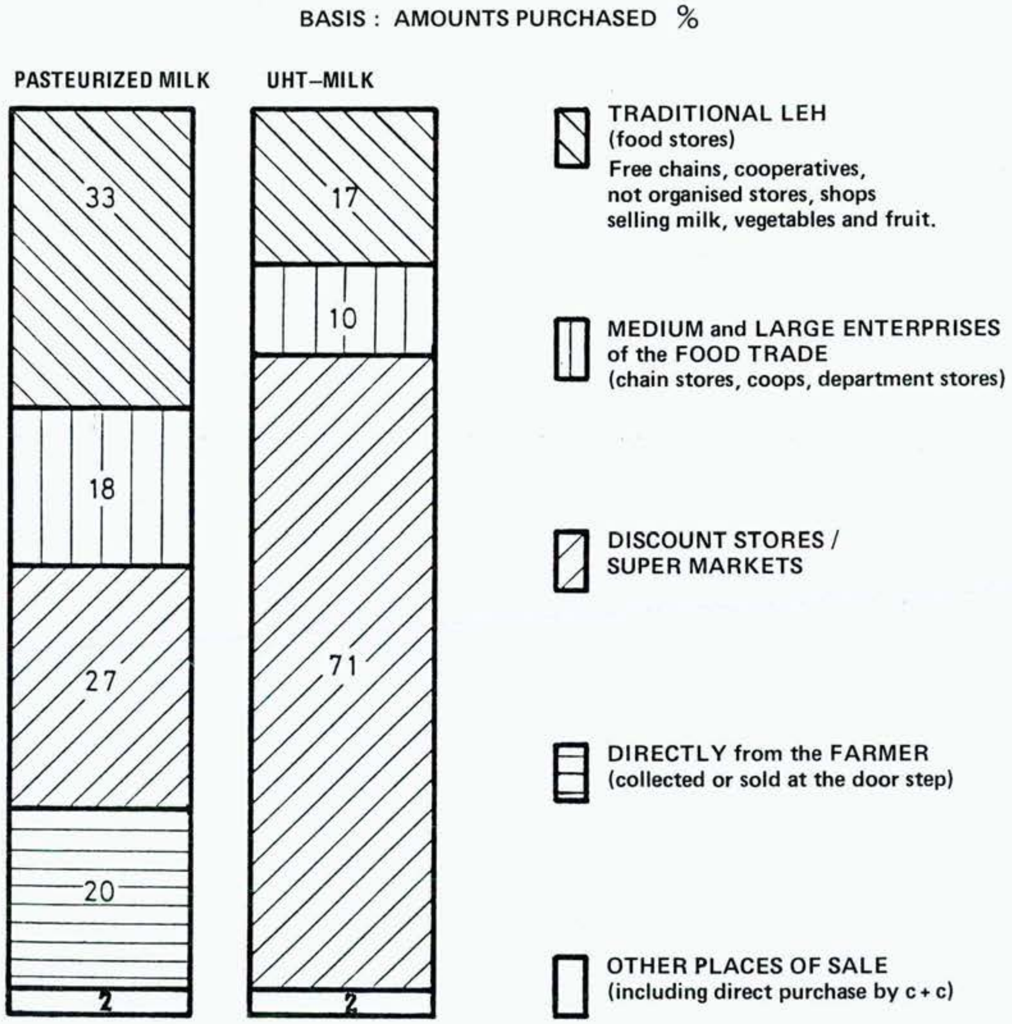


Figure 5.

Variation in the number of days of production at constant volume of production.

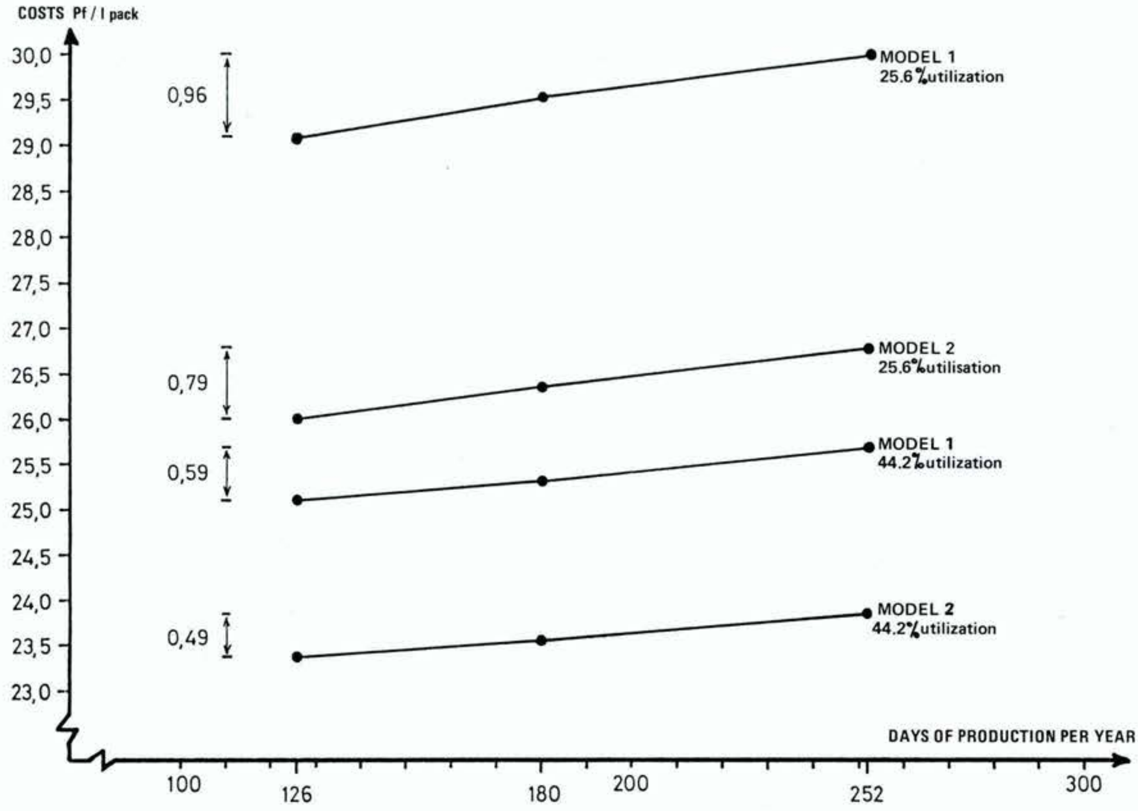
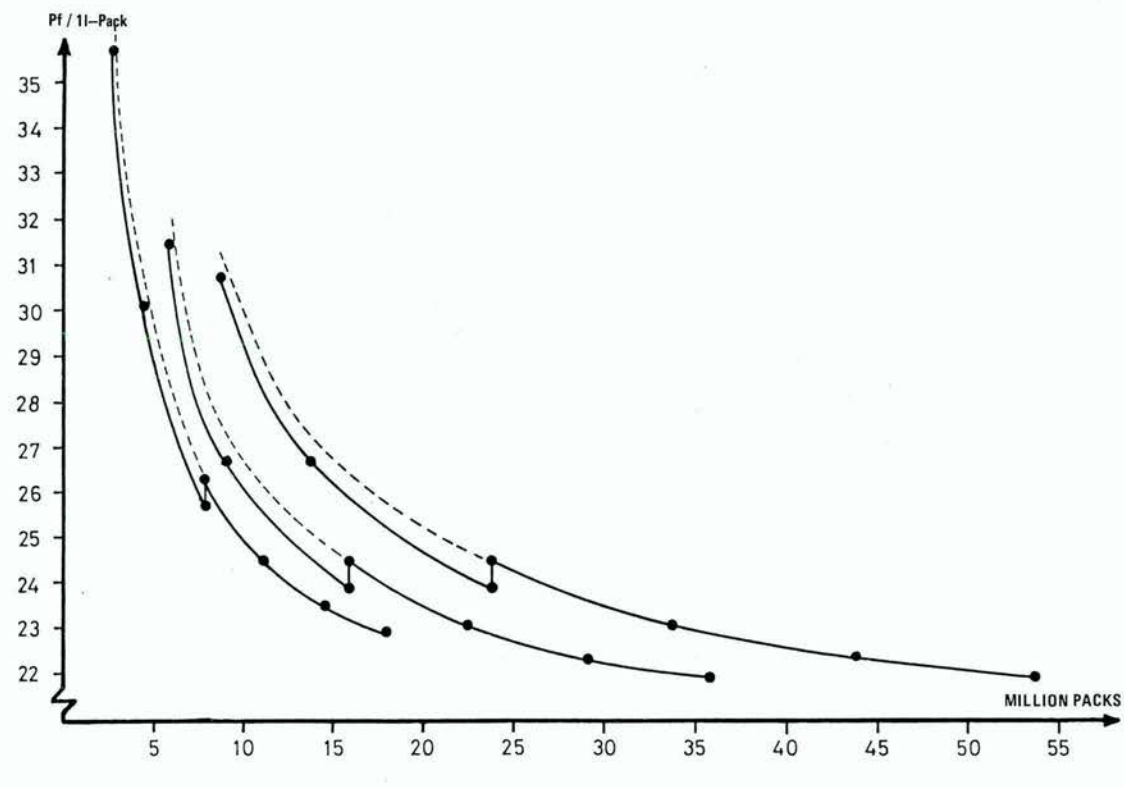


Figure 6.

Unit cost functions in the UHT section.



SECRETARIAT GENERAL: 41, SQUARE VERGOTE – 1040 BRUXELLES (BELGIQUE)
GENERAL SECRETARIAT: 41, SQUARE VERGOTE – 1040 BRUSSELS (BELGIUM)