Milk Processed at Ultra-High-Temperatures — A Review

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ABSTRACT

Ultra-high-temperature (UHT) processing today may describe either a sterilization or a pasteurization process. This review primarily covers the sterilization process which involves heating milk at 130 to 150 C for 1 second or more and then packaging it aseptically. The main topics covered are: history, economics, and theoretical basis of UHT processing; common UHT processes and available aseptic packaging systems; microbial, nutritional, biochemical, and physical aspects of UHT milk; and the flavor of UHT milk.

Reviews (21,41,66,90,99) and series of articles have extensively scrutinized the topic of ultra-high-temperature (UHT) milk. The most recent of these was an excellent symposium held in Birmingham, Great Britain. Several articles from this symposium (11,23,28,75,76) and a comprehensive monograph (40,72,87) will be referred to in this review and are highly recommended. While these publications are exhaustive in content, we feel that a review which consolidates and compiles information on all the topics encountered in UHT-milk literature is needed. The last such review was by Burton in 1969 (21). Burton’s material has been referred to; however, effort has been made to minimize duplication. It has been attempted to make this a selective but by no means a complete review of UHT-milk literature. Wherever relevant, products and systems other than UHT-milk have been included.

Two basically different processes have been labelled UHT. The first, UHT-sterilization, involves heating milk to a high enough temperature for a long enough time to produce a commercially sterile product. The other, UHT-pasteurization, is used principally in North America. Conventional pasteurization involves heating milk at 63 C for 30 min or 71 C for 15 sec. For UHT-pasteurization, milk is heated to a temperature higher than conventional pasteurization long enough to destroy pathogens (22). The resulting product is not sterile, although microbiologically it usually keeps better than conventional pasteurized milk. The UHT-pasteurization process was accepted officially in 1965 by the U.S. Public Health Service (74). Even in the U.S.A. and Canada, there is an increasing tendency to associate the terminology “UHT-milk” with UHT-sterilized milk (21,41). New U.S. Federal Standards of Identity (1978 Pasteurized Milk Ordinance) stipulate that a product labelled “ultra-pasteurized” must have been heated to 137.8 C or above for at least 2 sec (102). Detailed “pasteurization” standards for U.S. (102) and “sterilization” standards for other countries (87) have been established.

Few countries have legal definitions for UHT milk (87,102), probably because defining a sterile product is difficult and also because the filling system which affects the bacteriological quality of the milk cannot be controlled by the “definite temperature for a definite time” description (21).

In this paper, other than some specific references, the term “UHT-milk” will refer to milk that has been heated to at least 130 C for not less than 1 sec and then aseptically packaged. In general, UHT-milk processing involves temperatures of 130 to 150 C and holding times of 1 sec or more (21); 2-8 sec is the generally accepted holding time (41). Burton (21) recently suggested that below 135 C, the sterilizing process was unlikely to be sufficient for a commercial process unless the holding time was made undesirably long; conversely at above 150 C, the required holding time would probably be too short to be maintained effectively.

Burton (21) and Westhoff (102) summarized development of modern UHT-milk. Jonas Nielsen had pioneered the first recorded UHT processing plant by 1913 and later developed an aseptic canning system. The modern trend toward UHT, however, started in the late 1940s as plants started using higher processing temperatures, with correspondingly shorter holding times, to give products better bacteriological quality. This also resulted in less change in the color, flavor, and nutritive value of the milk.

In the U.S., “fresh-tasting” long shelf-life milk was produced by sterilizing milk in bottles as early as in the 1940s and in cans in the 1950s (41). Because these milks were sterilized inside containers, their flavors were not as good as the flavor of today’s pasteurized milk. In 1958, a rectangular polyethylene-coated paperboard container, with an aluminum foil laminate barrier, was introduced by Tetra Pak in Switzerland. After Switzerland, aseptically packaged milk entered Germany, Italy, France, United Kingdom, South Africa and other countries including Canada. In many European countries, UHT-milk is making strong inroads into fluid milk markets, e.g. as much as an estimated 50% in Italy and Germany in 1976 (75).
ECONOMICS

The economics of UHT-milk are dependent on processing costs and distribution costs. Neitzke in 1965 (66) compared the costs of four sterilization processes with the costs of pasteurized milk in Germany. Processing costs for UHT-milk (Uperization process) were the highest, and for pasteurized milk the lowest; this was mainly because disposable cartons were used to package the Uperized milk, whereas returnable bottles were used for other milks. Costs for cartons of UHT-milk were also compared to costs for bottles of pasteurized milk in the U.K. (79); UHT-milk was more expensive to produce; however, if both processes had used cartons, then presumably the processing costs for the milks would have been nearly equal. Since its introduction in 1965, the price of UHT-milk in the U.K. has remained 23 to 27% above the price of regular pasteurized milk (28). Bene (13) observed (Table 1) that in Norway, UHT-milk was more expensive to process and package than pasteurized milk. Distribution costs and other factors might equalize the processing costs.

Currently, UHT-milk appears to be competitive to pasteurized milk. In 1976, the average price of UHT-milk in Germany was 1.8% lower than that of pasteurized liquid milk (73). A 2% UHT-milk which was introduced in Canada on September 17, 1975, had in 2 years captured 20% of the fluid milk market in the areas it served (7). The UHT-milk sells for about 1 cent premium per liter (6). Exports account for it served (7). The UHT-milk sells for about 1 cent

TABLE 1.
The costs of UHT milk compared with pasteurized milk in Norway.α

<table>
<thead>
<tr>
<th>Item</th>
<th>UHT milkb</th>
<th>Pasteurized milkc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging material</td>
<td>4.48</td>
<td>2.81</td>
</tr>
<tr>
<td>Equipment</td>
<td>0.63</td>
<td>0.29</td>
</tr>
<tr>
<td>Labor</td>
<td>0.35</td>
<td>0.20</td>
</tr>
<tr>
<td>Energy</td>
<td>0.42</td>
<td>0.07</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5.88</td>
<td>3.37</td>
</tr>
</tbody>
</table>

αCondensed from Bene, 1974 (13). Based on production of one million liter units/year and an exchange rate of 1 Norwegian Kroner = 0.1888 U.S. dollar.
bPackaged in Tetra Brik cartons.
cPackaged in Pure Pak cartons.

would be greatly reduced as the operation of UHT units is highly automated. The need for expensive refrigerated storage would be drastically reduced, and inexpensive warehouses could be used. Home delivery would cease completely. Refrigerated display cabinets, now crowded, could be used to display items other than milk because milk would be displayed at room temperature. Milk could be delivered to the supermarkets once a week or twice a month. It would be shipped in unrefrigerated flat-top containers by pallet load rather than in wood, wire or plastic cases. Distance would no longer limit shipments; UHT-milk could be shipped almost anywhere a dairy could find a buyer.

Quality control tests would change from microbial quality to other factors, such as off-flavor, milk separation, and gel formation. Consumers would purchase dozens of quarts of milk, or milk products, at one time and store them in basements. Milk would be refrigerated only a few hours before consumption. The costs of processing and packaging the milk would increase, but the distribution costs would be reduced drastically.

THEORETICAL BASIS FOR UHT-PROCESSING

Microorganisms are destroyed by heat when the microbial proteins coagulate and enzymes required for their metabolism are inactivated (35). Heat treatment necessary to kill microorganisms or their spores varies with the kinds of organisms, their state, and the environment during heating. A term used to express the heat resistance of microorganisms is “thermal death time” (TDT), defined as the time at a certain temperature necessary to kill all of the organisms (or spores) under specified conditions. Processing times and temperatures are based on a TDT curve for whatever organism the process is designed to destroy (67). The TDT curve is obtained by plotting the logarithm of TDT versus temperature (35).

In food processing operations, the equation normally used to determine the processing time is called the $F_0$ or the sterilization equation (41):

$$\log F_0 = \frac{T - 250}{t}$$

where, $T = \text{the processing temperature in degrees Fahrenheit (F)}$

$t = \text{the holding time in minutes}$

$z = \text{slope of the TDT curve or the degrees } F$

$F_0 = \text{the sterilization value or number of minutes required to destroy all organisms at 250 F}$

From the sterilization equation, if three values are known, the fourth can be calculated. For convenience, alignment charts (nomographs) also are available to compute one value when the other three are known (39).

In the 110-125 C range, the rate of spore destruction for Bacillus stearothermophilus increases about 11 times for each 10-C rise in temperature (34). This relationship
also probably holds true beyond the 110-125°C range. Other Bacillus spores such as those of Bacillus subtilis are more sensitive, and their rate of destruction increases 30 times for every 10°C increase in temperature (41). Maillard browning, an important chemical reaction during UHT-processing, occurs when proteins interact with reducing sugars. This results in off-flavors and discoloration. Burton (18) determined that in the range of 95 to 120°C, the rate of browning increases about three times for each 10°C rise in temperature. He plotted a curve for the ratio of bactericidal (sporicidal) effect to browning effect versus temperature, as shown in Fig. 1 (22). The temperature quotient \( Q_{10} \), or the rate of increase of spore destruction for every 10°C increase in temperature, is designated as 20, (average for B. subtilis = 30 and B. steatothermophilus = 11) and that for browning is 3. The ratio does not change much until the temperature reaches about 135°C. Above 135°C, the bactericidal effect increases rapidly in relation to browning. At 150°C, the bactericidal effect is about 5000 times greater. Therefore, if milk is treated in the UHT range, 135-150°C, for a few seconds, it is possible to obtain a product virtually free of spores and with much less browning than milk from conventional in-can sterilization. The color of this product is similar to that of HTST (high temperature-short time) milk. Recently Woods (109) used Clostridium botulinum to make a similar comparison between sterilization rate and rate of chemical changes at UHT temperatures. UHT milk sterilization is based on these basic principles.

**PROCESS DESCRIPTION**

**UHT-sterilization**

UHT processes can be classified as either directly heated or indirectly heated, according to the kind of heat exchangers used. In processes using indirect heat, milk is heated through a heat-conducting barrier, usually stainless steel, which separates the heating agent from the milk. The heating surface may be either a corrugated plate, as in many HTST pasteurizers, or a tube with a relatively small diameter. Alternatively, the heat exchanger may be of the scraped-surface type, in which the milk flows through a large cylinder. The cylinder is heated externally by steam, and the inside wall of the cylinder is scraped by continuously rotating blades. The scraped-surface system is rarely used for milk but is suitable for viscous products in which it is difficult to induce turbulence (21).

In processes using direct heat, milk is mixed with saturated steam under pressure and heated rapidly as the steam condenses (21). Steam may be injected into the milk, or the milk may be sprayed into an atmosphere of steam. The heated milk is injected through an orifice into a vacuum vessel where water added to milk as condensate is removed, thereby cooling the milk. In one recent modification of the milk-into-steam technique, a free-falling-film UHT system (5,52,103) was developed. Here the product falls through a steam chamber as a thin, laminar, free-falling film. The final product is sterile and is reportedly similar in flavor to pasteurized milk.

In processes using direct heat, there also are indirectly-heated stages, with plates and tubes for preheating, regeneration and cooling. Conversely, equipment for indirect heat may sometimes include vacuum flash vessels to remove gas and vapor (21). Recently, complex UHT processes have been simplified by minimizing the number of intermediate steps (11). A special requirement for equipment using direct heat is that the steam be culinary and contain no toxic compounds (21).

UHT processes available have been summarized by Burton (21), Hsu (41) and Ashton (9). These have been combined in Table 2. In addition to these, Burton (23) stated that in one commercial system available now, the heating is from electric resistance (electric heaters), and in another heat is generated by friction, by passing a thin film of milk across the face of a high-speed rotor. Milk has also been sterilized by microwave energy, although not commercially.

**Aseptic packaging**

An aseptic filling process to avoid bacterial contamination after sterilization treatment is necessary for UHT-sterilized milk. Any aseptic filling installation must sterilize the container, fill it, and then seal it without contamination. Thus aseptic filling must be a single operation to carry out these functions.

The existing fillers can be classified according to either the kind of container filled, i.e. cans, cartons or bottles, or the differences in the basic principles used in the aseptic packaging machinery. The major operational
aseptic packaging systems for UHT dairy products are 
(41):

(a) Aseptic Tetra Pak. The Aseptic Tetra Pak was the 
first aseptic packaging machine used to package UHT 
milk in paper containers and was derived from the 
conventional Tetra Pak filler. Major problems in this 
system are the sterilization of paper inside the containers 
just before filling, keeping the condition aseptic during 
filling and making an aseptic seal after filling.

Both physical and chemical means have been used to 
sterilize the paper. Physical means include heat 
treatment, ultraviolet radiation, and high frequency 
electric fields. Chemical means include treatment with 
ethylene oxide, available chlorine or hydrogen peroxide. 
Hydrogen peroxide, combined with a subsequent high 
temperature treatment of the Tetra Pak paper, has 
become the main technique today. The Tetra Pak carton 
is formed from a polyethylene-coated paper strip and 
filled on the same machine. As the paper leaves the 
reel, a strip of polyethylene is added to reinforce the 
longitudinal seam. The strip of paper passes through a 
bath of dilute hydrogen peroxide; the excess is removed 
by squeezing to leave a thin film. After the paper has 
been formed and heat-sealed into a vertical tube, it 
passes an electric heating element totally enclosed by the 
tube. The heating element raises the inside surface 
temperature of the paper to 
200-250 C, decomposing the 
hydrogen peroxide to steam and nascent oxygen; the 
nascent oxygen sterilizes the surface. A thermally 
saturated supply tube conveys the milk down through the 
heating element into the paper tube, which is then cut 
and heat-sealed transversely to give tetrahedron-shaped 
cartons.

(b) Aseptic Tetra Brik. The Aseptic Tetra Brik was 
designed especially for aseptic packaging. The Tetra Brik 
process is similar to the Tetra Pak process and consists of 
three steps: from a reel, plastic-coated paper is shaped 
into a tube; filling is continuous into this tube and 
rectangular packs are produced after the tubes are sealed 
transversely below the surface of the product. Commer-
cial Tetra Brik carton board is laminated (from inside 
out) with two layers polyethylene, a layer of aluminum 
foil, polyethylene, two layers of paper, printing ink and 
a layer of polyethylene (94). Some unique characteristics 
of the Tetra Brik are: the shape of the container is 
rectangular, application of the sterilant (hydrogen 
peroxide) has been simplified - the peroxide bath itself is 
at 80 C and instead of squeezing rollers a new device 
known as “air-knives” removes excess hydrogen peroxide 
by means of an air-jet.

(c) Aseptic Pure Pak. The aseptic Pure Pak system was 
developed by the Ex-Cell-O Corporation of Detroit. The 
Pure-Pak system differs from other aseptic systems in 
that it relies only on chemical sterilization of the 
containers rather than the combination of chemical 
sterilization and heat; also Pure Pak operations are 
carried out in a “sterile” environment rather than a 
“sterilizing” environment. The former involves steriliz-
ing the packaging system at the beginning of a day and 
then maintaining a positive pressure of sterile air within 
the system for the rest of the day, whereas the latter 
involves sterilizing the entire environment of the package 
within the packaging system by heat or other means 
throughout the period of operation.

TABLE 2. Commercial UHT processing equipment.

<table>
<thead>
<tr>
<th>Category</th>
<th>Name of process</th>
<th>Developed and/or manufactured by</th>
</tr>
</thead>
<tbody>
<tr>
<td>INDIRECT HEATING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubular type</td>
<td>Sterideal and Mini-Sterideal</td>
<td>Stork of Holland</td>
</tr>
<tr>
<td></td>
<td>CTA system</td>
<td>CP Division, St. Regis, U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Spiratherm and Unitherm</td>
<td>Cherry-Burrell of U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Roswell</td>
<td>Roswell of U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Mallorizer</td>
<td>Mallory of U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Graves-Stambaugh</td>
<td>Graves-Stambaugh of U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Schmidt</td>
<td>Schmidt</td>
</tr>
<tr>
<td></td>
<td>Gerbig</td>
<td>Gerbig of Germany</td>
</tr>
<tr>
<td>Plate type</td>
<td>Ultramatic</td>
<td>APV of England</td>
</tr>
<tr>
<td></td>
<td>Dual-purpose system</td>
<td>Alfa-Laval De-Laval Group of Sweden</td>
</tr>
<tr>
<td></td>
<td>Sterilepak (Sordi-Lodi)</td>
<td>M. Sordi of Italy</td>
</tr>
<tr>
<td></td>
<td>Ahlborn</td>
<td>Ed. Ahlborn of Germany</td>
</tr>
<tr>
<td>Scraped surface</td>
<td>Swept Surface heater</td>
<td>CP Division, St. Regis of U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Votator Scraped Surface heater</td>
<td>Votator Division, Chemetron Corp., U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Therutator heater</td>
<td>Cherry-Burrell Corp., U.S.A.</td>
</tr>
<tr>
<td>DIRECT HEATING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam-into-milk (injection)</td>
<td>Vacu-Therm Instant Sterilizer (VTIS)</td>
<td>Alfa-Laval De-Laval Group of Sweden</td>
</tr>
<tr>
<td></td>
<td>Uplerization</td>
<td>Alpura Ltd. &amp; Sulzer Bros. of Switzerland &amp; APV of England</td>
</tr>
<tr>
<td></td>
<td>Aro-Vac system (No-Bac Aro-Vac)</td>
<td>Cherry-Burrell Corp. of U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Grindrod</td>
<td>Smith, Kline and French of U.S.A.</td>
</tr>
<tr>
<td>Milk-into-steam (infusion)</td>
<td>Laguillhre</td>
<td>Ets. Laguillhre of France</td>
</tr>
<tr>
<td></td>
<td>Thermovac (Thimonnier)</td>
<td>Brel &amp; Marrel of France</td>
</tr>
<tr>
<td></td>
<td>Palarisator</td>
<td>Paasch &amp; Silkeborg of Denmark</td>
</tr>
<tr>
<td></td>
<td>Ultra Therm</td>
<td>Creamery Package Division, St. Regis of U.S.A.</td>
</tr>
<tr>
<td></td>
<td>Free-falling-film</td>
<td>DaSi Industries of U. of Maryland, U.S.A.</td>
</tr>
</tbody>
</table>

JOURNAL OF FOOD PROTECTION, VOL. 43, MARCH, 1980
(d) Dole Aseptic Canning System. This process was patented by the James Dole Engineering Co. of Nevada. The original system consisted of UHT sterilization and aseptic canning linked together to form a complete system for heat-sensitive foods. For UHT-milk, only the aseptic canning part is used with one of the UHT-milk sterilizers. The packaging system consists of five major sections: can sterilizer, cover sterilizer, filling chamber, closing and sealing machine and the controls. Super-heated steam at 260 C is used to sterilize the cans and covers.

(e) Anderson Formseal. This machine was developed by the Anderson Brothers Manufacturing Company of Rockford, Illinois, mainly to package coffee cream or whiteners in small half-ounce plastic containers formed from heat-treated polystyrene sheets. Pressure is applied to shape the plastic into cups before they are filled with the sterilized product. The covers are treated both chemically and with ultra-violet light before being sealed to the cups.

(f) Dole System for glass jars and bottles. This was designed by the James Dole Engineering Co. and the Glass Manufacturers Institute.

(g) GEM-NIRD Aseptic Bottling Machine. This was designed by the National Institute for Research in Dairying at Reading and the Graham-Enock Manufacturing Co. Ltd., London, England.

MICROBIOLOGY

The shelf life of a UHT-product depends mainly on two factors: the sterilizing effect of the UHT-equipment, and the aseptic condition of the packaging. To assure quality, the product should be sampled at two stages: after the UHT heating unit and after the finished product is packaged (41).

A recent Russian survey (55) determined that the three main causes of microbial contamination in UHT-milk plants are lowering of sterilization temperature, inefficiency and carelessness in sterilizing the equipment and failure to ensure asepsis during packaging. A complete quality assurance program for UHT-milk was outlined by Roberts (76).

As complete sterility is approached, the number of microorganisms that survive is extremely small. Such a small number can be detected only when a huge volume of sample is examined. To make the analysis more practical, a pre-incubation technique is usually used. This technique was developed to increase the number of viable bacteria, or spores, if any, by pre-incubating the test samples at a suitable temperature for a suitable time. The conditions usually recommended are 32, 37, or 55 C for 5, 7 or 10 days. Under these conditions, if the product sours or coagulates, the presence of viable spores or organisms is established. Further, bacteriological analysis of all the samples can be made much more easily after this treatment. Complete asepsis must be provided when a UHT-product is analyzed because a single contaminant could confuse the entire situation.

A Finnish company (60) has recently developed a device to automatically control the quality of UHT-milk. This device operates on the basis of electrical registration of changes in hydrodynamic properties (e.g. viscosity) due to microbial activity. It checks each package separately and automatically rejects faulty packages which have microorganisms in the milk. Another potentially useful new tool is a lethality computer developed in the U.K. (86). The instrument computes F values continuously throughout a heat sterilization process from a temperature signal derived from a thermistor probe. The displayed F value is claimed to be accurate within 3%.

Wajid and Kalra (100) have described the use of an enzyme in increasing the shelf-life of a sterile milk. The shelf-life of sterilized milk inoculated with B. subtilis or B. stearothermophilus (100 spores/ml) and heat-treated at 109 C for 5 min was increased from 3-7 days to 60 days in the presence of 100 Reading Units (RU) of nisin/ml. A RU is a 25 parts per billion solution of the enzyme. Mahmoud et al. (57) obtained similar results with B. subtilis in pasteurized milk but found that 100-1000 RU of nisin/ml did not extend the shelf-life of milk inoculated with Escherichia coli, Enterobacter aerogenes or Pseudomonas fluorescens.

Cunliffe et al. (27) reported that pasteurization could not inactivate foot-and-mouth disease (FMD) virus in milk but UHT (148 C for 3 sec) could. UHT treatment of dairy products has been suggested as a means of eliminating regional or international distribution of infectious FMD virus.

NUTRITION

The nutritive value of UHT-milk can be reduced at two stages, either during UHT treatment or during storage. Nutritive value usually is lost because of changes in the chemical structures of the nutrients.

The effect of UHT processing conditions differs for the various nutrients of milk. The nutritive values of some components such as the fat, fat-soluble vitamins, carbohydrates and minerals are essentially unaffected, whereas values of other components such as the water-soluble vitamins and proteins are adversely affected (72). Proteins, especially the whey proteins, are denatured.

During storage, the main factors affecting nutrients are temperature, light and oxygen. The main nutritional changes that occur in milk during storage are associated with the vitamin components. Proteins are affected but not to any appreciable extent (72).

Vitamins

Burton (21), van Eekelen and Heijne (99) and Porter and Thompson (72) have reviewed in detail the effects of high heat treatment and prolonged storage on stability of vitamins in milk. They have observed that in general, vitamins are more stable under UHT processing conditions than under pasteurization or other “low temperature” heat treatments (21,72,99).
Vitamins A, D, E and carotene are little affected by high heat treatments used during milk sterilization (21, 72, 99). Vitamin A and carotene losses up to 35% have been observed on prolonged sterilization (99). Workers have reported a loss of up to 6% of vitamin D (99) and less than 10% of vitamin E (21) during UHT processing. Negligible loss of vitamins A and E was observed in UHT-milks stored at ambient temperature for 180 days (21).

Pantothenic acid, nicotinic acid and biotin are not affected by UHT treatments (21, 72, 99) and storage (21) of milk. Considerable variation has been observed in the losses of the other water-soluble vitamins during high heat treatments and subsequent storage. Losses reported vary from none up to 100% for some of the vitamins. For thiamine, losses greater than 20% have been observed during different UHT treatments and up to 50% with prolonged in-bottle sterilization. Riboflavin, which is stable to heat, is susceptible to the action of light (99). Less than 10% losses were observed in riboflavin during sterilization (21), but losses up to 60% were observed during a 3-month storage period (99). Results for vitamin B₆ vary considerably in the literature (21, 99). Van Eekelen and Heijne (99) suggested that these variations could be caused by differences in the original amounts of the vitamins in milk (the higher the initial concentrations of the vitamins in milk, the greater the losses), the assay technique and the storage time of the milk.

Losses of ascorbic acid, folic acid and vitamin B₁₂ are interrelated. Ascorbic acid is heat-stable but in the presence of oxygen is converted to heat labile dehydroascorbic acid. Because most of the results published have not distinguished between the two forms of the vitamin, UHT heat treatment losses of 0 to 30% have been reported. Ascorbic acid surviving heat treatment may be lost in storage (21). If the amount of oxygen dissolved in milk is limited, ascorbic acid losses are minimal (21, 72). Thus heat treatment plays a minor role in destroying ascorbic acid in milk; oxygen availability is the critical element. Low oxygen levels are achieved by either the use of a deaerator before heating or evaporative cooling after processing (72).

Folic acid appears to be stable on processing and storage as long as reduced ascorbic acid is present in milk. After ascorbic acid is eliminated, folic acid is lost rapidly (21, 72). During in-bottle sterilization, the greater part of vitamin B₁₂ is lost (99); however, under UHT conditions losses of only 30% have been recorded (21). During storage, losses of 60% have been reported after 90 days (99) and 180 days (21). The smallest losses were found for a plant using a deaeration unit before the UHT state of processing (21).

Minerals

Hansen and Melo (37) found that free calcium was reduced significantly in milk processed at 143 C for 8 to 10 sec. The free calcium could have been transformed into a colloidal form or could have precipitated along with other milk constituents. Experiments with rats have shown no change in the availability of the calcium of milk after indirect UHT processing (21). Pelet and Donath (70) used eight newborn infants to test the effect of Uperization of "humanized" cow's milk. "Humanized" cow's milk is milk that has been modified to conform closely in composition to human milk (33). Uperization did not affect nitrogen balance and phosphorus retention; however, calcium and potassium retention was higher in infants receiving Uperized milk than in those receiving pasteurized milk (70).

Protein

Severe heat treatment causes considerable denaturation (up to 80%) of the serum proteins of milk, especially β-lactoglobulin (21). UHT-milk heated directly had smaller amounts of serum protein denaturation than indirectly heated milk. β-Lactoglobulin, on denaturation, apparently complexes with casein. UHT processing increases the size of the casein aggregates and changes their composition (21). White and Sweetsur (104) did not observe any significant changes in the rate of heat-induced (110-140 C) aggregation of casein by removal of serum proteins or colloidal calcium phosphate or by prevention of K-casein/β-lactoglobulin interaction. During storage of UHT-milk, the α- and β-casein electrophoretic peaks become broader and less well-defined, with increases in non-casein and non-protein nitrogen (21). Increasing length of storage increases proportion of the casein aggregates; however, these is no corresponding increase in size of aggregates (24).

An increase in sugar content has been shown within the α-casein band, indicating a preliminary stage of the amino acid-sugar Maillard reaction (21). Isotope studies (98) with lactose and milk proteins has established that when heated together in model systems at 143.5 C for 10 sec, casein micelles incorporated 5 to 6 times the amount of lactose as α-lactalbumin and 8 to 12 times as much β-lactoglobulin; the lactose appears to be covalently bonded to the protein fractions.

Lysine levels in milk are reduced by milk sterilization; however, methionine and tryptophan which also are heat-labile were not much affected (99). On the other hand, Aboshama and Hansen (1) observed a 34% loss of cysteine and cystine (as cysteic acid), and methionine in skim milk during UHT processing versus only 5-10% during pasteurization. No significant changes have been observed for the other amino acids either during processing or storage of the UHT milk (99).

Two new basic amino acids have been detected by Finot et al. (30) in the acid hydrolysates of scorched roller-dried milk powder. Apparently furosine and pyridosine, which are the trivial names given to these new amino acids by the authors, are formed from ε-N-[(deoxy-D-fructosyl)-L-lysine (or fructose lysine) by the loss of three molecules of water. The structures of these compounds have been determined and their possible mechanism of formation has been postulated. The structures of these amino acids follow:
Animal feeding studies of UHT-milk have shown that, in general, the biological value, protein efficiency ratio and digestibility coefficient are not affected by UHT sterilization (21,72). Some studies, on the other hand, have shown that with denaturation of serum proteins, there is a proportionate decrease in the growth-supporting value of the milk protein for test animals. It was concluded that denaturation is not a significant factor in human infant nutrition (21,72). However, a recent study (7) changes this hypothesis. In a feeding test involving 400 newborn infants in Holland, 200 children drinking UHT-milk gained an average of 7 g more weight per day than the 200 drinking pasteurized milk. In addition, the normal weight loss immediately after birth was regained sooner by the UHT-fed infants. The UHT-milk also caused fewer digestive problems.

**Unsaturated fatty acids**

The loss of polyunsaturated fatty acids, in which milk is already poor, may be important. Heating milk at 130°C for 20 sec causes a loss of 34% linoleic, 13% linolenic, and 7% arachidonic acid (99).

**Enzymes**

Phosphatase activity is always zero after milk has been sterilized but may be reactivated after prolonged storage. The higher the storage temperature and the longer the storage time of the milk, the higher the degree of reactivation of the enzyme. According to some workers (41), this reactivation phenomenon may be an artifact caused by liberation of sulfhydryl groups which also react with the phosphatase test reagent and thus yield a positive test. Other workers (21) have established that the reactivated enzyme is identical in chemical form to the original enzyme and this reactivation is enhanced by free SH groups but retarded by oxygen and lower storage temperatures.

Peroxidases are almost always destroyed and proteases are usually destroyed at UHT sterilization temperatures. No reactivation of peroxidase has been observed under any storage condition. Some researchers (2,21) have suggested that proteases may be reactivated on storage. Kielwein (50) has suggested that UHT processing may not ensure complete inactivation of *Pseudomonas fluorescens* proteases. Adams et al. (2) found that 70-90% of raw milk analyzed contained psychrophilous which produced proteases that survived 149°C for 10 sec. These authors suggest that thermal input needed to destroy heat-resistant proteases would damage the milk severely. However, West et al. (101) suggested an effective method of inactivating proteases; when UHT-treated (149°C for 4.5 sec) skim milk was maintained at 55°C for 1 h, an average of 88.5% of the heat-resistant proteases were destroyed. Barach et al. (12) determined that bacterial protease activity in buffered solutions was reduced 90% during 10 min at 55°C. In either raw or sterile milk, however, the extent of inactivation was less, e.g. 70% during 60 min at 55°C. The rate of inactivation did not depend on protease concentration.

Kiermier and Doruk (51) have demonstrated that beta-glucuronidase in milk is completely inactivated by pasteurization (63°C for 30 min or 72°C for 15 sec) but not always fully by UHT processing. The heat liability (up to a maximum of 100°C) of lipase (46,84), catalase (46,84) and adolase, a-amylase, amylase, lysozyme and ribonuclease (84) also has been reviewed.

Greenbank and Pallansch (36) found that heating whole milk to 90°C for 15 sec inactivated xanthine oxidase. Yet, when the same milk was condensed to 50% total solids and homogenized at 4,500 psi, some reactivation was noted; this reactivation was not observed in powders from milks heated 93°C.

**Sedimentation, gelation and burn-on**

The intensive heat from the heating agent during UHT processing usually causes denaturation of the milk proteins or precipitation of the salts in milk; this causes sedimentation. The higher the sterilizing temperature, the more the sedimentation. Maximum sedimentation in UHT processing at 140, 145 and 150°C occurs with a 4-sec holding time (21,41). In general, sedimentation in UHT-milk is not a serious problem; in a recent study the average sediment of 77 trials was only 0.5 pl/cc (41). Calcium balance and addition of salts affect sedimentation. Adding sodium citrate or bicarbonate inhibits sediment formation, but calcium promotes sedimentation (41). Biryukova et al. (15) established that adding 0.025-0.1% sodium citrate or disodium phosphate increased the heat stability of milk against sedimentation by 50 to 100%.

Preheating helps stabilize milk exposed to high heat treatment (41) Biryukova et al. (14) tested the effect of preliminary heating on the stability of milk proteins. They concluded that for indirect UHT processing, the milk should be preheated to 75°C for 20 sec and the precipitated protein centrifuged out. Ball (11) suggested preheating milk in a retarder vessel at 85°C for 6 min. This would help alleviate the problem of milk-stone deposits on heating surfaces.

Homogenizing at temperatures lower than normal also reduces sediment formation. Homogenization after processing, rather than before processing, also cuts down on sediment formation (41). During storage, some of the sediment apparently returns to solution and thus the total amount of sediment is reduced (21).
Differing views have been cited, but usually indirect heating has been found to cause more sedimentation than direct heating (21,23). Perkin et al. (71), however, claimed that in none of the experiments comparing direct and indirect heating methods was any attempt made to control the severity of the heat treatment. In their experiments, when heat treatments of the same sporidical effectiveness were given, directly-heated UHT milk gave twice as much sediment as indirectly-heated milk.

Claesson et al. (25) have suggested that deposit formation in UHT sterilizers could be prevented by adjusting the pH of the milk to 6.9; however, this increases the non-protein nitrogen in the UHT milk.

Gelation in UHT milk is an important problem because it signifies the final limit of storage life (21). The mechanism for gelation has not been well established but is probably similar to that for clotting of milk during cheese-making. The main difference is that the former occurs naturally and the latter is induced. Also, a gel is softer than a clotted curd. Sensitivity to gelation is greater with UHT processing than with sterilization in a container. It also has been reported that after being autoclaved in the bottle, milk does not gel for long periods (79). The relationship between gelation and sedimentation is not clear. Andrews and Cheeseman (4) believe that gelation is a first step towards sedimentation. They have postulated, based on molecular weight changes of casein components, that at least two processes take place during storage of UHT milk. The first process is the result of physical forces of association, such as hydrophobic bonding between the casein and lactose, which leads to the formation of a gel. The second process is the Maillard reaction where formation of covalently-bonded polymers leads to browning and sediment formation.

Researchers are still not sure whether gelation is due to enzymatic action or chemical and physical processes (3). Some workers have considered possibilities that a reactivated proteolytic enzyme might cause gelation (21,79). Extensive protein breakdown of K-casein to para-K-casein (similar to rennet action) was observed in UHT milk that had gelled due to protease (P. fluorescens) activity (54). β-Casein was also broken down rapidly while α-casein was degraded slowly. Burton (21) has concluded that coagulation is caused by the slow action of proteolytic enzymes (eg. from psychrotrophs such as pseudomonads), which ultimately destabilize the casein. Nakai et al. (65) found no evidence of proteolytic enzymes in sterile concentrated milk after a few weeks of storage although the samples had gelled. Samel et al. (79) also found that proteolysis was not the primary cause of gelation in UHT-milk. Some researchers (21) have suggested that both coagulation and development of a bitter flavor might be caused by protein changes and might be related. High heat and long holding times increase the extent of coagulation. Studies (68,79) have indicated that reactive sulfhydryl groups may contribute to instability of milk protein leading to gelation and/or deposit formation. Citrate delays coagulation. An inverse relationship has been observed between the degree of protein decomposition and the time of onset of gelation in UHT-milk (79).

Corradini (26) determined that the resistance of UHT-milk to gelation on storage can be increased in three ways: by reducing the flow-rate of the milk through the sterilizing equipment, by adding 0.01-0.15% disodium phosphate and by storing the product at 10 C. Varying heat treatment improves control of gelation; however, adding polyphosphates controls best (21).

**Clotting properties**

When treated with enzymes such as rennin or pepsin, UHT-processed milks do not clot as well and require twice as much time to coagulate as pasteurized milk (21). When Burton (21) suggested that UHT-milk did not clot “well”, he probably meant that the curd obtained was not too firm, which would probably decrease cheese yields. Perkin et al. (71) found that indirect heating reduced the rate of UHT-milk clotting with rennin and pepsin more than direct heating. On the other hand, Stone et al. (89) reported conflicting results when they studied the effect of sterilization (113-158 C) treatment of milk on cheese starter activity and on the quality and yield of short-set cottage cheese curd. Their curd quality rated good, starter activity was 8-12% faster and yield was 4-12% higher for UHT curds than for curds from milk pasteurized at 62.7 C for 30 min. Stone et al. (89) confirmed that the UHT processes (115 to 157 C) that denatured up to 42% of the heat-denaturable whey proteins produced curd with flavor, body and texture similar to curd made from pasteurized milk (72 C for 30 min); also the rate of acid development was faster in the UHT curd. In a combination of two new processes, Schafer and Olson (62) found that UHT treatment (130 C for 2 sec versus 80 C for 2 sec) significantly increased yields and recovery of fat and solids-not-fat in Mozarella cheese made by direct acidification. Woods (109), in a review, found that though observations and opinions vary, many workers find that UHT treatment supports bacterial growth better than conventional pasteurization techniques. The relationship between heat treatment and the growth rate of lactic streptococci can best be described by a U-shaped curve. Oxygen expulsion, destruction of inhibitors, partial protein hydrolysis and whey denaturation were believed to be responsible for the low heat treatment stimulation (62-71 C for 30-40 min) of starter cultures, formation of toxic volatile sulfides was associated with inhibition in the middle heat treatment ranges (71 C for 45 min, 81 C for 10-45 min or 90 C for 1-45 min) and heat-induced (autoclaving or extreme heating) disappearance of sulfides resulted in stimulation of lactics at high temperatures. Woods (109) reported that the process of UHT-heating of skim milk to increase yields of cottage cheese has been patented.

**Freezing point**

It has been claimed that UHT processing raises the
freezing point of milk, leading to a false diagnosis of adulteration by water. In one study with indirectly-heated UHT milk, it was demonstrated that the freezing point remain unchanged. In other studies, it has been shown that for Uperization and vacuum pasteurization (processes where dissolved gases are removed from milk), the freezing point has been raised (21).

**Fat separation**

High temperatures of processing reduce the cream line in whole milk (21). The stability of fat dispersion in UHT-milk can be increased by proper homogenization. Homogenization at 211 kg/sq cm and 71-77 C with the homogenizer located down-stream from the heater will greatly reduce fat separation in UHT-milk (41).

**Color**

The appearance and color of milk primarily depend on the size gradient of the fat globules, distribution of the milk proteins and the browning reaction (40). Non-enzymatic browning of UHT-milk affects its flavor more significantly than its color (41). UHT-milk is whiter than the corresponding raw milk. Whitening is believed to be caused by denaturation and subsequent coagulation of soluble protein components of milk, which increase the amount of opaque particles in the milk (21). The smaller the fat globules, the whiter the color of milk because these fat globules help scatter light.

Hostetler (40) observed a striking difference in the color between Uperized and autoclaved milk under ultra-violet light; Uperized and pasteurized milks show yellow fluorescence while autoclaved milk shows blue fluorescence. Burton (18,19,20) demonstrated that UHT-milks reflect considerably more light in the 400-550 nm (violet, blue and green regions of the spectrum) range than do milks sterilized in bottles.

**Texture**

A chalky texture is a frequently-mentioned shortcoming of UHT processed milks, particularly those processed by direct heating methods. This is apparently an early stage of sediment formation. Homogenization after heat treatment alleviates this (21).

**FLAVOR**

The flavor of UHT-milk is only slightly different from pasteurized milk (40). At higher processing temperatures, the aromatic substances of the milk which cause odors such as feedy or barny are removed more efficiently. Thus, consumers find the UHT-milk to be flat or “purer.” On the other hand, some consumers also criticize the UHT-milk for off-flavors, such as cooked and stale.

In the direct-heating UHT processes where steam is injected into milk, or vice versa, the condensed steam has to be removed. This is accomplished when the milk is vacuum-cooled by flashing it into an expansion vessel under vacuum. Besides moisture, a major portion of the aromatic components, the sulfhydryl groups (SH) and oxygen also are removed. This deaeration helps retard the changes induced by oxygen. Cooling by flashing also is used after some indirect UHT processes; then the amount of moisture removed is returned to the milk (40).

Hansen et al. (38) processed milk at several temperatures between 107-143 C and stored the milks at 1.7 and 7.2 C in polyethylene bags or clear glass containers. The milks, evaluated by a 25-member panel at 2, 9, 16, 23 and 30 days, were judged from acceptable to good. The cooked flavor disappeared in 9 days and gave way to a slightly sweet flavor. In general, the flavor was most acceptable at 9-16 days.

Ashton (9) classified the general flavor changes in UHT-milk packaged in waxed paper and polythene laminate cartons and stored at between 4 and 22 C into 5 periods: (a) Period 1, immediately after processing. Unpleasant taste and smell, hydrogen sulfide, carbon disulfide and boiled cabbage flavors. (b) Period 2, at 2-3 days. Weaker hydrogen sulfide, cabbage and less unpleasant flavor, slight residual “cooked.” (c) Period 3, at 5-12 days. Best flavor is at this stage, traces of initial unpleasant flavor, creamy taste similar to pasteurized milk. (d) Period 4, at 12-18 days. Appearance of flat, chalky or slight residual cooked flavor. (e) Period 5, at 19 days. Slight development of incipient oxidative rancidity or “cardboardy”, becoming progressively more obnoxious with age.

According to Ashton (9), all the above stages progress faster if higher storage temperatures are used. The time necessary to pass through each stage does not depend on the thickness of the carton’s internal polyethylene layer. A black lining also does not affect the rate at which off-flavors develop; however, an aluminum foil lining helps increase the duration of each phase. The off-flavors that Ashton associates with Period 5 (incipient oxidative rancidity, “cardboardy”) are probably what some other researchers (29,96,105,106,107) call stale.

A U.S. committee on Flavor Nomenclature (85) has hypothesized that there are four kinds of heat-induced flavors: cooked or sulfurous, heated or rich caramelized and scorched. Milk when heated to 135 to 150 C for several seconds exhibits a strong sulfurous or cooked flavor; after several days of storage this flavor disappears to leave a rich or heated note. Volatile sulfides are believed to contribute to the cooked flavor and it has been suggested that nonenzymatic browning causes the caramelized flavor but the compounds responsible for the rich or heated note have not been clearly elucidated. It is possible that what many researchers refer to as “stale” (29,96,105,106,107) is a combination of “rich or heated” and “caramelized”. A method of preparing reference standards for these flavors has been presented (85).

**Cooked flavor and sulfhydryls**

The cooked off-flavor is one of two primary flavor criticisms of UHT milk. Cooked flavor is first noticeable when raw milk is heated momentarily to about 75 C or when it is exposed to lower temperatures for a prolonged time (42). Heat liberates volatile sulfides and sulfhydryls and lowers the redox potential. The sulfides and
mercaptans result from the heat denaturation of only the serum proteins (42). \( \beta \)-Lactoglobulin, the major component of the albumin fraction of the serum proteins, can account for almost all the volatile sulfur-bearing compounds. The susceptibility of generic variants of \( \beta \)-lactoglobulin to heat denaturation are in the order C > B > A (81). The volatile sulfur-bearing compounds probably originate from methionine, cysteine and cystine which are the only common amino acids containing sulfur. The probable mechanism of the cooked flavor involves conversion of those amino acids to hydrogen sulfide and methyl sulfide (69). Cabbagey defects in UHT-milks have been correlated with hydrogen sulfide, carbonyl sulfide, methanethiol, dimethyl sulfide and carbon disulfide (43).

Blankenagel and Humbert (16) showed that in the 82-140 C range, the primary effect of the increase in temperature on skim milk was denaturation of serum proteins; \( \beta \)-lactoglobulin is completely denatured at 130 C. They also reported that denaturation yields sulfhydryls which cause the cooked flavor. After a week of storage at room temperature, the volatile sulfur compounds were completely gone; but at 4.5 C, the rate of disappearance was much slower. This observation was confirmed by Lyster (56) for UHT-pasteurized milk stored in screw cap bottles. Burton (20), Hostetter (40) and Ashton (9) pointed out that UHT-milk had a hydrogen sulfide odor and a cooked flavor immediately after processing but they disappeared within 24 h after processing.

Patrick and Swaisgood (68) found that the reactive sulfhydryl groups in UHT-skim milk were oxidized more rapidly at room temperature than at refrigeration temperature. Concentrations of reactive sulfhydryls in UHT-milk were correlated with the undesirable "cooked" flavor, and it was speculated that these could contribute to instability of milk protein through disulfide interchange reactions.

Hostetter (40) cited evidence to show that the decrease in concentration of sulfhydryl compounds is accelerated by exposure to light and higher storage temperatures. Milkfat retards the loss of sulfhydryl compounds, and whole milk loses sulfhydryl compounds more slowly than does skim milk. Summer milk resists loss of sulfhydryl compounds better than winter milk.

It has been suggested that the differences in SH stability at different heating temperatures, holding times, and storage times are due to the enzyme sulfhydriloxidase which oxidizes the SH groups linked to protein compounds (50). Sulfhydriloxidase has been isolated from raw milk, purified and characterized by researchers at North Carolina State University (44,91); furthermore, they have developed a method of immobilizing the enzyme on a laboratory scale.

Jordan (48) confirmed the cooked flavor of milk disappeared within a few days because of oxidation. In the direct UHT process, oxidation occurs more slowly because oxygen is removed by vacuum cooling. When oxygen is passed through the product, oxidation of the reducing substances is accelerated. This process has been patented by AB Tetra Pak in Sweden (40).

Zadow et al. (112) tested the influence of anti-oxidants (10 mg of butylated hydroxy-anisole + 10 mg of toco-pherol + 50 mg of Tween 80 per kg of milk), storage time (1-week interval for 3 months), storage temperature (2 or 20 C), and re-examination 2 days after opening on the flavor acceptance of UHT-milk (150 C for 6 sec or more) stored aseptically in cans. Statistically, the presence of antioxidants was the most important factor; three of four panels preferred milk with antioxidants, the fourth objected to the metallic taste imparted by the antioxidants.

Ferretti et al. (29) recently recommended a sulfhydryl blocking agent to control cooked flavor in sterile milk concentrates. The blocking agent used was 2-acetamidoethyl-2-acetamidoethane-thiosulfonate at the rate of 3.8 mg/100 ml of reconstituted milk. Results indicated that if this blocking agent is added after the sterilization process, the milk flavor is more desirable - especially during the early days of storage at 4 and 21 C. As the storage time increased, however, the differences between the control and the treated samples narrowed, and the milks were criticized as stale, scorched or typical evaporated milk. Samuelsson (80) has patented use of 30 ppm of potassium iodate, and Food Innovation AB (32) has patented use of 5-70 ppm of sodium iodate, sodium bromate, potassium iodate or potassium bromate to inhibit formation of SH groups and thus improve the flavor of UHT milk. Badings (10) found that 30-70 mg of L-cystine added to every kg of milk before UHT sterilization reduced cooked flavor intensities and hydrogen sulfide concentrations.

**Stale**

Besides cooked, the other common flavor criticism of UHT milk is "stale." Two basic approaches have been used to study the stale flavor. The first involves elucidating the mechanism, and the second involves identifying the compounds associated with the flavor. The stale flavor becomes noticeable after the cooked flavor starts to diminish (29,96).

Schmidt (83) found that off-flavors developed in UHT-milk within 3-6 weeks at 20 C and 1 week at 38 C. UHT-milk of reduced fat content (1.7%) showed less sensory change during storage. Storage of sterilized milk in daylight caused sensory deterioration but did not affect free fatty acids and hydroxymethylfurfural content. On the other hand, Langsrd and Hadland (53) found that when UHT-sterilized goat's milk was stored at 4, 20-25, 30, 37 and 50 C, maximum increase in non-protein nitrogen was at 50 C accompanied by a bitter flavor (within 7 days), increased 5-hydroxymethylfurfural content, reduced lysine and distinct browning. At all temperatures except 4 C, there was progressive browning related to temperature, along with destabilization of fat and some sedimentation — but no gelation.

According to Thomas et al. (96), some investigators
associated the stale flavor with products of the Maillard reaction. 1-Amino-1-deoxy-2-ketohexose was identified as the stale principle in sterile milk concentrate (96). This is a product of the Maillard reaction and thus, browning and staling were related.

In a series of experiments (105,106,107), Whitney's research group proved that a stale-flavor component, which develops in dried whole milk upon storage, was present in the butter oil fraction. They also established ideal conditions for a steam distillation procedure by which the stale component could be distilled and trapped in fresh butter oil or distilled water.

In a recent series of papers, Moller et al. (61,62,63) studied chemical changes in UHT-milks during storage. Caseins from stored UHT-milks resisted proteolysis better than casein from unheated milk (61). This resistance was attributed to the Maillard reaction between milk proteins and lactose during storage of UHT-milk. The first stable intermediate (62) of this reaction was identified as lactuloselysine (L-N-deoxy-lactulosyl-L-lysine) and its hydrolytic breakdown product fructoselysine (L-N-deoxylactulosyl-L-lysine). Indirect evidence for their formation was obtained when Finot et al. (30) identified furosine and pyridosine in roller-dried milk powder. Among UHT-milks stored at different temperatures for different times, browning was most apparent at the highest temperature for the longest time (37°C for 3 years) and in this, only part of the lysine residues was accounted for as lactuloselysine and fructoselysine. Thus lysine had become involved further in sugar degradation products.

The volatile chemical compounds identified in a number of different kinds of stored milk products have been reviewed by Arnold et al. (8). The compounds identified are n-aldehydes (C1–C3, C5–C10, C12, C14), n-methyl ketones (C1–C3, C7, C9, C11, C13, C15), n-fatty acids (C4, C6, C8, C10, C12, C14, C16), 2-pentanone, 2-hexanone, 2-heptanone, δ-decalactone, δ-dodecalactone, furfuraldehyde, benzaldehyde, 2-methylheptanal, α-aminoacetophenone acetone, penty acetate and dimethyl sulfide. In experiments with stale, sterile concentrated milk, Arnold et al., identified 2-heptanone, 2-nonanone, 2-tridecanone, benzaldehyde, acetoephene, naphthalene, a dichlorobenzene, δ-decalactone, benzo-thiazole and α-aminoacetophenone. Of these compounds, only the dichlorobenzene and 2-heptanone were identified in the control milk. Control milk was stored at 1°C and the experimental milk at 22°C. More recently Jeon et al. (47) observed increases of acetone, methylketones (C3, C5, C7, C9, C11, C13), n-aldehydes (C1, C5, C6, C7, C9, C10) and 1-butanol in UHT (145°C for 3 sec)-milks stored at 3, 22 and 35°C for 5 months. Although the methyl ketones were most abundant, aldehydes appeared to be the significant contributors to the off-flavor of stored UHT milk. Oxygen in milk affected concentration of only the aldehydes, whereas storage temperature affected concentrations of aldehydes and the methyl ketones. Some observations of Jeon et al. were corroborated by Mehta and Bassette (58). Increase in stale off-flavor intensity for UHT-milk stored at 22°C occurred concurrently with increases in propanal, pentanal and hexanal and decreases in cooked flavor and methyl sulfide. No lipid oxidation was observed and although some relationship was observed between browning and UHT heat treatment, changes during storage were significant only during the first period (12 days) of storage. Mehta and Bassette (58) suggested that development of staling as cooked flavor disappeared suggested that the mechanism for staling depends on the oxidation-reduction potential. Refrigeration at 4°C helped retard but not eliminate the rate of increase of the aldehydes and stale off-flavor (59). Hostettler (40) confirmed that UHT-milk resisted formation of oxidized flavors better than did pasteurized milk because of reducing substances. These reducing substances are probably sulfhydryl in nature. Keeney and Patton (49) also associated some lactones with off-flavor in stored milk products. The flavor they described as non-oxidative was probably what other researchers referred to as “stale.” However, Lyster (56) associated δ-dodecalactone and δ-dodecalactone and Keeney and Patton (49) associated δ-decalactone with a coconut-like off-flavor in stored milk products.

Morgan et al. (64) patented a process for adding .002-0.4% of a citrus bioflavonoid, preferably hesperidin, to a milk product before sterilization. They claim that these bioflavonoids prevent stale flavors in sterilized canned milk products during storage.

Oxygen

Zadow (110) observed that after storage for short periods, UHT-milk with a high oxygen content was preferred. After storage for prolonged periods, the flavor of milk with low oxygen was found to be better. The deterioration in flavor resulted in oxidized or slightly rancid off-flavors. The two main factors that affect development of off-flavors in UHT-milk are level of oxygen and temperature of storage (111).

Tarassuk (93) studied the effect of oxygen content in the head-space of cans sterilized by autoclaving at 85-120°C. A correlation was found among carbon dioxide produced, oxygen depleted, the intensity of cooked flavor, and the degree of browning discoloration (measured by sensory evaluation). The data suggest that the flavor and color of sterilized milk may be improved by lowering the available oxygen in a can before sterilization. This also suggests that if the oxygen in the milk during UHT processing is limited, milk with a better flavor can be produced.

Thomas et al. (96) experimented with the effect of oxygen content on the flavor of indirectly-heated UHT-milk during a 150-day storage period at room temperature. The UHT-milk was prepared with initial oxygen contents of 8.9, 3.6 and 1.0 ppm which represent almost the entire range of concentration expected under normal processing conditions. Flavor acceptability was maximum at 6 days, after which it slowly declined. The
increase in acceptability from 0 to 6 days was associated with the decrease in the off-flavor described as cabbage; after 6 days, the milks started acquiring a stale characteristic. Up to 8-13 days, the higher the initial oxygen content, the more acceptable a milk was; however, after this, the acceptability did not depend on initial oxygen content. Losses of sulfhydryls, ascorbic acid and folic acid were less with lower initial oxygen and vice versa, but the benefits of high oxygen content on flavor were slight and were outweighed by the adverse nutritional effects.

Zadow and Birtwistle derived a relationship between the level of dissolved oxygen in a product and the head-space volume of a sealed container. The total mass of oxygen in a container can be calculated if the filling temperature, head-space volume, pressure of oxygen in the milk and the mass of the milk are known.

Packaging

The ideal packaging material should be odor-free, non-reacting, sterile and nearly impermeable to air and light. Hostettler has reviewed the effect of packaging on the flavor of milk. Frequently plastic foils used in the dairy industry have an odor. For instance, polyester foils (polyethylene terephthalate) may have terephthalic acid which has a paper-like odor; polyethylene foil, an odor of oxidized oil and wax; polypropylene foil, a burnt and phenolic odor.

Hansen et al. cited evidence to show that when UHT-milk was packaged in a polythene bag and cardboard box, the size of leaves and components in the cardboard were absorbed through the polyethylene (PE) films. The resultant cardboard flavor was eliminated when sterile glass containers were used.

Bojkow tested the effect of PE-laminates on the flavor of milk and water. He concluded that oxidation of the PE-film was the most common cause of PE-related off-flavors. Some stale, bitter and astringent flavors in milk were shown to emanate from the PE-film. These were more intense in the water than in the milk. The intensity of off-flavors transferred from the film decreased when the package materials were stored for a long time prior to use.

Flittkiger compared 1-liter PE-coated cartons with (AC) and without (PC) aluminum foil. The AC did not lose any weight during a six-week storage period. During the same period, the PC lost about 0.2% of the original weight during storage at 20°C and about 1% at 38°C. The oxygen in the milk in AC remained almost unchanged (1 ppm); however, in PC, the milk was saturated with oxygen (8 to 9 ppm) after a few days. Most of the oxidative changes in the PC took place in the first 2 or 3 days after processing. In other words, the reducing substances in the milk that offer protection against oxidation decreased rapidly in PC cartons. This milk was organoleptically acceptable up to 3 weeks when stored at 15°C. The AC milk was organoleptically acceptable up to 2 months even at a storage temperature of 38°C. Mehta and Bassette confirmed that UHT-milk in AC cartons retained a desirable flavor longer than that in PC cartons, at least partly because PC cartons were more permeable to gases. Wrapping either carton with Saran and aluminum foil was detrimental to flavor, probably because the wrapping not only excluded outside air from the milk but also served to exclude volatile compounds coming from either growth of microorganisms on the surface of the cartons or from the wrapping material itself.

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224 MEHTA


JOURNAL OF FOOD PROTECTION, VOL. 43, MARCH, 1980


JOURNAL OF FOOD PROTECTION, VOL. 43, MARCH, 1980