PG Institute of Dairy Education and Research, Mehsana

Doctoral Seminar (DE-692)

Advances in UHT Processing in Dairy Industry

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1.0 Background

The commercial sterilization of milk finds its origin from the beginning of the 20th century derived from the work of Nicholas Appert. The continous-flow sterilizer constructed to heat milk at temperature 130 – 140 ^{o}C had been first patented in the early 20th century. More practical solutions were developed by Jonas Nielson in 1908. (Burton, 1988). Since then, the UHT applications were adopted for market milk, cream, Pea soup, ice-cream mix, etc.(Scott, 2008). In 1957, an experiment done by Feliciotti and Esselen showed the advantage of high-temperature –short –time processing for retention of Vitamin B1 (Thiamine). Subsequently it was shown that many quality factors, including colour and flavour, show the same temperature dependence as the vitamins. (Lund, 2018). In 1961, the first commercial UHT system with aseptic packaging line was developed for milk (Robertson, 2016).

Initial industrial adoption of UHT and aseptic systems were facing the problems of material handling and packaging along with slower speed of the line. The speed was even slower than the commercial in-can sterilizer systems. FDA approved use of hydrogen peroxide as surface sterilant in 1981, even-though the processing line speed did not increased significantly. Aseptic processing lines seek development from 1981 to late 90’s in which the process was developed for products such as juices, starch based viscous puddings, etc. These developments were primarily driven by lower cost of flexible packaging materials as compared with metal containers. (Lund, 2018).

2.0 Introduction

Ultra-High-Temperature (UHT) processing involves the treatment of the product in a heat exchanger accompanied with filling it in a pre-sterilized container in aseptic environment (Burton, 1988; Holsinger *et al*., 1997; Gedam *et al.*, 2007; Fellows, 2009). It provides extended shelf life of the product with commercial sterility (Malmgren, 2008). The products are then checked for sterility by incubating at 55 ^{o}C for 7 days or 30 ^{o}C for 15 days (Sahoo et al., 2002).

UHT processing of milk is usually done at 135 – 150 ^{o}C in combination with appropriate holding times. All UHT processes involve the aseptic packaging of product in plastic bottles, laminated plastic cartons (Scott, 2008). This is an essential part of UHT processing as it ensures that the sterilized product is not contaminated while packaging, thus enabling the product to be stored at room temperature for several months. The packaging provides barrier properties and their selection have a significant influence over the shelf life during the storage period (Simon and Hansen, 2001). UHT sterilized product needs to be stable for a longer period of time but the desired shelf life is 3-6 months.

However, some physico-chemical changes such as are brown coloration, sedimentation, protein destabilization, fat separation, changes in protein, enzyme inactivation, destruction of vitamins in products are associated with UHT processing (Chavan *et al*., 2011). The achievement of thermal sterility with minimal changes in quality attributes is the key feature of UHT processing.

UHT processed dairy products include milk, modified milks, flavored milks, creams, ice-cream mixes, and whey-based drinks (Datta and Deeth, 2007). Several commercially UHT products are available in the market with the brand names of AMUL, Flourish, Nestle, etc.

2.1 Market Scenario

According the IMARC Group, the global UHT milk market has grown at a Compund Annual Growth Rate (CAGR) of 5.9% during 2011-2018, reaching a volume of around 107.4 Billion Litres in 2018 (Anon., 2018). In India, 2 % of the market share is by Value added dairy products like cheese, yoghurt, UHT, whey based products; out of which the UHT milk shares 1 % of the total dairy industry. However, the market share of UHT milk is increasing with a CAGR of 25 %. Its market share is estimated to be 104 billion Indian National Rupees by the year 2020. (Sheth and Jain, 2017)

2.2 Theory of thermal sterilization

The theory of thermal sterilization is based on the thermal death curve, expressed in terms of involves utilization of parameters like D-value, z-value, Q_{10} value, F_o value etc.. The theory of thermal death kinetics for microorganisms has been discussed by several authors in deciding the time-temperature combination for the heat treatment for processing of several dairy and food products (Burton, 1988; Haas *et al.* 1994; Chan *et al.*, 1996; Huemer et al., 1998; Sahoo *et al.*, 2002; Xu *et al*, 2006, Mullan, 2018). The sterilization effect can be studied by the Thermal Death Curve which can be represented by the equation.

$$\text{Log } (N/N_o) = -K_\theta\, t$$

2.3 B* and C* values

The effective working range of UHT treatments is also defined in some countries by two parameters: bacteriological effect: B* (known as B star) and chemical effect: C* (known as C star). B* is based on the assumption that commercial sterility is achieved at 135 ^oC for 10.1 s with a corresponding *z*-value of 10.5 ^oC. The C* value is based on the processing conditions with not more than 3% destruction of thiamine per unit. This is equivalent to 135 ^oC for 30.5 s with a *z*-value of 31.4 ^oC (Kessler, 1981, Chavan *et.al*, 2011). A UHT process operates satisfactorily with regard to the keeping quality of the product when the conditions of B* > 1 and C* < 1 are fulfilled (Deeth and Lewis, 2017).

3.0 Physicochemical changes occurring in UHT milk

Heat treatment involves two reactions: Type 1 reactions involve the denaturation, degradation and inactivation of whey proteins, enzymes and vitamins. Type 2 reactions involve the formation of lactulose, Hydroxy Methyl Furfural (HMF), furosine and others, which are not detected in the raw milk (Morales *et al.*, 2000). The cooked flavor after UHT processing is due to sulfhydryl (S–H) groups, which oxidize 5 - 10 days after processing (Chavan *et.al*, 2011). Shah et. al. 2014 reported that pouch packed UHT milk in multilayer EVOH packaging film showed physic-chemical changes during storage with shelf life of upto 90 days; simultaneously it was reported that the quality of UHT milk had no influence of seasonal variations in microbiological quality of raw milk.

The browning as consequence of Maillard reaction is more dominantly seen in UHT milk (Deeth, 2010). The formation of HMF can be described through Arrhenius equation (Singh and Patil, 1989). Maillard browning, as a function of heat treatment given to milk was detected by front face fluorescence spectroscopy and HMF analyses (Schamberger and Labuza, 2006). Since browning takes place in the non-fat part of milk, it is more marked in separated milk for the same intensity of heat treatment and much less in cream (Burton, 1988). Product browning is more pronounced with increase in process severity and storage temperature.(Scott, 2008; Raljic *et al.*, 2008)

Milk proteins change more than any other milk constituent due to UHT processing that contributes to loss of color, flavor, nutrition, gelation and sedimentation.(Depypere, 2009) The UHT processing increases the size of casein miscelle. (Morr, 1969, Scott, 2008) The gel which forms is a three-dimensional protein matrix initiated by interactions between the whey protein β-lactoglobulin and the k-casein of the casein micelle during the high heat treatment (Datta and Deeth, 2001).

Enzyme inactivation happens to be a positive chemical change of UHT processing. Furthermore, the effect of heat is minimal in Fat-soluble vitamins, as compared to water-soluble vitamins which are destroyed partially in UHT processing. The proteinases can produce a bitter taste and gelation, whereas the lipases can produce rancid flavors during storage. Age gelation is a popular defect in UHT milk. If KIO_3 (0.23 M) at the rate of 13 mL/30 L of milk, reduces protease activity in milk but on the contrary increases plasmin activity. Similarly plasmin activity reduces stability of UHT milk and increase sedimentation. Non enzymatic gelation is caused by polymerization of casein and whey proteins by Maillard reactions. Heat stable amylases can cause thinning in UHT desserts such as puddings and custards (Scott, 2008; Chavan *et al.*, 2011). Age gelation can be reduced by addition of emulsifier in milk, a combination of protein and Fat or Fat replacer at lower levels @ 1 % by weight (Conte et.al, 2014).

Lactulose is considered as the index of heat treatment, which is initially absent in milk but is formed during UHT processing. (Berg, 1993; Elliott *et al.*, 2003). Sedimentation in UHT milk is more if pH of milk is less than 6.65, and ionic calcium is more than 1.5mM (Gaur et.al., 2017). Lactose hydrolysed milk is more prone to chemical changes during storage (Jansson et.al. 2014).

UHT milk fortification with iron, magnesium and zinc upto 50 % of RDA values was carried out just before the main heating; the sensory attributes were acceptable however, off flavours and poor stability of milk beyond 60 days was observed (Abdulghani et.al, 2015).

4.0 Advances in UHT Systems in Dairy Industry

A wider range of heat exchangers are available which can be judiciously selected as per the feasibility of the operation The design of equipment and time-temperature combination plays significant role in final quality of the product.. Higher energy efficiency, hygienic design and higher heat transfer co-efficient are the key features of today's heat exchangers. Tubular and plate heat exchangers are more commonly used in the dairy industry (Sahoo *et al.*, 2002; Agrawal *et al*., 2014;). The temperature, cleaning agent, concentration, fluid velocity, and time affect removal of fouling in heat exchangers (Bylund, 2015). Rate controlling of alkaline cleaning step can improve efficacy of cleaning in heat exchangers.(Hagsten et. al. 2018.)

The various aseptic packaging machines are available that gives packaging with ambient temperature shelf stable fluid dairy products. Three general types of aseptic packaging equipment are employed commercially: vertical form/fill/seal in which the paperboard composite material is sterilized by hydrogen peroxide; erected preformed paperboard composite cartons that are sterilized by hydrogen peroxide spray; and bag-in-box in which the plastic pouch is pre-sterilized by ionizing radiation. Amongst which the vertical form-fill-seal machine is most popular.

Several advancements in instrumentation and equipment designs have been documented which can effectively control and monitor the process variables (Fryer *et al.*, 2011; Aguiar *et al.*, 2012). Major progress in process control system includes instrumentation for control and monitoring process variables which include sensors for measurement of process variables; and controllers for implementing a proper (digital) control structure (for e.g. PID and PLC based systems for predictive or adaptive control, electric transducers, electric-to-pneumatic transducers, etc.).

4.1 Direct vs Indirect UHT systems

Steam, hot water and electricity are three heating methods adopted in UHT equipment. The sterilizers utilizing steam or hot water can be further categorized into direct and indirect heating systems. Direct heating modes include steam injection and infusion into the product (Burton, 1988). In the indirect system, the product and heating medium do not have contact, as a barrier (stainless steel) is present. Indirect heating with electricity includes use of electric elements, conductive heating and friction. Regeneration heat transfer reduces energy consumption and is used for direct and indirect heating systems (Burton, 1988).

Plate or tubular heat exchangers are two heating modes for indirect heating which include heat transfer between heating medium and product through a metal surface. Heating in the indirect system occurs at a slower rate; therefore, the milk is subjected to the overall heat treatment for a longer time. Medium to high viscosity products are preferably processed using tubular heat exchangers. The heat transfer coefficient is greater with plate heat exchangers due to turbulence. Production run time is lesser in plate heat exchangers as compared to tubular heat exchangers due to fouling or burn-on (Scott, 2008; Datta *et al.*, 2002).

Several UHT manufacturers viz. Tetra-Pak Ltd., GEA Procomac, STORK, Elecstar, Combibloc, etc are indulged in providing UHT technology in Dairy industry. Tetrapak offers Form-fill-Seal system in shapes of Brik, Carton, etc. Combibloc uses the preformed container for filling (Scott, 2008).The TetraPak UHT processing line includes Tetra Therm Sterilizer, TBA packing machine, Accumulator, Tetra Cardboard Packer, Tetra Conveyor and Tetra Shrink systems.

4.2 Aseptic Sterilizers and Homogenizers

Sterilization temperatures are monitored with RTD sensors and thermocouples to verify and monitor the procedure. Wet heat sterilization using saturated steam is the most dependable sterilant, as microorganisms are more resistant to dry heat, which necessitates higher temperatures (Burton, 1988). UHT sterilizers uses a tubular or plate heat exchanger under aseptic conditions to obtain the sterile product. The operation is divided into four steps: Pre-sterilization, Production, AIC (aseptic intermediate cleaning) and CIP (TetraPak, 2013). Final UHT heating is done in the main heater section and the product is held in a holding tube for the required period of time. The product is then cooled to the filling temperature and the energy efficiency is optimized by heat regeneration.

Normally, homogenization takes place prior to final heating. The provision for downstream homogenization is also available to prevent fat separation. The sterile condition of the product in this case is ensured by aseptic seal at the second stage of homogenization. (Malmgren, 2008)

4.3 Aseptic Storage Vessels

Aseptic tanks in the line between the UHT unit and the filling machine, maintains the product quality even in products not suitable for recirculation, e.g. heat-sensitive dairy products. The product sterility could be maintained for a longer period inside these tanks. Moreover, it gives great flexibility and uninterrupted production. While cleaning of UHT unit, the aseptic tank can be filled and continue to run the filling machine. Also, while cleaning the filling machine, the product can be stored in aseptic tank and the UHT unit can be kept on running. It has the steam barrier system that maintains the sterility of the product and is designed with pneumatically operating feeding mechanism thus eliminating the pumps in the forward line. (Holanowski, 2008)

4.4 Aseptic Packaging Machines

There are two types of primary aseptic packaging systems viz. (i) fill UHT product into preformed sterile packages and (ii) use a form-fill-seal system (Datta and Deeth 2007).Aseptic fillers have sections containing sterile contact pipes and valves along with noncontact sections (sterile chambers) which are to be sterilized prior to production and must maintain sterility throughout production (Burton 1988). Aseptic fillers and associated pipes are sterilized typically with steam. In-line gaskets must be able to tolerate sterilization temperatures.

Sterilants are applied uniformly to the aseptic zone by spraying, whereas packaging material is typically sterilized by spraying or passing through a sterilant bath. Examples of sterilants include chlorine, iodine, food acids, ozone, hydrogen peroxide and ultraviolet light. (Scott David, 2008, Silva *et al.*, 2012)). Hydrogen peroxide is effective at higher temperatures aprrox. 65 -70^{o} C with an FDA minimum concentration of 30% (David *et al.* 1996, Cardoso *et.al*, 2011). The residual level of hydrogen peroxide is regulated with a maximum level of 0.5 PPM. The packaging material is also sterilized through this agent before filling. (Robertson, 2016, Dutta & Deeth, 2008).

The Aseptic Packaging Machine consists of various sections like web forming, drive system, sterile air system, peroxide system, design correction system, final folder, hydraulic system, induction heating, etc.(TetraPak, 2000; TetraPak, 2006).

4.5 Packaging materials and sterilants

The commonly used packaging materials in UHT systems include 7-layer laminated cardboard systems, 5 layer flexible EVOH film pouches, pre-fabricated cartons and plastics. Hydrogen peroxide is most effective at higher temperatures with an FDA minimum concentration of 30% Combination of UV(c) at wavelength 240-280 nm and H_2O_2 acts synergistically. Peroxy-acetic acid (PAA) is a potent bactericidal considered as environmental friendly, rapidly breaks down to water, oxygen and lower concentration acetic acid. Combination of PAA and H_2O_2 is effective even at 20 ^oC (Robertson, 2016).UV(c) light has germicidal effect due to breakdown in cross linkages of adjacent pyrimidine dimers in same DNA stand leading to clonological death of the cell incapable of transcription and replication of nucleic acids (Koca,et.al.,2018).

4.6 Commercial Sterility Testing

It involves the testing of package integrity and product testing. Raw materials are tested before receipt at a frequency determined by GMP's, HACCP risk analysis. Batches of formulated product are tested prior to processing for composition and product characteristics (e.g., brix, pH, turbidity, alcohol index test, etc.) Package integrity inspections for flexible containers include visual observation, dye test, squeeze test, syringe test, seal teardown and conductivity (Grow 2000).

4.7 PET bottling systems

The recent trend is going towards PET bottling systems as they are light weight, re-closable, unbreakable, carryable and cost effective, flexible in term of design, shape, engravings, neck finishes. GEA Procomac is the first PET bottle user in India for Milk products (GEA, 2013).

5.0 Problems, their causes and remedies

The common defects in UHT milk are discussed below in Table 1:

Table 1: Defects of UHT milk, their causes and remedies

Defects	**Causes**	**Remedies**
Age thickening	Enzymes or bacterial spores.	Prevent raw milk contamination. Bactotherm process.
Sweet curdling	Enzyme activity.	Prevent raw milk contamination. Bactotherm process.
Bulging	Post processing contamination, Bacterial spores. Improper package sealing. Package integrity break. Improper sterilization.	GHP, proper sealing, avoid pin holes in process lines.
Sedimentation	Enzyme activity, Improper homogenization. Maintaining pH of milk and ionic calcium content.	Proper homogenization.
Browning/Cooked-burnt flavour	Maillard reaction. Long time circulation of milk in sterilizer at the time of filling machine breakdown	Divert plant to water circulation when filling machine breakdown occurs for longer period.
Fat Separation/Fat plug formation	Improper creaming index	Creaming index below 10. Proper homogenization
Black particles	Very long run of sterilizer and in-efficient CIP	Take sterilizer to CIP when scaling and fouling increases and perform CIP effectively.

These defects may also arise due to the failures pertaining to UHT processing (Chavan et. al. 2011). These failures can be summarized as below:

- failure arising due to raw ingredient, handling, storage, or batching issues.
- failure arising due to improper CIP, sanitation, preventive maintenance, and presterilization issues.
- failure arising due to thermal process heating cycle including regeneration.
- failure arising due to the cooling cycle including surge tanks.
- failure arising due to sterilization issues with the package.
- failure arising due to sterility loss in the aseptic zone or from environmental load.
- failure arising due to loss of package integrity.

7.0 Conclusion

UHT processing has paced up in recent times and due to the extended shelf life through which product can be made available to farthest places. It has a large range of application in food and dairy industry as well. However, some physicochemical attributes are associated with UHT processing which could be undesirable. But the technological innovations have resulted into the precisely controlled systems in UHT Processing that can control the quality and provide thermally sterile products with minimal changes in quality attributes. Efficient monitoring of process variables can be done through modern systems. The PID control systems and the automatic sensors the offer great advantages in UHT processing systems. The automatic control systems and HMI (Human Machine Interface) systems has aided in monitoring the whole process throughout. Automatic conveying and cardboard packing systems has also reduced the labour and eliminated the human error in the process.

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