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A REVIEW

Recent technologies to enhance heat stability of milk concentrates

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Abstract : Evaporated milk is used in many fields due to their various nutritional and functional properties. Evaporated milk widely finds its application in infant food formulas, as well as used for drinking after dilution, for cooking or as a coffee whitener/creamer. Evaporated milk has a higher concentration of milk proteins which leads to one of the biggest challenges that is, heat-induced coagulation due to the denaturation of milk proteins, particularly the whey proteins, and their interactions during the intense sterilization operation that is typically used to ensure a longer shelf-life for these products. As this phenomenon highly influences the product quality and production equipment, it is of great importance to improve the heat stability of the milk-proteins. The present article reviews the recent advances in different techniques that improves the heat stability of evaporated milk.

Key Words : Evaporated milk, Heat stability, Recombined evaporated milk, Milk protein, Food additives

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INTRODUCTION

Nicolas Appert was the first person to preserve milk in the concentrated form during early nineteenth century. He boiled the milk in a water bath over a fire to concentrate it and then poured it in the glass bottles and further sterilized the final product (evaporated milk) by heating the bottles for 2 h in a boiling water bath. Evaporated milk is the commercial name for sterilized unsweetened condensed milk from which a considerable portion of the water has been removed. Evaporated milk should contain 7.5% milk fat (minimum), and not less than 25% milk solids (FSSR, 2011). Milk protein should be 34% (minimum) in milk solids-not-fat. Evaporated milk is the most appropriate option for those countries where internal milk production is low. Aim of the preparation of evaporated milk is to produce a product that would not perish during storage at ambient temperature for months, and would contain the valuable nutrients of milk. It is used for making tea, coffee and other sweet dishes. In coffee or tea, a relatively small amount is sufficient to give the drink a milky flavour and a white appearance. Moreover, the Maillard products in evaporated milk result in coffee or tea having a yellowish hue. As drinking milk, evaporated milk is consumed after 1:1 dilution with (boiled) water.

Evaporated milk preparation and heat stability :

In general, the preparation of evaporated milk involves majorly seven steps. These are:

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– Pre-heating : preheating is the heat treatment given to the milk before it is concentrated. The main purpose of preheating is to increase the heat stability of the final concentrated milk. Preheating also contributes in inactivation of spores if the milk is heated upto 110°C.

– Concentration : Milk is usually concentrated in a multistage falling film evaporator. Overconcentration of milk should be avoided as it may lower the heat stability of the product.

– Homogenization : The purpose of homogenization is to prevent the aggregation of fat globules and reduce the rate of creaming during storage. In a standard production method, the concentrated milk is homogenized immediately after it has left the evaporator. Heat stability is better if the homogenization temperature is higher; for example, 55–60°C is preferred to 45–50°C.

– Stability test : A stabilizer is used to regulate the heat stability of evaporated milk, usually Na_2HPO_4 or a mixture of NaH_2PO_4 and Na_2HPO_4, is added (Pouliot and Boulet, 1991).

– Cooling and cold storage : As the concentrated product can only be sterilized if the results of stability test are known. Thus, the product is cooled and stored for a while after homogenization to conduct the pilot sterilization test. Long duration in cold storage after homogenization should however be avoided to prevent bacterial growth.

– Packaging : A food grade packaging material with mechanical resistance and permeability to water, gases hydrophobic component and light is required. Tin cans, aluminium foil-lined milk cartons, portion cups made of aluminium or polystyrene are widely used as packaging material.

– Sterilization : The evaporated milk is sterilized at 120°C for 10 min or 130°C for 2 min. Sterilization is done to kill all the microorganisms and to inactivate all microbial spores that may germinate when the conditions are favourable *i.e.*, during storage in the market.

The process of conversion of concentrated milk to the final shelf stable evaporated milk, include multiple processing steps that can be arranged in different order and thus effect the stability of concentrated milk towards the final heat treatment (Nieuwenhuijse, 2011). In-container or more recently a UHT sterilization treatment is given to evaporated milk.

Advances in evaporated milk to improve heat stability :

Heat stability of milk was historically defined as the time required to visually coagulate a sample at constant heating temperature in an oil bath for laboratory-scale assessment. This time was recorded to describe the heat stability of milk and milk concentrates and denoted as heat coagulation time. Heat-induced coagulation is an undesired physical reaction that occurs during the process preservation of concentrated milk by heat to inactivate microorganisms, bacterial spores, and enzymes to increase their shelf life. Gail Borden was granted patent in the United States and England for producing concentrated milk by evaporation using vacuum without the addition of sugars and other preservatives in 1856. Concentrated milk is preserved by either in-container autoclave sterilization (115–120°C for 5–15 min), or more recently, by continuous UHT (135–150°C for 1–10 s) sterilization. For evaporated milk manufacture, continuous heating conditions in the range of 125 to 135°C for 1 to 8 min can be applied to achieve similar product characteristics compared with in-container sterilization.

The heat stability of concentrated milk is low, as the concentrated milk has SNF upto 18-21% which coagulates during sterilization even after pre-heating (Singh and Tokley, 1990). This indicates towards the conflict between microbial inactivation and stability of evaporated milk during sterilization. At higher total solids content, all the concentrates are unstable during sterilization even after pre-heating and stabilizer addition (Webband Bell, 1943). Therefore, different technological means such as processing steps, their order, and the use of food additives were considered in order to control or improve the heat stability of concentrated milk to achieve sterilization of evaporated milk without coagulation of caseins and sediment formation. A few researches have been reported to study the effects of some food additives on the heat stability of evaporated milk as summarized in Table 1.

Sometimes, novel processing technique such as high-pressure processing (at 250 MPa and 600 MPa for 30 min) can increase the heat stability of both for unconcentrated and concentrated milkat pH >6.9 (Huppertz *et al.,* 2004).

Use of dry heat treatment of SMP for recombined evaporated milk :

Recombined evaporated milk (REM) is an ultra-high heat treated (UHT) oil-in-water type emulsion

Table 1: Effect of chemical/food additives on heat stability of evaporated milk

Sr. No.	Chemical/ Food additive	Outcomes	Reference
1.	Sodium polyphosphate	A sixfold and threefold increase in the storage life of 3:1 and 2:1 concentrate was respectively, obtained by adding 0.05 g sodium polyphosphate per 100 g milk. The polyphosphates work as stabilizers against heat coagulation during the sterilization process. The anti-gelation activity of the polyphosphates increases with increasing concentration and chain length of phosphates	(Leviton and Pallansch, 1962)
2.	Sodium dihydrogen orthophosphate, di-sodium hydrogen orthophosphate, tri-sodium orthophosphate, tri-sodium citrate, sodium hydrogen carbonate and calcium chloride	Phosphates were reported to be the most effective in inducing an increase in basic heat stability when added to concentrated skim milk (22-5 per cent TS), and that this increase only occurs when the addition is accompanied by a forewarming stage prior to concentration.	(Sweetsurand Muir,1980)
3.	β lactoglobulin	Addition of β lactoglobulin to concentrated skim-milk reduced Heat coagulation time over the entire range of the HCT/pH profile	(Singhand Fox, 1987)
4.	Phospholipids from natural sources (buttermilk)	Addition of buttermilk before preheat treatment increased the overall heat stability	(Singhand Tokley, 1990)
5.	Casein glycomacropeptide (CMP)	CMP maintained calcium binding capacity in milk and this effect conferred heat stability	(Acosta, *et al.,* 2023)
6.	Calcium depletion or addition	A 25% calcium depletion resulted in altered casein micelle structure, increased pH and a slight increase of heat stabilityof buffalo milk. While heat stability decreased on calcium addition.	(Deshmukh *et al.,* 2024)

product which is made typically by homogenization of an aqueous mixture of skim milk powder (SMP) and fat.Ultra-short-time heat treatment involving exposure of product to 150–180°C for 1–0.01 s might be capable to reduce heat-induced changes on casein micelles and subsequent aggregation, especially in milk concentrates to extend their shelf life (Dumpler *et al.,* 2020). The biggest challenge during REM manufacturing is the heat-induced coagulation during UHT sterilization, which mainly depends on the heat stability of SMP. During sterilization, the whey proteins (WP) are highly susceptible to denaturation, as it has a denaturation temperature below 80°C. The denatured whey protein then forms aggregates which results in visible coagulation and fat separation or brown discoloration which adversely affects the product quality (Newstead *et al*., 1979). The pre-heating of aqueous SMP can help in producing more heat-stable SMP but it has damaging effects on flavour or water solubility, and cannot be used in some specific applications, such as recombined pasteurized milk and cheese-manufacturing. The REM emulsions stabilized by SMP with an appropriate dry heat incubation time (e.g., 8 h) could withstand at least 30 min of heating at a typical in-container sterilization temperature (120 °C) without coagulation (Wu *et al*., 2021a).

Concentration of milk using membrane technology:

Concentrating the milk using porous membranes such as ultra- or microfiltration results in better heat stability of milk protein concentrate when compared with the milk concentrate obtained from evaporation. This is due to several reasons:

– Reduced concentration of soluble salts, especially soluble calcium, as the serum composition of milk concentrated by porous membranes is similar to un-concentrated milk

– a pH that is closer to the pH of the maximum stability of milk

– a reduced amount of whey proteins when microfiltration is applied, which increases the heat stability at pH >6.7

Ultrafiltration of milk in diafiltration mode using deionized water further increased the heat coagulation time of the final concentrate possibly due to an increase in pH and reduced ionic strength (Sweetsur and Muir, 1980). Diafiltration media that maintain the serum composition and pH of milk, such as simulated milk ultrafiltrate without lactose, could lead to optimal heat stability of the concentrate and further insights into heat-induced changes in whey protein-free milk systems with modified serum composition (Dumpler *et al*., 2020).

Addition of phospholipid enriched dairy-by-products in recombined evaporated milk :

Buttermilk is the by-product obtained during churning of cream while butter making process. Buttermilk is the reservoir for water soluble component of cream such as lactose, milk proteins and minerals (Sodini *et al*., 2006). The milk fat globule membrane (MFGM) material, rich in phospholipid is disrupted during churning and migrates into the buttermilk portion. The phospholipid fraction of the MFGM consists of phosphatidylethanolamine (PE), phosphatidylcholine (PC), phosphatidylserine (PS) and phosphatidylinositol (PI) (Patton and Keenan, 1975). MGFM- enriched and phospholipid enriched dairy-by-products, such as sweet butter milk and cream residue powder were used to improve the heat stability of recombined evaporated milk. The addition of sweet butter milk and cream residue powder gave a heat stabilizing effect in recombined evaporated milk by largely preventing the heat induced increase in viscosity and particle size. The MGFM-enriched dairy products gradually reduced the protein surface load, thereby decreasing the protein-protein interactions that leads to aggregation and viscosity increase (Kasinos and Van der Meeren, 2014).

Conjugation of milk proteins and reducing sugars:

The primary difficulty during the manufacturing concentrated milk is the possibility of heat- induced coagulation or gelation, or invisible aggregates that precipitate during storage (Huppertz, 2016). As the heat instability of milk largely caused due to protein interactions and other protein-based changes, the alteration of milk proteins through Maillard conjugation with reducing sugars can be considered as an alternative for the enhancement of the heat stability of (recombined) evaporated milk. Considering the fact that dairy products naturally contain reducing sugars, such as lactose in most dairy products and glucose/ galactose in lactose-free dairy products so no extra ingredients are needed, which is favourable for industrial application. Therefore, the conjugation of milk proteins and carbohydrates via Maillard reaction can help to develop a strategy to tackle the heat stability of recombined evaporated milk (Setiowati *et al*., 2017). In a study it was observed that the heat stability was increased in Whey Protein Isolate (WPI) - stabilized emulsions by dry heating of a mixture of WPI and lactose at 60 °C and 74% of RH (A'yun *et al*., 2020). The researchers concluded that the extra steric hindrance provided by glycated sugars and increased bound water could effectively prevent the milk proteins from aggregation during heating. The acquired knowledge from the research on the conjugation of milk proteins and carbohydrates can help to develop a strategy to tackle the thermo-stability of products like (recombined) evaporated milk. More research work on the conjugation of commercial products is still needs to be done to translate the massive experience obtained from model systems into the industrial application (Wu *et al*., 2021a and Wu *et al*., 2021b).

Use of wet heat treatment of SMP dispersion for recombined evaporated milk :

Skim milk powder (SMP) aqueous dispersions were subjected to wet heat incubation at various temperatures (70-90 °C) to enhance the heat stability of recombined filled evaporated milk (RFEM) emulsions (Wu *et al*., 2022). The effects of conjugation of indigenous lactose and milk proteins in SMP due to preliminary wet heating on the heat stability of RFEM emulsions was studied. From the experiments it was concluded that the heat stability of RFEM emulsions was greatly improved upon wet heat pre-treatment of SMP dispersions, whereby the incubation time needed to enable a heat stable RFEM emulsion was largely reduced at weakly alkaline pH conditions (*i.e.*, pH 7.6 to 8.0) as compared to the original pH (*i.e.*, pH 6.6). Lactosylation of both whey proteins and caseins occurred upon heating of SMP dispersions at 70–90 °C, which proved to be the most important reason for the enhanced heat stability of the derived RFEM emulsions. RFEM emulsions stabilized by SMP with appropriate incubation times could withstand a typical in-container sterilization procedure (30 min of heating at 120 °C) without visible coagulation. Generally, the higher the incubation temperature, the shorter the incubation time needed to enable a heat-stable emulsion against 30 min of heating at 120 °C: 4 h, 2 h and 0.25 h of wet heating was needed upon incubation at 70, 80 and 90 °C, respectively (Wu *et al*., 2021c). The results in this study are possibly significant in industrial applications of SMP where a high heat stability is desired, such as in recombined filled evaporated milk or infant formulas.

Conclusion:

Numerous studies have been investigated for the recent advances for the heat stability of milk and evaporated milk. The motivation of this article originated from the heat-induced coagulation as one of the biggest challenges in dairy sterilization, particularly in manufacturing products with a high concentration of milk protein, like (recombined) evaporated milk. The coagulation is mostly due to the destabilization of milk proteins during heating. Hence, it is of great importance to improve the heat stability of milk proteins, especially the thermolabile whey proteins. Considering the increasing demand of these concentrates and the decline of evaporated milk market share various techniques to enhance the heat stability of evaporated milk is gaining importance.

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