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Low Temperature Extrusion of Ice Cream: A Review

Awani Shrivastav and Tridib Kumar Goswami*

Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur–721302, West Bengal, India

***Corresponding author:** Goswami TK

tkg@agfe.iitkgp.ernet.in

Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur-721302, West Bengal, India.

Tel: 03222-283122

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Abstract

Low temperature extrusion (LTE) is a novel process in which frozen desserts (ice cream) are subjected to higher shear stresses to improve the various qualities attributes of the final frozen product. Ice cream coming out of continuous freezer is pumped into the extruder. The various microstructural changes take place in low temperature extruded ice cream comparative to conventional scraped surface freezing process. The ice crystals and air bubble size is reduced due to the shear stress which results in more smoother and creamier ice cream. This review describes the various quality changes occur in finally obtained LTE ice cream and comparison of low temperature extruded ice cream with the convention freezing process.

Keywords: Surface freezing; Blending; Pasteurizing; Homogenizing; Ice crystals

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Introduction

Ice cream can be defined as a complex colloidal mixture, which mainly consists of ice crystals, fat globules, air bubbles and continuous serum phase. They all are present in discrete phase surrounded by polysaccharides, protein, sugar, salt and water [1-13]. Ice cream manufacturing process in any industry mainly consists of blending, pasteurizing, homogenizing, cooling and aging followed by freezing and aeration [14-17]. They are subjected to high shear condition in a scraped surface freezer (SSF) [18-22]. The structure formation of ice cream started from the beginning of manufacturing process [15]. But, combined freezing and whipping are the most important processes for the microstructure development. They bring about major changes in the microstructure development of final ice cream [13-25]. The ice cream must have the smooth texture with no detectable ice crystals and the size of ice crystals must be as small as possible [23]. The ice crystal of size about 10-20 µm gives ice cream a desirable creaminess and is not detectable [8,11]. In the conventional ice cream freezer (Scraped surface freezer), ice cream comes out of the freezing cylinder at the draw temperature of -5 to -6°C at this condition about 40-50% of water is frozen. The remaining water is frozen in a hardening tunnel which is maintained at a temperature about -40°C (residence time of 1-3 h) [25]. It was found that during hardening, ice crystals grew to an average size of about 25 to 45 µm [1,10,16,19,21,24]. Therefore, rapid hardening must be done to promote the smaller ice crystals formation. But in case if there is slow hardening, the water that is remaining in ice cream will start migrating towards the center and therefore will result in the formation of larger ice crystal formation [14]. Low temperature extrusion (LTE) is a novel technology to get more acceptable quality of final ice cream [26]. The LTE of ice cream is done after freezing in conventional SSF. The first patent of LTE extrusion of ice cream was filed in 1992 [27]. The aim of including this process in the ice cream manufacturing is to improve the microstructure and other quality characteristics [28]. It was found that combined freezing-LTE process reduced the size of ice crystal by a factor of two or more than two as compared to conventional freezing-hardening process [29].

Background of the development of the process

In the conventional freezing process, ice cream after coming out of the freezer goes for packaging and hardening. For hardening, they are transferred to either forced convection or plate-type conduction freezer [9]. During the hardening process, it was found that there was poor rate of heat transfer from the ice cream to the air. Also the ice crystals that were formed during hardening tended to grow in size. It is found that rate of heat transfer is improved and smaller ice crystals are found in Low temperature extrusion of ice cream [25]. In former studies, ice crystal size of final ice cream was compared between conventional and LTE process [30-34]. It was found that mean ice crystal size is significantly reduced in case of LTE process. Also various sensory qualities like melting rate, consistency etc. was found to be improved [28,12] has studied earlier the effect of LTE process on fat globule aggregate structure. Subsequently,

[30] has shown in their study the influence of LTE process on fat globule aggregation and the final shape retention during melting [27] suggested that deformation oscillation test can be carried out for microstructural study of ice cream as the device is sensitive to mechanical and thermal treatment. Oscillatory thermo-rheometry (OTR) was done [25] to study the various quality attributes of LTE treated ice cream.

Mechanism of low temperature extrustion (LTE) system

Low temperature extrusion is a novel process in which the frozen product is shear treated in the low temperature range of about -10 to -20°C [17,29]. The rotational speed in the extruder is between 5 and 50 rpm which is less than conventional freezer. In the ice cream manufacturing process, ice cream mix after aging achieves the temperature of 4˚C. Subsequently, the ice cream mix is pumped into the freezer barrel and simultaneously air is incorporated. The frozen product temperature coming out of the freezer has the temperature of -5˚C. Ice cream is then pumped into the low temperature extruder. Ice cream temperature is about -5˚C to -15˚C when it comes out of the freezer. The detailed description of combined ice cream freezer and LTE system is shown by the flow chart as shown in **Figure 1.** The LTE process can be accomplished by either single screw or twin screw systems [24,25]. The twin screw low temperature extrusion (TS-LTE) system is provided with the feeding gear pump which is geared to twin screw. Therefore screw serves two functions: shearing and stirring [24,30]. The screw system also dissipates the energy generated in the TS-LTE. As a result of higher stress and higher viscosity of the product, finely dispersed microstructure of the product is formed. According to Windhab et al. [32], four shear gap zones exist in between the twin screw and the barrel wall as shown in **Figure 2**. Zone 3, i.e., tangential gap, also sometimes termed as the mixing zone. For the energy dissipation and microstructure formation, zone 1 and zone 2 are the most important and relevant in TS-LTE process. As the zone 2 is narrowest one, shear stress will be higher in this zone and the product volume will be less in this zone. Therefore, among the zone 1 and zone 2, most of the microstructure development will occur in zone 1, i.e., in the screw channel gap.

Impact of low temperature extrusion (LTE) process on the ice cream microstructure and quality

Viscosity of ice cream: Chang and Hartel [5-8] have shown in their study on batch ice cream freezer the dependency of ice cream viscosity on the size of air bubbles. As the temperature decreases, viscosity of the ice cream increases and air cell size decreases simultaneously. In the rheometer, measurement is made by considering that shear stress and viscosity of ice cream is a function of shear rate and temperature. It was found that for the temperature decrease of -5˚C to -15˚C, shear stress increased by a factor of 10.5 to 11.0 [25,26]. The authors [27-34] have shown the shear thinning behavior of ice cream by the Herschel-Bulkley flow model. The equation expressing shear stress τ as a function of shear rate γ̇ is shown in eqn. 1.

$$\tau(\dot{\gamma}, T) = \tau_0 + K.\dot{\gamma}^n$$

where, τ_0, K and n are the model parameters and are function of the temperature. The flow index 'n' decreases with decrease in temperature and therefore increases the shear thinning behavior of ice cream. The decrease in temperature from -5°C to -15°C in the LTE process results in increase in the parameters like yield value τ_0 and consistency factor K by almost 2 log cycle **(Figure 3).** Also the effect of shear rate and temperature on the viscosity of ice cream is described in **Figure 4.** This figure shows that with increase in shear rate, temperature is decreasing from -5˚C to -15˚C and the corresponding viscosity is increasing.

Cryo-SEM analysis of ice cream: The size of ice crystals, fat globules and air bubbles are measured by cryo-scanning electron microscopy (cryo-SEM). Many authors have done the cryo-SEM analysis to determine the frozen product, such as microstructural

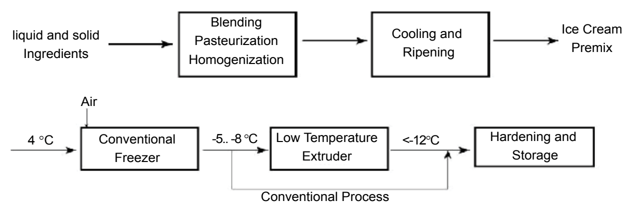

Figure 1 Flow chart of combined continuous freezer and LTE process of ice cream manufacturing.

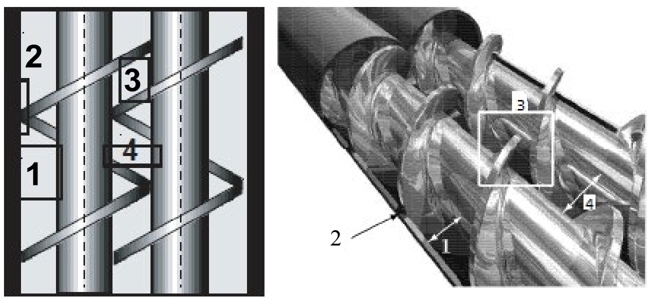

Figure 2 Shear zones in TS-LTE: Screw channel gap (zone 1), clearance gap (zone 2), tangential gap (zone 3) and screw roots gap (zone 4).

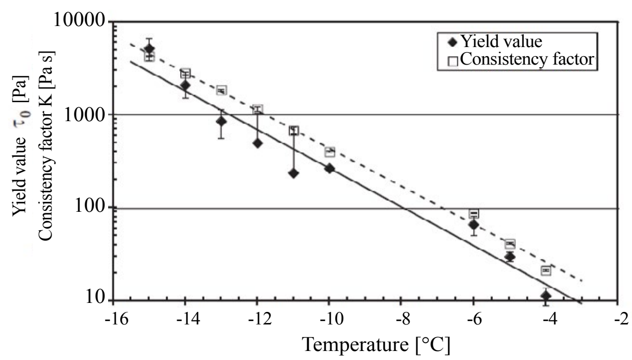

Figure 3 Graph of yield value τ_0 and consistency factor K as a function of temperature.

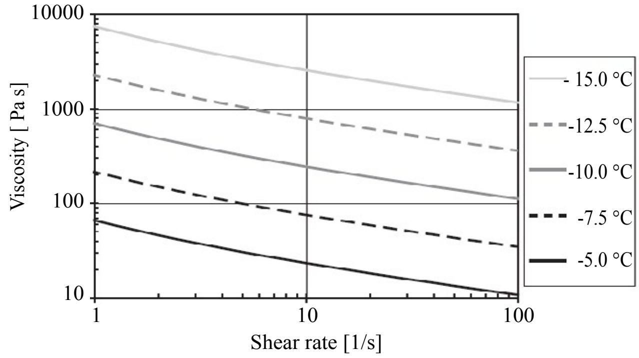

Figure 4 Graph representing Yield value τ_0 and consistency factor K as a function of temperature for the ice cream.

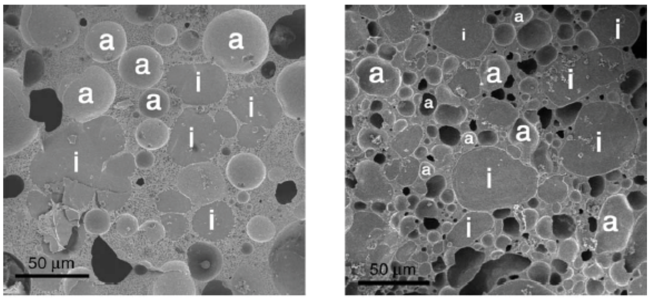

Figure 5 Cryo-SEM analysis of ice cream.
(Left) Image of ice cream processed in convention freezer at drawing temperature of -4.7 ˚C
(Right) Image of ice cream processed in combined freezer / LTE system at drawing temperature of 13˚C
(i) ice crystals (a) air cells.

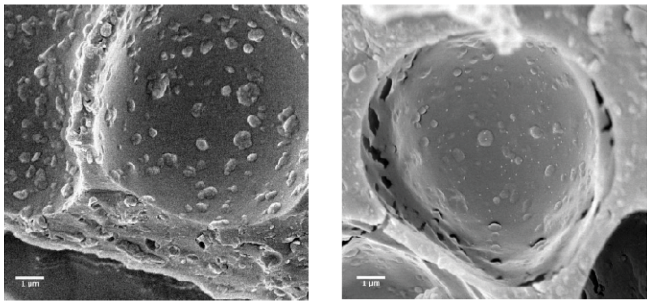

Figure 6 LEFT: Cryo-SEM image of SS-LTE showing more aggregate fat particles over bubble surface.
RIGHT: Cryo-SEM image of TS-LTE showing less aggregated fat particles over bubble surface.

characteristics [4,12,30]. The cryo-SEM analysis was done for ice cream and was compared the differences that occurred in case of conventional freezer and combined freezer/LTE system **(Figure 5).** It can be seen from the figure that conventional freezer forms the cluster which will result in large ice crystal size after hardening [25]. It was also found that air cells became more stabilized in case of combined freezer/LTE system at the drawing temperature of -13˚C. [5-8] found out that the size of air cells started increasing after 60 minutes of draw from the freezer, but at temperatures below -15˚C, growth rate of air cell size decreased due to increase in viscosity.

Phase of fat in ice cream: Single screw LTE and twin screw LTE microstructure was compared and it was found that diameter of fat globule in case of SS-LTE was greater than that for TS-LTE system. The highest value of fat globule size was 6 mm for TS-LTE, and 14 mm for SS-LTE as shown in **Figure 6** [25]. The process of induction of aggregation of fat globules was investigated by several authors [3]. Fat aggregates also play an important role in shape retention and melt down. They suggested that structure became more stabilized when fat aggregates attained the size of the lamellae between air bubbles [19,20].

Conclusion

Low temperature extrusion of ice cream helps to improve the quality attribute of the final ice cream. It greatly influences the size of ice crystals and air bubbles, and also improves (increases) the viscosity of the final ice cream. The final ice cream is smoother and creamier, obtained from combined freezer/LTE system as compared to conventional freezer. Since the size of air bubbles reduces as a result of extrusion, more creaminess sensation was observed in the final obtained ice cream.

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