Module 6. Physico-chemical properties of ice cream mixes and ice cream

Lesson 17
PHYSICO-CHEMICAL PROPERTIES OF ICE CREAM-II

17.1 Introduction

Ice cream structure is often described as a four phase system. These phases include fat, air and ice which are all discrete phases, and the serum phase which surrounds them. The fat phase begins as homogenized globules in the mix that are stabilized by a membrane of adsorbed protein and emulsifier.

17.2 Process of Fat Crystalization

The fat globules crystallize during cooling and ageing, so after ageing, they contain numerous fat crystals and some non- crystallized liquid oil. Some of the protein is displaced from the fat globule membrane by the emulsifiers during ageing, the result of which is that the globules have a very thin membrane (due to the relatively small molecular weight of the emulsifiers, compared to proteins). During freezing some of the fat globules partially coalesce due to the whipping and shearing action of the dasher scraper unit. As the globules collide with each other they stick and form aggregates. The liquid oil cements the globules together while the fat crystals maintain the integrity of the globular shape, so that the aggregates become chains and clusters, rather than large droplets (hence the need for crystalline fat during freezing). The extent of partial coalescence (fat destabilization) is a measure of the extent to which the globules are converted to fat globule clusters. These clusters exist both adsorbed to air bubbles and in bulk phase surrounding the ice and air. The air in ice cream is in the form of finely dispersed bubbles that are formed by the whipping action of the dasher. The air bubbles are stabilized by the globules and clusters, which adsorb to the air surface, and by a membrane of milk protein and emulsifier. The ice crystals are also formed during freezing. **(Fig.17.1)**

The objective during freezing is to create as many small crystals as possible and then to stabilize them from recrystallization during frozen storage, to maintain their small size and smooth texture that arises from them. The formation of pure ice crystals results in the freeze concentration of the sugars, proteins and stabilizers which results in the formation of the unfrozen phase that surrounds the discrete elements. The ratio of ice to unfrozen water is dictated by the concentration of solutes, hence more sugar in the formulation means less ice at any given temperature.

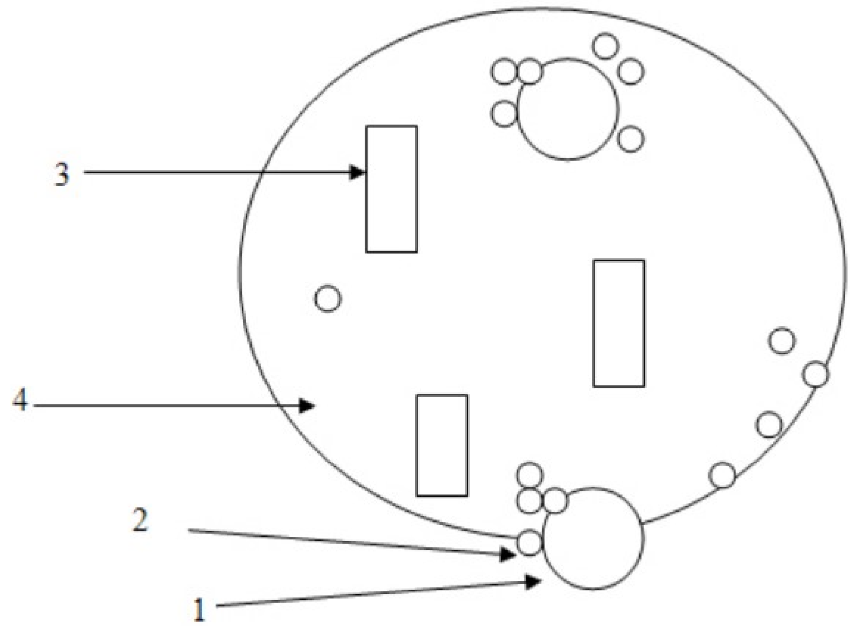

Fig. 17.2 The structure of ice cream

Where,

1- Air cells

2- Fat globules and partially coalesced fat surrounding cells

3- Ice crystals

4- Unfrozen freeze concentrated solution of dissolved and suspended solids

17.3 Process of Ice Crystallization and Re-Crystallization

Ice crystals are relatively unstable, and during frozen storage, they undergo changes in number, size, and shape, known collectively as re-crystallization. This occurs due to temperature fluctuations. If the temperature during the frozen storage of ice cream increases, some of the ice crystals, particularly the smaller ones, melt and consequently the amount of unfrozen water in the serum phase increases.

Conversely, as temperatures decrease, water will refreeze but does not renucleate. Rather, it is deposited on the surface of larger crystals, so the net result is that the total number of crystals diminishes and the mean crystal size increases. Each time the temperature changes, the smaller ice crystals disappear while the larger ones grow even larger. Re-crystallization can be minimized by maintaining low and constant storage temperatures

17.4 Melting Properties

The meltdown of ice cream is important property because it is both a consumer attribute of high interest and it provides considerable information about the structure of the ice cream. Consumers generally want an ice cream that will melt at a reasonably slow rate. However, they do expect it to eventually collapse and flow into a smooth liquid with no curdiness or watery separation. When an ice cream melts two events occur. The ice crystals melt, and the rate of which they do is a function of the temperature of ice cream (and the ice content of that temperature, which is primarily a function of the sugar content) and the temperature of the environment. As the ice is melting, the structure of ice cream must also collapse and flow, but usually at a slower rate thereby providing shape retention. This process is governed primarily by the fat structure of ice cream.

As the ice crystals melt, the water dilutes the unfrozen phase. With no other structure in the system, the melted ice cream will collapse and flow at a rate that is dictated solely by the melting of the ice. The air bubbles would soon collapse as the protein surrounding them would be insufficiently strong to support the weight. The melt would resemble the mix from which it was made and would include all the discrete fat globules. However, if fat destabilization occurred, the presence of fat globules adsorbed to the air bubbles and the presence of chains and clusters of aggregated fat would support the weight of the structure as the ice crystals melted, hence resulting in a slower meltdown, dictated not only by the rate of melting of the ice but also by the collapse and flow of the fat network structure. With more extensive destabilization of fat, there may be very high shape retention and little collapse after several hours.

17.5 Overrun

Ice cream is frozen foam and incorporation of air is an important quality feature and also a significant economic consideration because ice cream is usually sold by volume and not by weight. It is also of much interest because of its influence on the texture as well as the cost of production of ice cream. The measure of air incorporation is given by the volume of mix used and is termed overrun.

Overrun is usually defined as the volume of ice cream obtained in excess of the volume of mix, and is expressed as percent overrun

$$\text{Overrun \%} = \frac{\text{Wt. of a given volume of mix} - \text{Wt. of same volume of ice cream}}{\text{Wt. of same volume of ice cream}} \times 100$$

The overrun to be calculated using volume, is shown below:

$$\text{Overrun \%} = \frac{\text{Vol. of ice cream} - \text{Vol. of mix used}}{\text{Vol. of mix used}} \times 100$$

The amount of overrun desired in ice cream depends on the composition of the mix and the processing conditions employed. Too much overrun is likely to result in a product with a snowy, fluffy defect. On the other hand, too little overrun would result in a soggy, heavy product.

Percent overrun is dependent upon the type of frozen dessert and the freezing equipment. Packaged ice cream may contain 70-75% overrun, while bulk ice cream may contain 90-100% overrun. Super-premium ice cream is generally in the 30-50% overrun range. Sherbet normally has 30-40%; milk shakes have only 10-50%. When packages are being filled on a processing line, package weights should be closely monitored. Deviations can be attributed to variations in the fill level of the package (packaging machine adjustment),variations in the ratio of ice cream to particulate addition (ingredient feeder or ripple pump adjustment), or variations in the overrun of the ice cream (freezer barrel adjustment). The overrun achieved typically increases with whipping speed, until a plateau is reached when equilibrium is established between the rate of bubble formation and the rate of break up.

The length of time that the ice cream needs to spend inside the hardening tunnel depends on several factors, namely the overrun, the formulation, the outlet temperature, the size of the product and the amount of packaging. The greater the overrun, the lower the heat capacity and the thermal conductivity of the ice cream.

17.6 Interfacial Tension, Surface Tension, Adsorption and Whipping

Inter facial tension in ice cream mix refers to the force acting at the interface between the fat and water, which is largely determined by the type and quantity of material adsorbed at the fat interface. Surface tension refers to the force acting at the interface between water and air which is also determined by the type and quantity of material adsorbed at the air interface.

Adsorption involves substances migrating to the interface, forming a layer or film, and hence reducing the inter facial or surface tension. Good ‘surfactants’ (surface active agents) are those with both hydrophilic and hydrophobic portions and sufficient molecular flexibility to rearrange at interfaces. The hydrophilic portion resides in the aqueous phase while the hydrophobic portion resides in the fat or air phase. Examples are proteins and emulsifiers. Substances accumulate at a surface in order of their abilities to lower down the interfacial tension.Thus, emulsifiers displace proteins adsorbed to the fat globules. Therefore,interfacial tension with regard to emulsifier action is a predictor of protein adsorption/displacement, which in turn is primarily responsible for controlling the extent of fat destabilization. Surface tension provides an indication of ease of air incorporation in the mix and the stability of the resulting air bubbles.

Tobe more enjoyable on eating, most frozen deserts must contain air that has been whipped in as minute bubbles. The rate of incorporation of these bubbles and their individual stabilities determine the overall whipping rate. Mixes with lower surface tension values tend to produce higher overrun and smaller air bubbles. Increasing surface tension above that of freshly processed mix made from fresh ingredients is difficult; however, the surface tension may be readily decreased by the addition of emulsifiers. Mixes with too low surface tension values caused by the addition of emulsifier have shown excessive rates of whipping, fluffy and short body characteristics, and high susceptibility to shrinkage.

The major factors at work during the freezing process that affect whipping rate are (1) effective agitation, (2) the presence of a controlled volume of air, and (3) concomitant freezing of the mix. It is vital that the mix contains surface-active components that will quickly migrate to the surfaces of the formed air cells to stabilize them. Proteins, phospholipids and added emulsifiers, perform this function. It is also important that the fat globules and ice crystals do not mechanically interrupt and weaken the lamellae of the air cells. Therefore, as the freezing progresses, it is required that the fat globules be small and well dispersed. However, to prevent collapse of the foam,especially during storage, and to produce dryness and stiffness, it is vital that fat globules be partially destabilized.

The size, number and physical condition of the fat globules in an ice cream mix determine the rate of whipping and stability of the whipped product. Small fat globules and limited clumping enhance whipping. Non-fat mixes whip more rapidly than those containing fat, but when frozen, they possess a foam structure that is susceptible to shrinkage. Partial coalescence of the fat of ice cream during freezing produces a bridging structure that provides resistance to shrinkage. Protein from MSNF is important for whipping. Factors that lead to less protein functionality such as excessive heat and denaturation or poor solvent quality from ethanol addition, for example may adversely affect the whipping properties of protein.

Added sodium caseinate improves whipping properties and affect air cell and ice crystal distribution to an extent hardly expected of any other commonly used ice cream constituent. However, high levels of caseinate may lead to insufficient fat destabilization, due to its excessive adsorption at the fat interface. Egg yolk solids and buttermilk solids from sweet cream improve whipping ability presumably due to lecithin existing as a lecithin-protein complex. Emulsifiers also improve whipping ability. Finally, the design and operation of the freezer determine whether maximum whipping ability of a given mix is obtained.