FINDING SCIENCE IN ICE CREAM

Prof. H. Douglas Goff, Ph.D.
Dept. of Food Science, Univ. of Guelph
Guelph, ON, N1G 2W1
Tel: (519) 824-4120 ext. 53878
Email: dgoff@uoguelph.ca

For further information about Finding Science in Ice Cream:
https://www.uoguelph.ca/foodscience/book-page/ice-cream-ebook

This page was designed as a supplement to a classroom experiment for secondary school teachers on ice cream making. Details of ice cream ingredients, manufacturing, structure, and many other aspects can be found on my website above.

As the hot weather approaches and students minds begin to drift from the rigors of the school classroom or laboratory, a fun afternoon might be spent making ice cream and in so doing, introducing several aspects of the science and technology "behind the scenes". To suggest that there is no science in ice cream could not be further from the truth. I have made a career out of ice cream research which has taken me into aspects of physical and organic chemistry, microbiology, and chemical engineering to name but a few. Because all of you are from different disciplines and teach in different ways, I will give you enough background information and practice from which you can prepare your own experimental work. You can use the ice cream lab, for example, to demonstrate heat transfer in physics classes, freezing point depression phenomena and emulsions and foams in chemistry classes, or pasteurization and the food use of seaweeds(!) in biology classes. By so doing, we may be interesting students in science in general because they can relate to ice cream, and in dairy science in particular as they see the applications of science in action. However you use the following information, even if it is for your own family picnic this summer, I hope you enjoy it!

THE HISTORY OF ICE CREAM

Once upon a time, hundreds of years ago, Charles I of England hosted a sumptuous state banquet for many of his friends and family. The meal, consisting of many delicacies of the day, had been simply superb but the "coup de grace" was yet to come. After much preparation, the King's French chef had concocted an apparently new dish. It was cold and resembled fresh- fallen snow but was much creamier and sweeter than any other after- dinner dessert. The guests were delighted, as was Charles, who summoned the cook and asked him not to divulge the recipe for his frozen cream. The King wanted the delicacy to be served only at the Royal table and offered the cook 500 pounds a year to keep it that way. Sometime later, however, poor Charles fell into disfavour with his people and was beheaded in 1649. But by that time, the secret of the frozen cream remained a secret no more. The cook, named DeMirco, had not kept his promise.

This story is just one of many of the fascinating tales which surround the evolution of our country's most popular dessert, ice cream. It is likely that ice cream was not invented, but rather came to be over years of similar efforts. Indeed, the Roman Emperor Nero Claudius Caesar is said to have sent slaves to the mountains to bring snow and ice to cool and freeze the fruit drinks he was so fond of. Centuries later, the Italian Marco Polo returned from his famous journey to the Far East with a recipe for making water ices resembling modern day sherbets.

In 1774, a caterer named Phillip Lenzi announced in a New York newspaper that he had just arrived from London and would be offering for sale various confections, including ice cream. Dolly Madison, wife of U.S. President James Madison, served ice cream at her husband's Inaugural Ball in 1813. Commercial production was begun in North America in Baltimore, Maryland, 1851, by Mr. Jacob Fussell, now known as the father of the American ice cream industry.

The first Canadian to start selling ice cream was Thomas Webb of Toronto, a confectioner, around 1850. William Neilson produced his first commercial batch of ice cream on Gladstone Ave. in Toronto in 1893, and Neilson ice cream was sold for nearly 100 years.

THE COMPOSITION AND INGREDIENTS OF ICE CREAM

Today's ice cream has the following **composition** : a) greater than 10% milkfat by legal definition, and usually between 10% and as high as 16% fat in some premium ice creams; b) between 9 and 12% milk solids-not-fat, the component which contains the proteins (caseins and whey proteins) and carbohydrates (lactose) found in milk; c) 12% to 16% sweeteners, usually a combination of sucrose and glucose-based corn syrup sweeteners; and d) 0.2% to 0.5% added stabilizers and emulsifiers, necessary components that unfortunately have unfamiliar sounding names that occupy three- quarters of the space of the ingredient listing and that will be described subsequently. The balance, usually 55% to 64%, is water that comes from the milk.

The **ingredients** used to supply this composition include: a) a concentrated source of the milkfat, usually cream or butter; b) a concentrated source of the milk solids-not-fat component, usually evaporated milk or milk powder; c) sugars including sucrose and "glucose solids", a product derived from the partial hydrolysis of the corn starch component in corn syrup; and d) milk.

The **fat** component adds richness of flavour, contributes to a smooth texture with creamy body and good meltdown, and adds lubrication to the palate as it is consumed. The **milk solids-not-fat** component also contributes to the flavour but more importantly improves the body and texture of the ice cream by offering some "chew resistance" and enhancing the ability of the ice cream to hold its air. The **sugars** give the product its characteristic sweetness and palatability and enhance the perception of various fruit flavours. In addition, the sugars, including the lactose from the milk components, contribute to a depressed freezing point so that the ice cream has some unfrozen water associated with it at very low temperatures typical of their serving temperatures, -15^{o} to -18^{o}C. Without this unfrozen water, the ice cream would be too hard to scoop.

Freezing point depression of a solution is a colligative property associated with the number of dissolved molecules. The lower the molecular weight, the greater the ability of a molecule to depress the freezing point. Thus monosaccharides such as fructose or glucose produce a much softer ice cream than disaccharides such as sucrose. This limits the amount and type of sugar which one can successfully incorporate into the formulation.

The **stabilizers** are a group of compounds, usually polysaccharides, that are responsible for adding viscosity to the unfrozen portion of the water and thus holding this water so that it cannot migrate within the product. This results in an ice cream that is firmer to the chew. Without the stabilizers, the ice cream would become coarse and icy very quickly due to the migration of this free water and the growth of existing ice crystals. The smaller the ice crystals in the ice cream, the less detectable they are to the tongue. Especially in the distribution channels of today's marketplace, the supermarkets, the trunks of cars, and so on, ice cream has many opportunities to warm up, partially melt some of the ice, and then refreeze as the temperature is once again lowered. This process is known as heat shock and every time it happens, the ice cream becomes more icy tasting. Stabilizers help to prevent this.

Gelatin, a protein of animal origin, was used almost exclusively in the ice cream industry as a stabilizer but has gradually been replaced with polysaccharides of plant origin due to their increased effectiveness and reduced cost. The stabilizers in use today include: a) *carboxymethyl cellulose*, derived from the bulky components of plant material; b) *locust bean gum,* which is derived from the beans of exotic trees grown mostly in Africa (Note: locust bean gum is a synonym for carob bean gum, the beans of which were used centuries ago for weighing precious metals, a system still in use today, the word carob and Karat having similar derivation) ; c) *guar gum*, from the guar bush, a member of the legume family grown in India for centuries and now grown to a limited extent in Texas; or d) *carrageenan*, an extract of Irish Moss or red algae, originally harvested from the coast of Ireland but now mostly come from the Phillipines or Chile. Often, two or more of these stabilizers are used in combination to lend synergistic properties to each other and improve their overall effectiveness.

The **emulsifiers** are a group of compounds in ice cream that aid in developing the appropriate fat structure and air distribution necessary for the smooth eating and good meltdown characteristics desired in ice cream. Emulsifiers are characterized by having a molecular structure which allows part of the molecule to be readily solubilized in a polar compound such as water, and another part of the molecule to be more readily solubilized in non-polar solvents such as fats. As a result, emulsifiers reside at the interface between fat and water, and lower the free energy or tension associated with two immiscible liquids in contact with each other. Their action will be more fully explained in the section below on emulsions and foams.

The original ice cream emulsifier was egg yolk, which was used in most of the original recipes. Today, two emulsifiers predominate most ice cream formulations: a) *mono- and di-glycerides* , derived from the partial hydrolysis of fats or oils of animal or vegetable origin; and b) *Polysorbate 80*, a product consisting of a glucose molecule bound to a fatty acid, oleic acid. Both of these compounds have hydrophobic regions (the "fat loving" part), the fatty acids, and hydrophilic regions (the "water loving" part), either glycerol or glucose. All of the compounds mentioned above are either fats or carbohydrates, important components in most of the foods we eat and need.

Together, the stabilizers and emulsifiers make up less than one half percent by weight of our ice cream. They are all compounds which have been exhaustively tested for safety and have received the "generally recognized as safe" or GRAS status.

THE MANUFACTURING PROCESSES

Ingredients are chosen by the manufacturer on the basis of desired quality, availability, and cost. The ingredients are blended together and produce what is known as the "ice cream mix". The mix is first **pasteurized**. Pasteurization is a process which is designed to kill all of the possible pathogens (disease causing organisms) that may be present. Organisms such as *Mycobacterium tuberculosis, Salmonella, Staphylococcus, Listeria,* and others that cause human disease can be found associated with farm animals and thus raw milk products must be pasteurized. In addition to this very important function, pasteurization also reduces the number of spoilage organisms such as psychrotrophs, and helps to "cook" the mix. The mix is also **homogenized** which forms the fat emulsion by breaking down or reducing the size of the fat globules found in milk or cream to less than 1 μm. Homogenization helps to produce a smooth product when frozen. The mix is then **aged** for at least four hours and usually overnight. This allows time for the fat to cool down and crystallize, and for the proteins and polysaccharides to fully hydrate.

Following mix processing, the mix is drawn into a **flavour** tank where any liquid flavours, fruit purees, or colours are added. The mix then enters the **dynamic freezing** process which both freezes a portion of the water and whips air into the frozen mix. The "barrel" freezer is a scraped-surface, tubular heat exchanger, which is jacketed with a boiling refrigerant such as ammonia or freon. Mix is pumped through this freezer and is drawn off the other end in a matter of 30 seconds, (or 10 to 15 minutes in the case of batch freezers) with about 50% of its water frozen. There are rotating blades inside the barrel that keep the ice scraped off the surface of the freezer and also dashers inside the machine which help to whip the mix and incorporate air. Ice cream contains a considerable quantity of air, up to half of its volume. This gives the product its characteristic lightness. Without air, ice cream would be similar to a frozen ice cube.

As the ice cream is drawn with about half of its water frozen, **particulate matter** such as fruits, nuts, candy, cookies, or whatever you like, is added to the semi-frozen slurry which has a consistency similar to soft-serve ice cream. In fact, almost the only thing which differentiates hard frozen ice cream from soft-serve, is the fact that soft serve is drawn into cones at this point in the process rather than into packages for subsequent hardening. After the particulates have been added, the ice cream is **packaged** and is placed into a **blast freezer** at -30^{o} to -40^{o}C where most of the remainder of the water is frozen. Below about -25^{o}C, ice cream is stable for indefinite periods without danger of ice crystal growth; however, above this temperature, ice crystal growth is possible and the rate of crystal growth is dependant upon the temperature of storage. This limits the shelf life of the ice cream.

SALT AND ICE

Making ice cream at home requires the use of an ice cream machine. The "homemade" or hand-crank freezer used was the forerunner to today's modern equipment. Many people enjoy fond memories of hot summer days spent preparing the ice cream mix, loading the bucket with ice and salt, and cranking the freezer for a half hour until it was considered too stiff to continue or until one's hunger got the best of them. All of the various steps in making ice cream via the bucket are similar to the commercial processing stages. The mix is prepared and pasteurized, aged, dynamically whipped and frozen in a freezer equipped with blades and dashers, and then hardened prior to consumption. At home, we use ice and salt, however, rather than the ammonia or Freon jacket in the commercial freezer above.

The concept of melting ice with salt is not new to anyone in this latitude. Indeed, our roads, driveways, and sidewalks are kept bare in the winter by such a process. As salt is applied to ice, the ice crystal structure is broken due to the depressed freezing point of the resulting brine solution. As the salt continues to dissolve more ice melts to accommodate this concentrated salt solution with its very low melting point. At the same time, both the heat of solution of the dissolving salt, and the latent heat of fusion of the melting ice are adsorbed from the ice itself, thereby lowering the temperature of the salt, ice and brine mixture. The temperature of this mixture can be controlled by the amount and ratio of salt and ice present. The lowest temperature which can be achieved with a sodium chloride brine is -21^{o}C, at a concentration of 23% salt. Higher concentrations result in salt crystallization.

This brine, in turn, is adsorbing heat from the freezing ice cream inside the can, and thus ice and salt need to be continually added to keep the ice temperature low enough to freeze the ice cream. (Bear in mind that the freezing temperature of the ice cream is depressed below 0^{o} due to the presence of dissolved sugars.) This process is a lesson in heat transfer in itself!

THE STRUCTURE OF ICE CREAM - EMULSIONS AND FOAMS

An **emulsion** is defined as liquid droplets dispersed in another immiscible liquid. The dispersed phase droplet size ranges from 0.1 - 10 μm. Important oil-in-water food emulsions, ones in which oil or fat is the dispersed phase and water is the continuous phase, include milk, cream, ice cream, salad dressings, cake batters, flavour emulsions, meat emulsions, and cream liquers. Examples of food water-in-oil emulsions are butter or margarine. Emulsions are inherently unstable because free energy is associated with the interface between the two phases. As the interfacial area increases, either through a decrease in particle size or the addition of more dispersed phase material, i.e. higher fat, more energy is needed to keep the emulsion from coalescing. Some molecules act as **surface active agents** (called surfactants or emulsifiers) and can reduce this energy needed to keep these phases apart.

A **foam** is defined as a gas dispersed in a liquid where the gas bubbles are the discrete phase. There are many food foams including whipped creams, ice cream, carbonated soft drinks, mousses, meringues, and the head of a beer. A foam is likewise unstable and needs a stabilizing agent to form the gas bubble membrane.

Ice cream is both an emulsion and a foam. The milkfat exists in tiny globules that have been formed by the homogenizer. There are many proteins which act as emulsifiers and give the fat emulsion its needed stability. The emulsifiers discussed above in the Ingredients section which are added to ice cream actually reduce the stability of this fat emulsion because they replace proteins on the fat surface. When the mix is subjected to the whipping action of the barrel freezer, the fat emulsion begins to partially break down and the fat globules begin to flocculate. The air bubbles which are being beaten into the mix are stabilized by this partially coalesced fat. If emulsifiers were not added, the fat globules would have so much ability to resist this coalescing due to the proteins being adsorbed to the fat globule that the air bubbles would not be properly stabilized and the ice cream would not have the same smooth texture (due to this fat structure) that it has.

This fat structure which exists in ice cream is the same type of structure which exists in **whipped cream**. When you whip a bowl of heavy cream, it soon starts to become stiff and dry appearing and takes on a smooth texture. This results from the formation of this partially coalesced fat structure stabilizing the air bubbles. If it is whipped too far, the fat will begin to churn and butter particles will form. The same thing will happen in ice cream which has been whipped too much.

Also adding structure to the ice cream is the formation of the **ice crystals**. Water freezes out of a solution in its pure form as ice. In a sugar solution such as ice cream, the initial freezing point of the solution is lower than 0^oC due to these dissolved sugars. As ice crystallization begins and water freezes out in its pure form, the concentration of the remaining solution of sugar is increased due to water removal and hence the freezing point is further lowered. This process, known as **freeze concentration**, continues to very low temperatures. Even at the typical ice cream serving temperature of -16^oC, only about 72% of the water is frozen. The rest remains as a very concentrated sugar solution. This helps to give ice cream its ability to be scooped and chewed at freezer temperatures. The air content also contributes to this ability as mentioned above in discussing freezing.

Thus the **structure of ice cream** can be described as a partly frozen foam with ice crystals and air bubbles occupying a majority of the space. The tiny fat globules, some of them flocculated and surrounding the air bubbles also form a dispersed phase. Proteins and emulsifiers are in turn surrounding the fat globules. The continuous phase consists of a very concentrated, unfrozen solution of sugars.

One gram of ice cream of typical composition contains 1.5×10^{12} fat globules of average diameter 1 μm that have a surface area of greater than 1 square meter (in a gram!), 8×10^6 air bubbles of average diameter 70 μm with a surface area of 0.1 sq. m., and 8×10^6 ice crystals of average diameter 50 μm with a surface area of another 0.1 sq. m. The importance of surface chemistry becomes obvious!

The Logistics of the Experiment

Depending on the available resources, an old-fashioned hand-crank or electric type freezer can be used. Please see information about Homemade Ice Cream on my webpage for directions.

However, there are alternatives. Here are directions from a clever experiment I received from a science enrichment Grade 1-4 teacher: Each student places in a small zip loc baggy (the heavy-duty, freezer type) - 1 T sugar, 1/2 t vanilla, 1/2 cup milk. Secure zip loc and place small baggy in a larger zip loc baggy (also the heavy duty kind). Surround the small baggy with ice to 1/2 large baggy full and put in 6 T salt on ice. Next, shake the baggies 5-10 minutes and the students have made their own serving of ice cream. Chocolate syrup on top is really good.

An alternative is to use liquid nitrogen for the freezing. Use a mix of standard recipe (see homemade ice cream page). Place the mix on a very large stainless steel bowl, about 1/3 full, and have a student stir the mix very quickly with a wire whisk (very quickly!). Have someone else pour a small quantity of liquid nitrogen into the mix while being stirred (stir as long and as fast as you possibly can). It will freeze instantly. Let the ice cream sit for a few minutes to ensure there is no liquid nitrogen left, and then eat when it is at the right consistency. A few words of caution - this experiment is pretty safe for older children (I have done it many times in high school classes), but liquid nitrogen needs to be handled cautiously. Wear gloves, don't spill on skin, etc.

I hope you have enjoyed this overview of ice cream processing and chemistry and have gained some useful insights into the field of Food Science, and that from this overview you might be able to have some fun with your students and pass along to them some of our enthusiasm for the field of Food Science. In today's world of rapidly expanding technology, evident even on the grocery store shelf, we need students who are willing to learn and apply new and existing technologies to the stable, exciting, vital, and profitable food industry.