Food Emulsions and Foams

13

Introduction

Many convenience foods, such as frozen desserts, meat products, margarine, and some natural foods, such as milk and butter, are emulsions. That is, they contain either water dispersed in oil or oil dispersed in water. These water and oil liquids do not normally mix, and so when present together, they exist as two separate layers. However, when an emulsion is formed, the liquids are mixed in such a way that a single layer is formed with droplets of one liquid dispersed within another. Food emulsions need to be stable; if they are not, the oil and water will separate out. Stability is usually achieved by adding a suitable emulsifier. In some cases, a stabilizing agent is also required.

Food foams, such as beaten egg white, are similar to emulsions except that instead of containing two liquids, they contain a gas (usually air or carbon dioxide) dispersed within a liquid. The factors affecting stability of emulsions also apply to foams. Some foods, such as ice cream and whipped cream, are highly complex being both an emulsion and a foam.

Understanding of food emulsions and foams is complex, yet is important if progress is to be made in maintaining and improving the stability and hence the quality of these types of foods. This chapter will discuss the principles of formation and stability of emulsions and foams and the characteristics of the ingredients necessary to stabilize them.

Emulsions

Definition

An ***emulsion*** is a ***colloidal system*** containing droplets of one liquid dispersed in another, the two liquids being immiscible. The droplets are termed the ***dispersed phase***, and the liquid that contains them is termed the ***continuous phase***. In food emulsions, the two liquids are oil and water. If water is the continuous phase, the emulsion is said to be an ***oil-in-water*** or ***o/w emulsion***, whereas if oil is the continuous phase, the emulsion is termed a ***water-in-oil*** or ***w/o emulsion***. Oil-in-water emulsions are more common and include salad dressings, mayonnaise, cake batter, and frozen desserts. Butter, margarine, and some icings are examples of water-in-oil emulsions.

An emulsion must also contain an ***emulsifier***, which coats the emulsion droplets and prevents them from ***coalescing*** or recombining with each other. Emulsions are colloidal systems because of the size and surface area of the droplets (in general, around 1 μm, although droplet size varies considerably, and some droplets may be a lot larger than this). Emulsions are similar to colloidal dispersions or sols, except that the dispersed phase is liquid and not solid. Colloidal dispersions are mentioned in Chap. 2.

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Surface Tension

To form an emulsion, two liquids that do not normally mix must be forced to do so. To understand how this is achieved, we must first consider the forces between the molecules of a liquid. Imagine a beaker of water placed on a desk (Fig. 13.1).

The water molecules are attracted to one another by hydrogen bonds as described in Chap. 2. A molecule in the center of the beaker has forces acting on it in all directions, because water molecules surround it. The net force on this molecule due to attraction by other water molecules is zero, because these forces are acting in all directions. However, this is not the case for a water molecule on the surface. Since there are no water molecules above it, there is a net downward pull on the molecule. This results in the molecule being pulled in toward the bulk of the liquid.

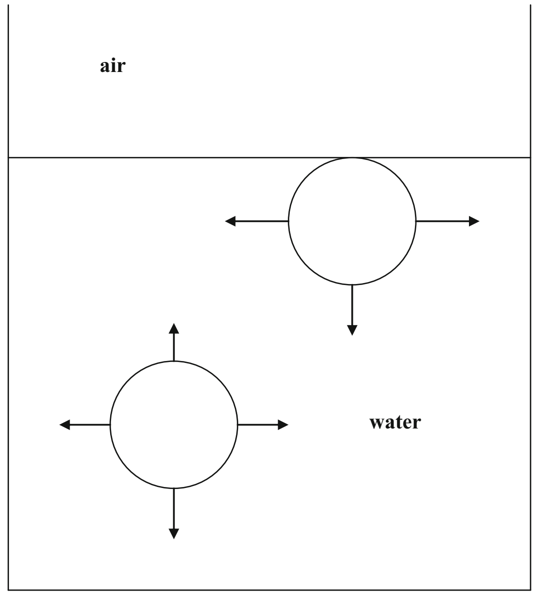

Fig. 13.1 Schematic diagram of the forces acting on water molecules in the bulk and at the surface of the liquid

This downward pull can be seen when one fills a narrow tube such as a pipette or a burette with water. The surface of the liquid curves downward at the center, and the curve is called the meniscus. The greater the attractive forces between the liquid molecules, the greater the depth of the meniscus. Water molecules have strong attractive forces among them, and so it is relatively hard to penetrate the surface, or to get the water to spread. Try placing a needle gently on the surface of clean or distilled water. It will float, because the attractive forces between the water molecules keep it on the surface. (To make it sink, see below.)

If there are strong attractive forces among the molecules of a liquid, the force required to pull the molecules apart, to expand the surface, or to spread the liquid will be high. This force is known as ***surface tension***. A liquid such as water, with strong attractive forces between the molecules, has a high surface tension. This makes it hard to spread. You can see this if you put water on a clean surface. It will tend to form droplets rather than spreading evenly as a thin film across the surface. (A droplet has minimal surface area and maximal internal volume, and so it is the most energetically favorable shape for liquids with a high surface tension, where the molecules are being pulled into the interior.)

The term surface tension is normally used when a *gas* (usually air) surrounds the *liquid* surface. When the surface is between two *liquids*, such as water and oil, the term ***interfacial tension*** is used.

A high surface or interfacial tension makes it hard to mix the liquid either with another liquid or with a gas. This is a drawback when making an emulsion or foam and needs to be overcome. So how can surface tension be reduced?

Surface-Active Molecules

To reduce the surface or interfacial tension, something must be done to decrease the attractive forces between the liquid molecules, so that it is easier to spread them. This can be achieved by adding a ***surface-active*** molecule, or a ***surfactant***. As their name suggests, surface-active molecules are active at the *surface* of a liquid, rather than at the bulk of it. Surfactant molecules prefer to exist at the surface of a liquid rather than at the bulk because of their structure. In all cases, a section of

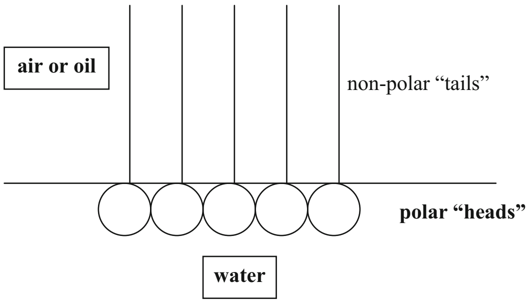

Fig. 13.2 Orientation of amphiphilic molecules at an interface

the molecule is water-loving or ***hydrophilic*** because it is polar or charged, and a section is water-hating or ***hydrophobic*** because it is apolar. In other words, the molecules are ***amphiphilic***.

The apolar section has little or no affinity for water, and so it is energetically favorable for this section to be as far away from the water as possible. However, the polar section is attracted to the water and has little or no affinity for the oil. Therefore, the molecule orients at the surface with the polar section in the water, with the apolar section either in the air or in the oil (see Fig. 13.2).

Due to the fact that the molecule ***adsorbs*** at the surface, it reduces the attractive forces of the water molecules for themselves and makes it easier to expand or spread the surface. In other words, it reduces the surface or interfacial tension.

Detergent is an example of a surfactant. When detergent is added to water, it enables the water molecules to spread much more easily, so that they wet a surface more readily. After adding detergent, water will flow over a surface, forming a thin sheet, instead of tending to gather into droplets. Going back to the example of the needle floating on water (see above), if a small drop of detergent is added, the needle will sink. The surface tension is reduced, allowing the water molecules to spread more easily, and so the needle no longer stays on the surface.

Obviously, detergents are not used as food ingredients! (However, they are used when washing dishes, because they enable the water to spread across the surface and remove food particles more easily.) There are many food ingredients that are surfactants. Polar lipids such as lecithin, which has a polar "head" and an apolar "tail," are surfactants and may be used as food additives to increase the wettability and aid in mixing of products like hot chocolate mix.

Proteins are surface-active because they contain both hydrophilic and hydrophobic sections. The nature and extent of these sections depend on the specific amino acid sequence of each protein, and some proteins orient at the surface more readily than others do (Proteins are discussed in Chap. 8).

Some spices, such as dry mustard and paprika, are also used as surface-active ingredients. These finely divided powders tend to gather at the surface rather than the bulk of the liquid.

Molecules that are either hydrophilic or hydrophobic do not orient at an interface. The molecules remain in the bulk of the liquid. For example, sugars, which are hydrophilic, or salt, which dissociates into ions, will be located in the bulk water phase. These types of molecules are not surface-active and will not decrease the interfacial tension. In fact, they may increase it, depending on their ability to bind the water molecules, hence increasing molecular attraction.

Emulsion Formation

An emulsion is formed when oil, water, and an emulsifier are mixed together. Although there are different food emulsions, they *all* contain these three components. To form an emulsion, it is necessary to break up either the oil or the water phase into small droplets that remain dispersed throughout the other liquid. This requires energy and is usually carried out using a mixer or a homogenizer. As the oil and water are mixed, droplets are formed. (They may be oil or water, yet are usually oil droplets.) An emulsifier is adsorbed at the surface of new droplets, decreasing the interfacial tension and allowing formation of more and smaller droplets. The lower the surface or interfacial tension of the oil and water, the more easily one liquid can be disrupted to form droplets and the more easily the other liquid will flow around the droplets.

The liquid with the higher interfacial tension will tend to form droplets, and the other liquid will flow around the droplets to form the continuous phase. The emulsifier generally determines the liquid that would form the continuous phase. Emulsifiers that are more easily dispersed in water (and therefore are more hydrophilic overall) tend to reduce the interfacial tension of the water more than that of the oil, promoting formation of o/w emulsions. Emulsifiers that disperse more readily in the oil phase tend to form w/o emulsions. The emulsifier is usually dispersed in the preferred phase before the oil and water are mixed together.

Principles of Formation of a Stable Oil-in-Water Emulsion

- Emulsifier is dispersed in the aqueous phase.
- Oil is added and the interfacial tension of each liquid is reduced by the emulsifier.
- Energy is supplied by beating or homogenizing the mixture.
- The oil phase is broken up into droplets, surrounded by water.
- Emulsifier adsorbs at the freshly created oil droplet surfaces.
- Small droplets are formed, protected by an interfacial layer of emulsifier.
- The interfacial area of the oil becomes very large.
- The aqueous phase spreads to surround each oil droplet.
- The emulsion may become thick due to many small oil droplets surrounded by a thin continuous phase.
- If the interfacial film is strong, the emulsion will be stable.

An emulsifier does not simply reduce interfacial tension. It must also form a stable film that protects the emulsion droplets and prevents separation of the emulsion. The droplets are continually moving through the continuous phase, and so they constantly encounter or collide with each other. When two droplets collide, one of three things happens, as shown in Fig. 13.3:

(a) The emulsifier film stretches or breaks, and the droplets combine to form one larger droplet (or in other words, they ***coalesce***). This ultimately leads to separation of the emulsion.
(b) The two emulsifier layers surrounding the droplets interact and an aggregate is formed. This occurs when a cream layer develops on top of fresh milk.
(c) The droplets move apart again.

Which of these three events occurs depends on the nature of the emulsifier molecules and on their ability to completely coat all the emulsion droplets with a stable, cohesive, ***viscoelastic*** film. A viscoelastic film tends to flow to coat any temporarily bare sections of the surface and is also able to stretch instead of breaking when, for example, another droplet bumps into it. Therefore, it is less likely to break when droplet collisions occur. As the droplets are formed, their surface or interfacial area increases dramatically, and sufficient emulsifier must be present to completely coat all the droplet surfaces. Incompletely coated droplets will coalesce resulting in larger droplets and ultimately in separation of the emulsion.

Emulsifiers

Emulsifiers must be able to:

- Adsorb at the interface between two liquids such as oil and water
- Reduce the interfacial tension of each liquid, enabling one liquid to spread more easily around the other
- Form a stable, coherent, viscoelastic interfacial film
- Prevent or delay coalescence of the emulsion droplets

Reduction of the interfacial tension facilitates emulsion formation, because it reduces the amount of energy needed to break up one liquid into droplets and to spread the other liquid around them. Formation of a film that prevents coalescence promotes emulsion stability.

All emulsifiers are surfactants, because all emulsifiers adsorb at the surface and reduce

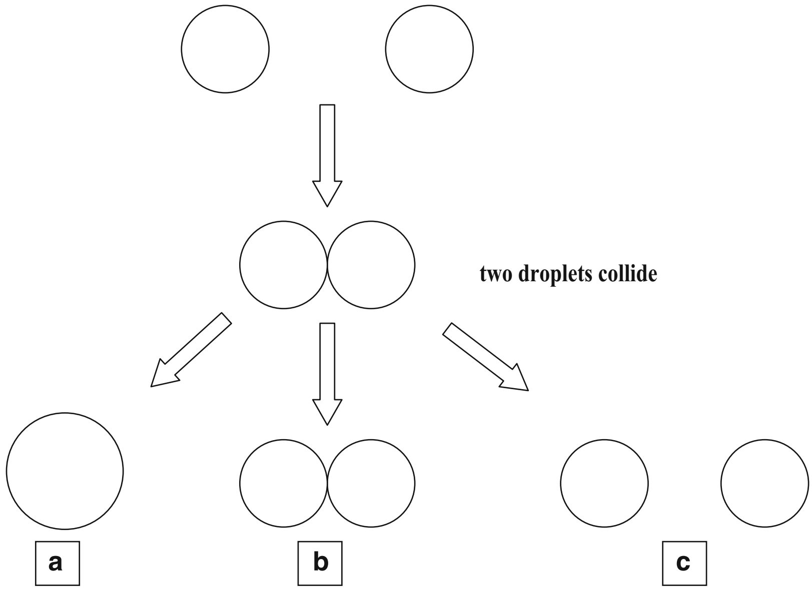

Fig. 13.3 Diagram to illustrate what may happen after two droplets collide: (*a*) coalescence, (*b*) aggregation, and (*c*) droplets move apart again

interfacial tension. However, all surfactants do *not* make good emulsifiers, because not all surfactants are able to form a stable film at the interface and prevent coalescence. The stability of the film is important in determining the stability and shelf life of the emulsion. Some emulsifiers work better than others do, in terms of forming a stable emulsion.

In general, large macromolecules such as proteins form stronger surface films than smaller surfactant molecules such as lecithin because of their greater ability to extend over the droplet surface. They also have a greater ability to interact with other groups within the same molecule or on different molecules and are able to form viscoelastic surface films.

Small molecules are not usually able to form stable interfacial films by themselves, and their role is normally that of a surfactant rather than an emulsifier, in that they lower interfacial or surface tension and promote spreading or wettability. Although they do not make good emulsifiers, they are often called emulsifiers. Many food scientists do not differentiate between surfactants and emulsifiers, and so the words may be used interchangeably in some cases. However, in the world of a colloid scientist, there is a clear distinction between the two!

Characteristics of an Emulsifier

- Contains hydrophilic and hydrophobic sections (amphiphilic)

Functions of an Emulsifier

- Adsorbs at the oil/water interface
- Reduces interfacial tension

} facilitates formation emulsion

- Forms a stable interfacial film
- Prevents coalescence

} promotes emulsion stability

Natural Emulsifiers

The best emulsifiers are proteins, which uncoil or denature and adsorb at the interface, and interact

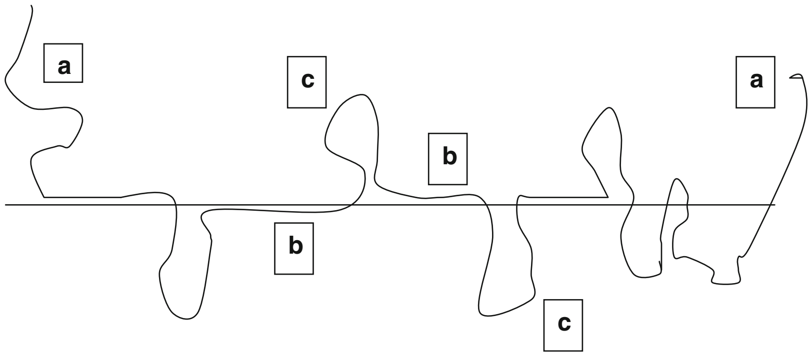

Fig. 13.4 Schematic diagram of a protein adsorbed at an interface: (*a*) tails, (*b*) trains, and (*c*) loops

to form a stable interfacial film. Proteins tend to uncoil such that their hydrophobic sections are oriented in oil, and their hydrophilic sections are oriented in water. Hence, a series of loops, trains, and tails may be envisioned at the interface, as shown in Fig. 13.4.

The loops and tails are able to interact with each other, thus forming a stable film that resists rupture. The proteins of *egg yolk* tend to be the best emulsifiers, as exemplified by their use in mayonnaise. These proteins are lipoproteins and are associated with each other and with phospholipids such as lecithin, in structures known as micelles. These micellar structures appear to be responsible for the excellent emulsifying properties of egg yolk proteins.

The *caseins* of milk are also excellent emulsifying agents. They are important emulsifiers in homogenized milk and in dairy desserts. In fresh (unhomogenized) milk, the caseins are associated with each other in structures known as casein micelles. Electron micrographs have shown that after homogenization, intact micelles are present at the fat globule surfaces, as well as individual protein molecules. It is thought that the micelles are responsible for the stability of homogenized milk, rather than the individual protein molecules.

Other food proteins used as emulsifiers include *meat* proteins and *soy* proteins. Lecithin is often considered to be an emulsifier. Lecithin is a surfactant and is useful for promoting wettability and aiding mixing of products such as hot drink mixes. It is also an essential ingredient in chocolate, where it aids in dispersion of the sugar and fat. Lecithin does not usually form strong interfacial films by itself and so would not be the emulsifier of choice unless other emulsifiers or stabilizers were added.

However, proteins are usually present in food emulsions, which may allow for formation of a strong interfacial film involving lecithin. Soy lecithin may be added to emulsions containing egg yolk, in order to reduce the amount of egg yolk needed, since soy lecithin is cheaper than egg yolk.

Synthetic Emulsifiers or Surfactants

Most synthetic emulsifiers would more correctly be termed *surfactants*, because they are relatively small molecules compared with proteins, and they are used mainly to aid in dispersion of fat, rather than to stabilize emulsions.

Surfactants such as *mono*- and *diglycerides* are added to shortening and to cake mixes, to aid in dispersion of the shortening. Cakes are complex, in that they contain fat droplets and air bubbles, and so are both emulsions and foams. (Foams are discussed later in this chapter.) The mono- and diglycerides enable the shortening to be dispersed into smaller particles, and this promotes incorporation of a large number of air cells, which increases cake volume and promotes a more even grain in baked products (Chap. 15).

Glycerol monostearate is an example of a monoglyceride that is commonly used in foods. Acids may be esterified with monoglycerides to give another group of surfactants, including sodium stearoyl-2-lactylate, which is often used in baked products. Two other groups of manufactured surfactants include the *SPANS*, which are fatty acid esters of sorbitan, and the *TWEENS*, which are fatty acid esters of polyoxyethylene sorbitan. Although all surfactants are amphiphilic, they have different degrees of hydrophobic (***lipophilic***) and hydrophilic character. This can be expressed as the ***hydrophilic/lipophilic balance***, or ***HLB***.

An HLB scale has been developed, which goes from 1 to 20. Surfactants with a low HLB (3–6) have more hydrophobic or lipophilic character. These would be used to form a w/o emulsion. Examples include glycerol monostearate and sorbitan monostearate (SPANS 60). Surfactants with a high HLB (8–18) have more hydrophilic character and form w/o emulsions. Examples would be polyoxyethylene sorbitan monostearate (TWEENS 60) or sodium stearoyl-2-lactylate. SPANS usually have a low HLB and form w/o emulsions, whereas TWEENS have a high HLB and form o/w emulsions. Use of the HLB scale may be going out of favor, yet is useful to food scientists to help them in determining which emulsifier is most suited to their needs.

Examples of Emulsions

French dressing is an example of a ***temporary emulsion***, or in other words, an unstable emulsion that separates fairly soon after formation. The basic ingredients of French dressing are oil (the dispersed phase), vinegar (the continuous phase), dry mustard, and paprika. Other ingredients may be added for flavor. The "emulsifiers" used here are the mustard and paprika. Combining the ingredients and shaking them vigorously forms the emulsion. The mustard and paprika adsorb at the interface and reduce interfacial tension as the dressing is shaken, thus facilitating formation of an emulsion, yet they do not interact at the interface to form a stable film. Hence, when shaking is stopped, the oil droplets are not protected, and so they soon coalesce, and the oil and vinegar layers separate.

Mayonnaise is an example of a ***permanent emulsion***, since it is stable and does not separate under normal handling conditions. The main ingredients of mayonnaise are oil (the dispersed phase), vinegar (the continuous phase), and egg yolk. The egg yolk proteins, being excellent emulsifiers, protect the oil droplets against coalescence. Mayonnaise usually contains about 75 % oil, which exists as stable droplets surrounded by a thin aqueous film. It is unusual in that it contains so much more dispersed phase than continuous phase. Generally, the continuous phase of an emulsion is present in greater quantity.

Mayonnaise is made by slowly pouring small amounts of oil at a time into the vinegar and egg yolk mixture and continuing to beat to break up the oil into droplets and form the emulsion. As more oil is added, more droplets are formed, and the surface area increases dramatically. The continuous phase spreads out to surround the oil droplets and becomes a thin film. It is hard for the droplets to move around, since they are packed tightly together, and separated only by a thin film of aqueous phase, and so the mayonnaise becomes very thick and may even be stiff enough to cut. Some salad dressings may be similar to mayonnaise, except that they contain less oil and have a thinner consistency. Adding stabilizers such as gums or starches often enhances the stability of the emulsion.

Milk is an example of an emulsion that occurs in nature (Chap. 11). Milk contains about 3.5 % fat in emulsified form. In fresh (unhomogenized) milk, the fat droplets are stabilized by a complex protein membrane known as the milk fat globule membrane. Fresh milk is a stable emulsion; however, it will cream fairly quickly if left to stand. The fat droplets vary in size from about 0.1 to 10 μm. There are many more small droplets than large ones; however, because of their size, the larger ones account for most of the fat. Because of the density difference between the milk fat and the aqueous phase, the fat droplets tend to rise though the milk. This is especially true for the larger droplets.

Milk fat globules are unique in that as they rise, they tend to cluster together. This results in larger fat particles, which rise even faster. Hence, after a few hours, a cream layer can be seen at the top of the milk. This is not a true separation of oil and water, since the cream layer is still an emulsion and the interfacial film is still intact. The milk has separated into a concentrated emulsion and a dilute one. The cream can be removed and either used as cream or made into butter.

Homogenizing the milk, which breaks up the fat globules into much smaller ones, prevents this creaming effect. By Stokes law, the smaller particles would take almost infinite time to coalesce and aggregate, thus remaining as small droplets.

Factors Affecting Emulsion Stability

Obviously, the main factor affecting emulsion stability is the *emulsifier* itself. As has been discussed, emulsifiers that form stable interfacial films produce stable emulsions. There must also be sufficient emulsifier to completely coat the surface of all the droplets in order to ensure stability. *Droplet size* is also important because larger droplets are more likely to coalesce. Also, because of the density difference between oil and water, large oil droplets will tend to rise through the emulsion more quickly, creating a more concentrated emulsion closer to the surface, as is seen in milk. This may cause the emulsion to break.

Changing the *pH* by adding acid or changing the *ionic strength* by adding salts may reduce the stability of the interfacial film, especially if it is made of protein. Such changes may denature the protein, as explained in Chap. 8, and cause the emulsion to separate.

Another factor affecting emulsion stability is the *viscosity* of the emulsion. The thicker the emulsion, the slower the movement of the molecules within the system and the longer it will take for the two phases to separate. Emulsions can be made thicker by adding ingredients such as gums, pectin, or gelatin. If gums are added to French dressing, a permanent emulsion may be formed without the need for egg yolk as the emulsifier.

Gums are often added to emulsions as stabilizers. They are not emulsifiers themselves, and they do not normally adsorb at an interface, because they are hydrophilic. However, they act by increasing the viscosity of the system, which slows movement, and hence reduces the number of collisions between droplets. This slows down and may even prevent separation of emulsions.

Storage and *handling* affect emulsion stability. Although some emulsions are termed permanent, it should be noted that all emulsions are delicate systems that are inherently unstable, because they contain two immiscible liquids, and the wrong handling conditions can cause emulsion breakage.

Temperature also affects emulsion stability. When emulsions are warmed, the oil droplets become more fluid and coalescence is more likely. On the other hand, cooling an emulsion to refrigeration temperatures may cause some solidification of the oil droplets, depending on the composition of the oil. This may enhance stability. Most emulsions do not survive freezing conditions. This is usually because the proteins at the interface become denatured, or because the interfacial film is physically disrupted by the formation of ice crystals. *Gums* are often added to emulsions that are to be frozen to enhance their stability.

Heat and *violent shaking* are also likely to disrupt emulsions. For example, cream is converted to butter by churning the warm emulsion. The emulsion breaks, the aqueous phase is drained off, and a water-in-oil emulsion is formed, with water droplets (approximately 18 %) dispersed throughout the butterfat.

Factors Affecting Emulsion Stability
- Type of emulsifier
- Concentration of emulsifier
- Droplet size
- Changing pH or ionic strength
- Viscosity
- Addition of stabilizers
- Heating, cooling, freezing, and/or shaking

Foams

Foams make a vital contribution to the volume and texture of many common food products. They give volume and a distinctive mouthfeel to products such as whipped cream and ice cream and they give a light, airy texture to baked goods. Improperly formed or unstable foams result in dense products with a low volume, which are unacceptable to consumers. Foams are inherently unstable, and it is imperative that food scientists increase their knowledge of the factors affecting foam stability, in order to enhance the quality and shelf life of these products.

A foam contains gas bubbles dispersed in a liquid continuous phase. The liquid phase may be a simple dispersion, as in egg white, which is a dilute protein dispersion, or it may be complex, containing emulsified fat droplets, ice crystals, and/or solid matter. Examples of complex food foams include ice cream, angel food cake, marshmallows, and yeast-leavened breads. Foams such as meringue and baked goods are heat-set, which denatures the protein and converts the liquid phase to a solid phase. This gives permanence to the foam structure.

Comparison Between Foams and Emulsions

Foams are similar to emulsions, in that the gas bubbles must be protected by a stable interfacial film otherwise they will burst. Therefore, the factors affecting emulsion formation and stability also apply to foams, and, in general, good emulsifying agents also make good foaming agents. However, there are some important differences between emulsions and foams. The bubbles in foams are generally much bigger than the droplets in emulsions, and the continuous phase surrounding the gas bubbles is very thin.

In fact, it is the continuous phase that has colloidal dimensions, rather than the dispersed phase. The density difference between the two phases is much greater in a foam, and there is a tendency for the liquid continuous phase to drain due to gravity, and for the gas bubbles to escape. The factors affecting formation are similar for both emulsions and foams. However, there are additional factors involved in foam stability.

Foam Formation

In order to produce a foam, energy must be supplied (by whipping) to incorporate gas into the liquid, to break up large bubbles into smaller ones, and to spread the liquid phase around the gas bubbles as they form. The foaming agent, which is contained in the liquid phase, adsorbs at the surface of the liquid, reducing surface tension and also forming a film around the gas bubbles. It is important that the surface tension is low, so that the liquid will spread rapidly around the gas bubbles during whipping. If newly formed gas bubbles are not immediately coated with foaming agent, they will burst or coalesce and be lost.

The amount of energy supplied during whipping is also important; the higher the energy, the smaller the bubbles and the greater the foam volume, provided that sufficient foaming agent is present to completely coat and stabilize the bubbles.

Foam Stability

The stability of a foam may be measured in terms of loss of foam volume over a period of time. When a liquid is whipped to form a foam, the volume of the liquid increases due to incorporation of air. If the foam is stable, the volume does not change very much. However, loss of air from an unstable foam may cause a considerable reduction in volume.

Foam stability may be *reduced* due to the following factors:

- The tendency of the liquid film to drain due to gravity. As it drains, a pool of liquid gathers at the bottom of the container, and the film surrounding the gas bubbles becomes very thin. This may allow the gas to escape and the volume of the foam to shrink.

- The tendency for the film to rupture and allow coalescence or escape of gas bubbles.
- Diffusion of gas from small bubbles to larger ones. This results in fewer bubbles and the foam shrinks.
- Evaporation of the continuous phase also affects foam stability, but to a lesser extent. If the liquid evaporates, gas bubbles burst and foam volume is reduced.

If gas bubbles are lost due to any of these factors, a more dense, low-volume foam is produced, which is not usually desirable, especially in foods such as angel food cake or ice cream.

To produce a *stable* foam with a high volume, film rupture, liquid drainage, and evaporation must be prevented or at least minimized. As with emulsions, the gas bubbles must be stabilized by the presence of a stable interfacial layer, which resists rupture. However, the composition of the continuous phase is also very important in determining foam stability. The liquid phase must have a low vapor pressure, so that it does not evaporate readily at storage and handling temperatures.

More importantly, drainage of the continuous phase must be minimized. Thick liquids drain more slowly than thin ones, and so increasing the viscosity of the continuous phase will reduce drainage. A high viscosity is essential if a stable foam is to be produced.

Foaming Agents

The two most important characteristics of a foam are foam *volume* and foam *stability*. Foam volume depends on the ability of the foaming agent to adsorb at the interface and rapidly reduce interfacial tension and on the level of energy input during whipping. Foam stability depends on the ability of the foaming agent to produce a stable interfacial film and a viscous continuous phase. Although all surfactants are able to reduce surface tension and produce foams, not all are able to form stable foams. In fact, some may act as foam suppressants!

A good foaming agent has the same characteristics as an emulsifier, in that it is able to adsorb at the interface, reduce interfacial tension, and form a stable interfacial film that resists rupture. As might be expected, the best foaming agents used in foods are proteins. Although many proteins are able to produce foams, egg white proteins are superior foaming agents and are used in food foams such as meringues, angel cake, and other baked goods. Other proteins used as good foaming agents include gelatin and milk proteins.

When egg white is whipped (Chap. 10), the proteins denature at the interface and interact with one another to form a stable, viscoelastic, interfacial film. Some of the egg white proteins are glycoproteins containing carbohydrate. When these proteins adsorb at the interface, the carbohydrate sections orient toward the aqueous phase. Being hydrophilic, they bind water and increase the viscosity of the liquid. This helps to reduce drainage, thereby contributing to foam stability.

Gelatin is a good foaming agent, and a warm gelatin sol can be whipped to three times its original volume. When cooled, the gelatin solidifies or forms a gel, which traps the air bubbles and stabilizes the foam; marshmallows are gelatin foams.

The Effect of Added Ingredients on Foam Stability

Many food foams have additional ingredients added to *enhance stability*. For example, egg white foams, such as meringue or angel food cake, also have sugar added. The *sugar* increases the viscosity of the liquid, aiding stability. It also protects the proteins from excessive denaturation and aggregation at the interface. Too much interaction results in an inelastic film which is not resistant to rupture, and in reduced foam volume. Therefore it is important to guard against this when making egg white foams.

Factors Affecting Foam Stability

- Drainage of the liquid film between gas bubbles
- Rupture of the interfacial film around gas bubbles
- Diffusion of gas from small to large bubbles
- Evaporation of the continuous phase

Factors Promoting Foam Stability

- Stable viscoelastic surface film
- Very viscous continuous phase
- Low vapor pressure liquid

Effects of Added Ingredients

Foam stabilizers	Foam destabilizers
Gums	Lipids
Thickeners	Phospholipids
Sugar	Small molecule surfactants
Acid	Salts
Solid particles	

Acid, such as cream of tartar or lemon juice, may also be used to increase foam stability. Addition of acid reduces the pH, which reduces the charge on the protein molecules and usually brings them closer to their isoelectric point. This generally results in a stronger, more stable interfacial film. When added to egg whites, acid prevents excessive aggregation at the interface. However, acid delays foam formation. It may therefore be added toward the end of the whipping process. In the case of egg whites, it is often added at the "foamy" stage. Whipping is not complete until the egg whites have formed stiff peaks. (Egg white foams are discussed in more detail in Chap. 10.)

Other ways to increase viscosity of the continuous phase include addition of *gums* and other *thickening agents*. Also, addition of *solid matter* may promote stability. Whipped cream, for example, is stabilized by solidified fat globules that are oriented in the continuous liquid film. The emulsified fat increases viscosity and is responsible for the stability of whipped cream. To form a stable foam, cream to be whipped must contain at least 30 % fat. Creams with lower fat contents may be whipped successfully if thickening agents such as carrageenan are added. If the cream is warm and too much of the butterfat is liquid, then whipping will not produce a stable foam. Instead, the emulsion will break and the cream will be converted to butter.

Ice cream is another example of a complex foam, which is stabilized by emulsified fat droplets and small ice crystals oriented within the continuous phase. Angel food cake contains solid particles, in the form of flour, which are folded into the egg white/sugar foam. The flour contributes to stability by increasing the viscosity of the liquid, which minimizes film drainage. The increased viscosity and presence of solid particles also reduces breakage of the interfacial film, hence minimizing loss of foam volume.

Anti-foaming Agents and Foam Suppressants

As all cooks know, egg whites will not whip to a stable foam if there is any egg yolk present (Chap. 10). This is because the phospholipids and lipoproteins in the yolk adsorb at the surface, in competition with the egg white proteins, and interfere with formation of a stable egg white protein film. Unlike the egg white glycoproteins, which are hydrophilic, the phospholipids and lipoproteins are unable to increase the viscosity of the continuous phase, because they are hydrophobic, and so orient away from the water. This prevents formation of a stable foam.

Such molecules are termed ***foam suppressants***. They suppress foam volume because they adsorb at the interface, thus suppressing adsorption of the desired foaming agent and preventing it from forming a stable foam. They do not have the properties required to form a stable film or to sufficiently increase the viscosity of the continuous phase. Hence, their presence makes formation of a stable foam impossible. Typical foam suppressants include fats, phospholipids, and other small amphiphilic molecules.

Salts also tend to act as foam suppressants, because they weaken interactions between the protein molecules at the surface, thus weakening the interfacial film around the gas bubbles. However, their effect is not as important as surfactant molecules, because they do not adsorb at the interface.

Anti-foaming agents are able to break up foams or prevent them from forming. Anti-foaming agents are added to fats and oils used in frying, to prevent foaming during the frying process. Like foam suppressants, they act by adsorbing at the air/liquid interface in place of the foaming agents, and because they do not have the characteristics of a foaming agent, they prevent foam formation.

Other Colloidal Systems

Although this chapter covers emulsions and foams, gels should be mentioned, since they are also colloidal systems. A ***gel*** consists of a liquid dispersed phase held within a solid continuous phase. Gels are formed when conditions allow the solid dispersed phase of a colloidal dispersion or sol to bond at strategic points, forming a three-dimensional network that traps liquid within itself. Conditions that are likely to cause formation of such a network include heating, cooling, addition of calcium or other divalent ions, and/or change of pH. Important food gels include starch gels (discussed in Chap. 4), pectin gels (Chap. 5), and gelatin, egg white, and other protein gels (Chap. 8).

Conclusion

Food emulsions and foams are complex colloidal systems, and understanding of their formation and stability is important if the quality and shelf life of these products is to be improved.

Emulsions contain liquid droplets stabilized by an interfacial layer of emulsifier and dispersed throughout a liquid continuous phase. Foams are similar, although the dispersed phase consists of large gas bubbles surrounded by a very thin, continuous, liquid film. The nature of the emulsifier or foaming agent is crucial in determining stability. It must adsorb at the interface, reduce surface tension, and form a stable, viscoelastic interfacial layer that resists rupture, so that coalescence of liquid droplets or loss of gas bubbles is avoided. Additional factors are important in foam stability; it is important that the liquid film between the gas bubbles is very viscous, so that drainage due to gravity is minimized. Evaporation of the liquid must also be prevented during normal storage and handling conditions.

Both natural and synthetic emulsifying agents are available to food companies. The best emulsifiers and foaming agents are proteins. Egg yolk proteins are known as the best emulsifiers, whereas egg white proteins are considered to be the best foaming agents used in food products.

Notes

CULINARY ALERT!

Glossary

Adsorb To bind to a surface.

Amphiphilic A molecule containing both hydrophobic and hydrophilic sections.

Coalescence (coalescing) Two liquid (or gas) droplets merge (merging) to form one larger droplet.

Colloidal system Emulsions, foams, dispersions (or sols), and gels are all colloidal systems. A colloidal system contains one phase (usually the dispersed phase) with dimensions ranging mainly from 0.1 to 10 μm. The dispersed phase contains large numbers of small droplets or particles, and so the surface or interfacial area of this phase is very large. This is an important characteristic of colloidal systems.

Continuous phase The phase or substance that surrounds the liquid droplets or gas bubbles in an emulsion or foam.

Dispersed phase The discrete bubbles (air, carbon dioxide, or liquid) that are surrounded by liquid in an emulsion or foam.

Emulsifier A substance that enables two normally immiscible liquids to be mixed together without separating on standing.

Emulsion An emulsion contains liquid droplets stabilized by a layer of emulsifier and dispersed throughout a liquid continuous phase.

Foam A foam contains gas bubbles coated with a stable interfacial layer and surrounded by a thin, viscous liquid continuous phase. In food foams, the gas is usually air or carbon dioxide.

Foaming agent A molecule that is able to promote foam formation. Useful foaming agents in foods are also able to promote foam stability by forming a stable interfacial layer and also by increasing the viscosity of the continuous phase.

Foam suppressant A molecule that prevents or hinders foaming, generally by adsorbing to the interface in place of the desired foaming agent and interfering with the action of the foaming agent.

Gel A two-phase system consisting of a solid continuous phase and a liquid dispersed phase. A gel may be considered to be a three-dimensional network with liquid trapped within its spaces.

Hydrophilic Water-loving. Hydrophilic molecules are either charged or polar and have an affinity for water.

Hydrophilic/lipophilic balance or HLB A scale that goes from 1 to 20 and indicates the ratio of hydrophilic and hydrophobic groups on a molecule. It is used to determine the suitability of emulsifiers when formulating an emulsion. A high HLB indicates a molecule with more hydrophilic groups, which is suitable for o/w emulsions. A low HLB indicates that there are more lipophilic groups, and the molecule has a greater affinity for oil and is more suited for w/o emulsions.

Hydrophobic Water-hating. Hydrophobic molecules are nonpolar and have an affinity for apolar solvents.

Interfacial tension The force required to increase the interfacial area of a liquid, or to spread it over a surface such as oil. See also, surface tension.

Lipophilic Fat-loving, or water-hating. Lipophilic molecules are nonpolar and have an affinity for lipids and other apolar solvents.

Oil-in-water or o/w emulsion An emulsion containing oil droplets dispersed in water. Oil is the dispersed phase and water is the continuous phase.

Permanent emulsion A stable emulsion that does not separate over time.

Surface tension The force required to increase the surface area of a liquid, or to spread it over a surface. Surface and interfacial tension are often used interchangeably. Generally, surface tension applies at the surface of a liquid (i.e., when it is in contact with air), whereas interfacial tension applies when two liquids are in contact with each other.

Surface-active A molecule that adsorbs at the surface of a liquid. Surface-active molecules contain both hydrophobic and hydrophilic sections, and it is energetically favorable for them to exist at the interface rather than in the bulk phase of a liquid.

Surfactant A surface active molecule (see above).

Temporary emulsion An unstable emulsion, which separates into two layers on standing.

Viscoelastic Exhibits both viscous (liquid) and elastic (solid) properties. In other words, the material will flow if force is applied, but it will also stretch. When the force is removed, the material does not return completely to its original position. It is important for an emulsifier film to flow around droplets to cover temporary bare patches, and also to be able to stretch, so that when disrupted, it does not break.

Water-in-oil or w/o emulsion An emulsion containing water droplets dispersed in oil. Water is the dispersed phase and oil is the continuous phase.

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