"Food mixing in the industrial processes"

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General**:**

Many foods have to be preceded by a mixing process in order to achieve characteristics that are important for the final product such as texture, homogeneity, composition and temperature. Mixing can start as early as the preparation of ingredients and can be continuously used until the end of the process. It has been one of the most used steps for food preparation for a long time. Even if it is a very basic step it has not been understood in its totality because of its wide variety of uses. Food mixing can go from nano-emulsions to large particle suspensions, highly viscous pastes to dry powders with or without the incorporation of gas. The major parts of food mixing that are covered are: the basic objective of mixing (homogeneity), the types of equipments used for mixing, solids as well as fluids, and the mixing power correlations.

The prime objective of mixing is to have homogeneity (uniform distribution) in the product. Usually, the homogenization involves the reduction of particle size achieved by the action of shearing forces. Homogenization is applied very frequently in the food industry such as the processing of fluid milk, emulsification of salad dressing and sauces, mashing of infant food, stabilization of concentrates, etc. Different products require different goals, for example, creams and margarines have to disperse one liquid phase in another forming a stable emulsion; ice creams and chocolate should incorporate gas bubbles as an ingredient into liquid or viscoelastic materials, but for sauces and salad dressings bubble incorporation is undesirable.

The ingredients being mixed directly influence the equipment type that should be used depending on the mixing scenario (solid-solid mixing [powders or textural effects], solid-liquid mixing [coffee, sugar] or liquid-solid mixing [butters, pastes and dough], liquid-liquid mixing [emulsions: margarines and spreads] and gas-liquid mixing [fermentation or chlorination]). It is important to consider a balance between the equipment and ingredients properties in order to obtain an effective size of production without using a large quantity of time and energy consumption, this would relapse in a better process and energy efficiency. Another important parameter for sizing the equipment is the rheology. In the food industry hygienic design and suitability of cleaning are very important issues to consider because of the consequences that could result from a poor hygienic standard, for example the contamination of the product by microbial growth. For the mixing of fluids some of the most important equipment items used are: the paddle mixer, anchor mixers, turbine mixers (different impellers), propeller mixers and the new generation of static mixers. **Figure 1** shows one option to do liquid-liquid mixing.

Figure 1: Equipment for Liquid-Liquid mixing (emulsions)

All these types of fluid mixing equipments are used for different applications: to prevent scorching, to promote heat transfer (jacketed kettles), mass transfer, phase dispersion, low or high viscosities or the combination of two or more of these items. Mixing of solids is more difficult than liquids because of its tendency to segregate and the different sizes, shapes and densities. The equipment for solids could be divided in two sections: Diffusive mixers (random motion of particles by the effect of gravity or vibration) and convective mixers (mechanical agitation). The most common diffusive mixers are the drum blender, the double-cone tumbler and the V-shaped tumbler; for convective mixing, the most common equipment pieces are the paddle mixer and the trough mixers that have a ribbon mixer, a very common solid mixer, in its category. **Figure 2** shows different mixers used for solid mixing. There are some complex foods like dough and paste-like products that need to have intensive mixing. The equipment for these types of operations are built to deliver high rotational momentum even with low rotational speed giving us a considerable energy input per unit mass. The mechanical energy applied to these types of products is transformed into heat and this is the reason why a cooling jacket is often provided in order to prevent overheating. Some machines for kneading are: the planetary mixers, horizontal dough mixers, sigma blade mixers and cutter mixers. The planetary mixer is shown in **Figure 3.**

Figure 2: Equipment for Solid-Solid or Solid-Liquid

Figure 3: Planetary mixer for kneading

"The quality of mixing depends on the effective energy input by unit mass or unit volume fluid."[1] The **power number**, the **Reynolds number** and the **Froude number** are important power correlations in the field of mixing. These are the numbers that help to know and understand all the important forces taking place in each case of mixing, relating the dimensions, type and operating conditions. The Froude number contains the gravitational forces, the Reynolds number contemplates the inertial and viscous forces and the power number relates the power (torque) with the diameter of the impeller, speed shaft and density of the liquid. The Reynolds number is a very important parameter because it helps to understand the **flow regime** and it also helps to determine if the power number is constant or not. The Froude number is just important if the Reynolds number is over 300 and if the vessel is not baffled (only where vortex formation takes place) [8].

Mixing in the food industry is used mainly to obtain homogeneity with the best possible equipment and the best relation of the power correlations. Food mixing has not been totally developed because of the constant change in products with different additives, functional ingredients and changing stringent labeling, and because of the many purposes of the “mixing” equipment, for example, the modification of the structure of food or the development of texture in order to get better sensory characteristics. The fact that some viscoelastic products should retain the gas produced during the process and some other products should avoid gas dispersion, make the situation more complicated. With the development of Computational Fluid Dynamics (CFD), it is easier to explain fluid flow as well as heat and mass transfer phenomena leading to better equipment design and process control for the mixing process. Finally it is necessary to underline the most important differences between the chemical mixing and the food mixing: cleanliness and sanitation, where official regulations are involved, and the adaptation of the general mixing in order to prevent degradation or unwanted cooking, for example the material of the equipment parts that are going to be in contact with the product should be made of stainless steel or other materials that could stand vigorous cleaning and sanitizing. Food mixing can happen between liquid-liquid, gas-liquid, and solid-liquid. This article focuses on emulsions, one of the most complicated liquid-liquid mix, and gas-liquid mixing due to its wide application and the reappearance and creation of products based on air as the most abundant ingredient.

Emulsions:

One of the biggest groups of mixing is Liquid-Liquid mixing, containing emulsions as an important part of it due to its complexity. Many products in the food industry are emulsions or have been produced via an emulsion. Emulsions are not just complex in their structure but also in their composition as well as in their dynamic. [4] “An emulsion consists of two immiscible liquids [...], with one of the liquids dispersed as small spherical droplets in the other [...].”[4] Some examples of food emulsions are milk, butter, desserts, soups, mayonnaise, salad creams, and sauces. [4] The main objectives of the food industry are to get a homogeneous fluid [5] as well as to use the basic principles and techniques to improve the food quality [4] keeping the price low. High-quality emulsions can be produced by choosing the right emulsifier, the most suitable process to produce the emulsion, proper packaging, and storage. [4] The quality itself is affected by the properties of the emulsion, which is strongly influenced by concentration, distribution, and size of the droplets. [4] There are a large variety of emulsions because of the diversity of ingredients that can be used. The physiochemical and organoleptic properties of an emulsion are defined by its structure, type, concentration as well as the interactions between its components. Usually emulsions are polydisperse systems, which mean that the diameter of the droplets varies from droplet to droplet. If necessary, monodisperse emulsions may also be produced. **Figure 4** illustrates a monodisperse as well as a polydisperse emulsion. Even if the properties of every single component of an emulsion are known, the actual behaviour of the emulsion cannot be predicted.

[4] This is because of complex interactions between its ingredients as well as between the droplets. [4] Those droplet-interactions are responsible for the rheology, stability, appearance, and many other characteristics of the emulsion. If the temperature [3], the pH [1] or the concentration of emulsifier [6] change or if some salt is added [1], the properties of the emulsion can change immensely. Therefore the important parts of an emulsion are: the emulsifier, the type of emulsion and its stability and the equipment used to achieve the required properties.

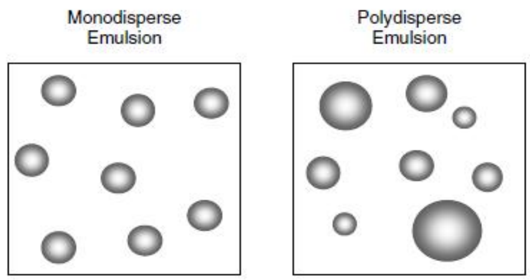

Figure 4: Monodisperse and polydisperse emulsion [4; Chapter 1, page 9, Figure 1.5]

The emulsifiers are so-called surface-active molecules, which are absorbed by the surface of the droplet right after its formation, and keep them from reunifying. [4] There are natural and synthetic emulsifiers. The natural ones are just a few; the synthetic ones are made of natural emulsifiers by treating them with chemicals. Many emulsifiers are amphilic molecules, which mean that they consist of a polar and a non- polar part. [6;4] This enables them to form a connection between the immiscible liquids. If there is just a lipophilic, then there will be no dispersion at all. A slightly dispersed solution is created by increasing the ratio of the hydrophilic and decreasing the one of the lipophilic which produces a water-in-oil emulsion. When the portion of the hydrophilic rise, the emulsion changes from water-in-oil to an oil-in-water emulsion and finally to a colloidal solution.

Even though the emulsifiers decrease the interfacial tension between both liquids, it does not improve the disruption, which is accomplished through mechanical agitation. [3; 6] In the food industry, it is normal to take a combination of a couple of emulsifier, so that multiple functions are covered. [1] The use of this kind of combined emulsifier enables, for example, a cake to be soft, moist and fluffy at the same time. Usually the emulsifiers in the food industry are small surfactants, phospholipids, proteins and polysaccharides. [4] Some of them are based on mono-glycerol and its derivates. [6]

Furthermore the type of emulsion and its stability have to be considered. Emulsions can be classified by their relative distribution of the oily and aqueous phase [4]. Besides the classic emulsion of water-in-oil (W/O) and oil-in-water (O/W), there are so-called 'multiple emulsions' such as water-in-oil-in-water (W/O/W) and oil-in-water-in-oil (O/W/O). [4] In the W/O/W emulsion, the dispersed phase consists of a water-in-oil emulsion, which has then been 'emulsified' in an aqueous phase. [4] These differnt types of an emlusion are visualized in Figure 5, while Figure 6 show a picture of a polydisperse oil-in-water emulsion.

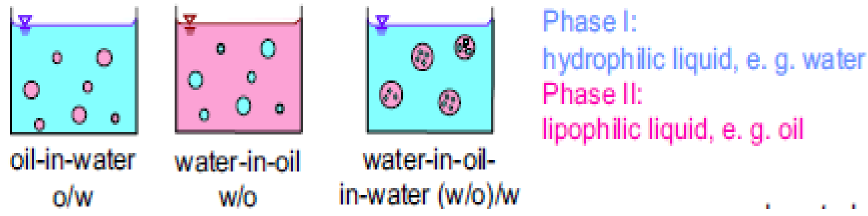

Figure 5. Types of emulsions: [3; Chapter 1, page 5, parts of Figure 1.2]

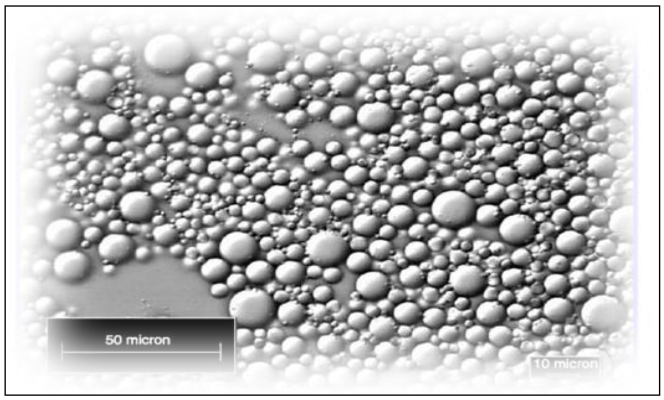

Figure 6 Polydisperse oil-in-water emulsion: [4, Chapter 1, page 3, Figure 1.1]

Many food emulsions not only contain an aqueous and oily phase and an emulsifier, but also other substances such as vitamins, fatty acids, proteins and sugar for example. [4] The stability of an emulsion is the most important property which means that the emulsion's propertie's do not change over time. [3] The diameter of the droplets is supposed to be constant and therefore physically stable. [3] Without any emulsifier a mixture of oil and water will separate immediately when the mixing process stops. By the usage of an emulsifier, the mixture can be kinetically stabilized for a certain period of time [4] or as stated by P.J. Cullen, the emulsion is “kinetically trapped”. [2] The stability of an emulsion can be negatively influenced by chemical reactions such as oxidation. This phenomenon can be inhibited by adding antioxidants. Instability can also be caused by other external factors such as light. If the viscosity of the continuous phase is increased, the droplets are not able to move easily, so that the stability of the emulsion is enhanced. [4] To raise the viscosity, thickening or gelling agents may be used. [4] “Among the principle food stabilizers are alginates, cellulose derivate, gelatine, pectin, starch and other jelly forming substances.” [6; page 94-1 until 94-2]

The mixing of **immiscible** liquids with an appropriate emulsifier can be carried out by using intense mechanical agitation such as high speed blenders and high pressure valve homogenizers. [4] Emulsion can also be produced by forcing the liquid, the dispersed phase, either through a membrane or a micro-structured system, or by using ultra sound. [3] Here the droplets will be detached by the flow of the continuous phase.[3] Another type of equipment is homogenizers. Homogenization is the diameter reduction of droplets in an already existing emulsion [4] by applying high shear forces and often high pressure (up to 70 MPa). [5] High-pressure homogenization is widely used in the food industry, especially for the production of fine dispersed emulsions. [4] As an example, in the dairy industry high-pressure homogenization is used to prevent milk from creaming. [5] Salad dressings, sauces, and soups are emulsified by a homogenizer. [5] To mix highly viscous immiscible liquids there are mixers, which are characterized by their ability to deliver a high rotational moment at a low speed. [5] Thereby energy is often converted into a lot of heat, so that the process is usually cooled. [5] Planetary and sigma-blade mixers are examples for those kind of agitators. [5] In these agitators, the shear force is intense and because of this reason, enormous changes in the structure of the emulsion takes place. [5]

Emulsions are an enormous part of the food industry. For example, "Milk [...] is transformed into a vast array of dairy products: fluid milks and creams, evaporated and dried products, yogurt and fermented milk products, butter, ice cream, and cheese." [7] Raw milk is an oil-in-water emulsion with approximately 4% fat present in the dispersed phase. [7] The droplets are sized between 1 - 4µm and are surrounded by a membrane, which helps to stabilize them. If the milk were not homogenised, the fat droplets would cream. [7] In mayonnaise, on the other hand, an acidified aqueous phase is mixed with oil to an emulsion by using egg yolk and phospholipids as emulsifier [1]. There are a lot of reasons why emulsions are complex and the diameter, the size distribution as well as the density of the droplets changing during homogenization are some of the most representative.

Gas-Liquid:

Besides liquid-liquid mixing, gas-liquid mixing plays an important role in the food industry. Gas-Liquid mixing is explained because of its wide application and the new development of products based on air as the most abundant ingredient. Gas incorporation is an important process in the food industry, as many foods such as bread, beer, champagne, ice cream and even some chocolates contain bubbles. "The inclusion of bubbles in foods permits creation of very novel structures." (Cullen, 2009) Gas incorporation is also important for foods such as cheese and yogurt for bacteria growth. Foams are common in many food products such as beer, breakfast cereal, and ice cream. The two principal methods for mixing gas into liquids are mechanical agitation under positive pressure and steam-induced mixing. The method of mixing the phases is not the only important part of the Gas-Liquid mixing also the amount of gas incorporated should be analyzed.

Gas hold up is seen to be the gauge of the level of bubbles in liquid foods. "Gas-hold up values in bubble-containing liquid foods range from 15% to 20%, for example, in milkshakes, to over 90% in extruded products such as popcorn and rice cakes." (Cullen, 2009) Gas hold up can be defined by the following equation:

$$\text{Ø} = \left(1 - \frac{mf}{mi}\right) * 100$$

Where Ø is the gas hold up, *mi* is the mass of the continuous phase in kg and *mf* is the mass of the foam in kg. This equation can be applied to liquids and pastes having viscosities ranging from medium to high, which includes such things as ice cream and whipping creams. For solid foams such as aerated chocolate, it is complicated to accurately obtain a sample volume. The flotation method is more suitable for these cases (Haedelt, Pyle, Beckette, & Niranjan, 2005). For systems that are less vicious such as beer and cappuccino, the gas hold up is calculated using the height of the foam and the height of the liquid.

Using agitation under positive pressure is a very common method and can be seen in almost every kitchen with an electric whisker. This process effectively beats air into the material to produce bubbles in the liquid “larger air bubbles are initially incorporated from the head space and their sizes diminish as agitation proceeds.” (Prins, 1988) Another common positive pressure gas liquid device is a carbonator, as pictured in **Figure 7.** A carbonator relies on mass transfer principles and allows close contact between the gas (Carbon Dioxide) and the liquid. Other important factors to influence the degree of carbonation include the pressure of the system, gas solubility, time and area of contact. (Cullen, 2009)

Figure 7. Carbonation unit used for carbonating water however, the same type of unit can be used to carbonate such things as soda and beer. (Water botteling systems)

Steam-induced mixing is applied to such products as cereals, puffed rice and popcorn. The structure of these products are formed by introducing pellets into a toasting oven, where the material is exposed to a temperature of up to 300^{o}C for up to 90 seconds. This extreme heat causes the trace amount of water in the porous structure to evaporate into steam, which then forces its way out of the pellet creating the expanded product (Cullen, 2009) as shown in **Figure 8**. Steam-induced mixing can also be found in every coffee shop. Steam is injected into the milk and air is entrained in the headspace of the coffee cup.

Figure 8. Puffed rice is created by treating rice in the presence of steam under high temperature and pressure. (Puffed Rice)

Gas incorporation is an important to the field of food mixing because so many products use air for visual looks and product shaping. Methods of completing these tasks include mechanical agitation under positive pressure. This includes carbonators which are used to carbonate such things as soda and beer. Steam-induced mixing is used for such things as puffed rice, popcorn, and many kinds of coffee.

Sanitation:

Although the interactions between liquids, solids and rheology in all mixing situations are important, it is necessary to emphasize the difference between general mixing and the mixing in food industry, sanitization. The cleanliness of the equipment is crucial in maintaining product quality. In simple mixers, such as a paddle type mixer (**Figure 9(a)**), the sanitation issues that arise are relatively simple. Other than basic cleaning and drying of the mixing paddles, the main issue that arises is the placement of the bearings and grease fittings. To ensure the quality of the product, bearings and fittings must be placed away from the product stream, in case leakage occurs. When it is impractical for such placement, the bearings are required to be sealed in a casing, which must be periodically checked for leaking. As the mixers become more complex, sanitation problems become more complex. Mixers such as reel-type mixers and twin screw mixers (**Figure 9(b)**) experience problems because build up occurs at the side walls and at the end of the mixers. There are two cleaning procedures that are used for more complex equipment, cleaning out of place and cleaning in place (Troller, Sanitation in Food Processing, 1983).

(a)  **(b)** 

Figure 9. (a) Marion Paddle Mixer (Chemical Compounding Company, n.d.). (b) Twin Screw Mixer (Ajax Equipment, n.d.).

Cleaning out of place (COP) operation requires the mixer be disassembled to properly expose all soiled surfaces that may compromise product quality. Each individual component of the mixer is rinsed, cleaned, sanitized, dried, and reassembled. Common practice dictates that tubing and equipment parts be machine cleaned using turbulent fluid flow and brushes, while permanent equipment, such as tanks and holding vessels, are manually cleaned using high pressure nozzles, detergents and sanitizers. Since COP operation requires the equipment to be disassembled into its individual components, it is quite intensive labor and therefore it has obvious negative economic consequences (Berk, Food Process Engineering and Technology, 2009). For this reason centralized cleaning in place, or CIP, are being investigated to replace COP systems.

CIP operation allows the mixers to be cleaned in place by passing strong hot cleaning solutions at high velocities through the equipment. In order to ensure proper sanitation inspection of the equipment is still required, and thus mixers are designed so they can be easily dissembled with simple tools (Clark, Practical Design, Construction and Operation of Food Facilities, 2008). A typical CIP system contains a central metering pump, a detergent source, and a piping system to distribute the cleaning solution (Troller, Sanitation in Food Processing, 1983). Rinsing, cleaning, and sanitizing fluids circulate along the path of the product and provide the detergents and mechanical action needed to remove any contaminants. In the food industry two types of CIP systems are prevalent: single use and reuse systems. In a single use system, the detergents and sanitizers are run through the system for only one cleaning cycle and are then discarded. Advantages of these systems are that they tend to be fairly inexpensive and require very little space. Reuse CIP systems are more expensive and require more floor space because they recycle the cleaning fluids by storing them between subsequent cycles. **Figure 10** depicts a simple reuse CIP system (Berk, Food Process Engineering and Technology, 2009). Converting from COP to CIP is thought to be one of the greatest advances in food plant design, as it causes a significant decrease in the labour needed for sanitation processes, which increases economic return (Clark, Practical Design, Construction and Operation of Food Facilities, 2008). Since CIP systems are more efficient and cost friendly than COP systems, they are slowly becoming more common in the food industry (Troller, Sanitation in Food Processing, 1983).

The main focus of food mixing is to ensure the homogeneity of the product. The equipment used and the mixing power correlations are important to know in order to properly understand mixing applications in the food industry and the complexities faced by each. Additionally, the problem of contamination/cleanliness of the equipment can effect the entire production (batch), which can cause changes in the properties of the product or even lead to the complete degradation of the product.

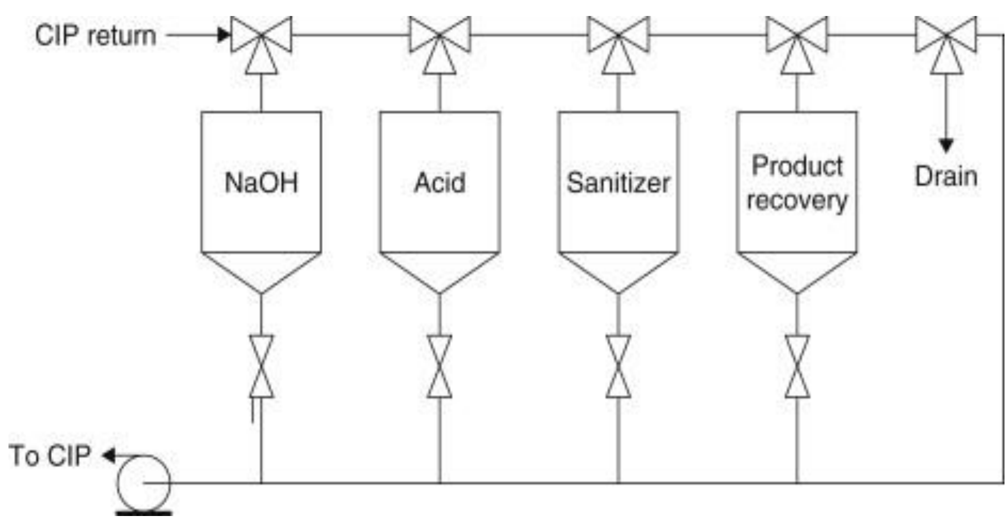

Figure 10. A Basic Reuse Cleaning in Place (CIP) System (Berk, Food Process Engineering and Technology, 2009).

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