Mixing in the Consumer Products Industry

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Overview

This article pertains to mixing in the consumer products industry. For other mixing applications, see **industrial mixing**.

Consumer products are divided into three categories: detergents, personal care products, and cosmetics. The manufacture of each individual product involves complex mixing procedures and requirements which can change from one product line to another. To generalize, the major mixing problems pertaining to industry involve: liquid blending, liquid-liquid dispersions and emulsions, solid-liquid dispersion. Other mixing requirements are often present in the manufacture of consumer products due to complex formulations, stability, and performance requirements of each product.

The **rheology** of the final and intermediate consumer products typically determines the mixing regime and the type of equipment required in the manufacturing process[1]. Relatively few consumer products are **Newtonian fluids**, though the rheology of a product may change at any stage of production[2]. Most consumer products are **viscoplastic** materials, meaning that they are both **shear thinning** and **yield stress** fluids[3]. Certain pastes demonstrate **shear thickening** behaviour. Changes in rheology may occur while mixing certain consumer products. This often requires specialized equipment, such as variable speed mixing drives. Multiple impellers may be required to deal with the changing viscosity of a fluid. For example, in the addition of **thickeners**, the viscosity of the fluid being mixed is increased, which could cause a turbulent mixing operation to enter the laminar regime[3]. Insufficient shear during a polymer hydration operation in the production of tooth paste could cause accumulation of a thick polymer coat on the outer wall of a stirred tank, requiring that a wall-scraping impeller be used in the production process[5]. The design of mixing equipment must consider all possible phase transitions and fluid rheologies.

A helical ribbon is ideal when mixing highly viscous pastes, gels, and creams. (Accompanying text).

Source: SunKaier Mixing Solutions; http://www.sunkaier.com/run/upload/product/content/23.jpg

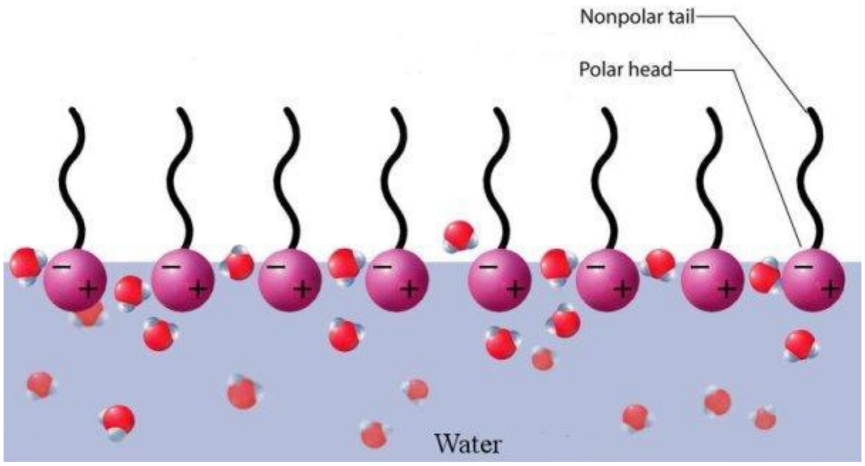
Classifications of Specific Consumer Products

Most consumer products can be classified as liquids, creams, gels, pastes, lotions, solid dispersions, or powders. **Liquid** products are typically simple in nature and are usually composed of a liquid phase, a surfactant, and perfumes or other active ingredients. Household cleaners and perfumes are generally liquids[4]. These liquids are generally Newtonian fluids of varying **viscosity**. **Creams** and **lotions** contain two or more liquid phases, typically water and oil. Creams and lotions are usually **viscoplastic** fluids. Common examples include shampoo, conditioners, lotions, and sunscreens[3]. **Gels** such as hair gel and certain deodorants are fluids composed of a polymer matrix containing a dispersed fluid phase[3]. This can be any fluid phase, though **aerogels** and **hydrogels** are very common. Gels are typically **viscoplastic** fluids. **Solid dispersions** are also very common, and occur in laundry detergents, household cleaners, nail polish, lipstick, toothpaste, and other household products[5]. Solid dispersions exhibit various rheological properties, and can be used to stabilize **emulsions**. **Pastes** are concentrated **solid-liquid dispersions** which are can be either shear thinning or shear thickening, are yield stress fluids. Some pastes, like toothpaste, are often mistaken as gels[3].`

Surfactant Requirements

Surfactants are often used in the production of consumer products. These affect the surface properties of fluids and solids and accumulate at the interface, and can be hydrophilic or lypophilic. Some surfactants can be used to stabilize or de-stabilize **emulsions**, while others can be used to accelerate or prevent the formation of **flocs** in solid suspensions. Surfactants are essential to the coexistence of multiple phases in a final product, and are essential for product stability. Surfactants are often used to incorporate solids into liquids in powder mixtures and detergents. They are also primary cleaning agents in any detergent.

A sufficient degree of mixing is critical when dispersing surfactants, since surfactants are expensive and are only required in parts per million (ppm) [7]. Mixing complications can arise when the surfactant is insoluble or extremely viscous[1]. To take effect, the surfactant must also migrate from the bulk solution to the interface, which is a kinetic process[7]. Accordingly, longer blend times must be used to account for this behaviour. Since surfactants are either hydrophobic or hydrophilic and are present in low concentrations, interactions with the mixing equipment can lead to problems. Additional blend time or injection strategies such as dip pipes, dilution, or pre-mixing may be needed to account for this phenomenon.



Surfactant molecules accumulate at the oil-water interface (Accompanying text)

Source: http://wpcontent.answers.com/wikipedia/commons/0/03/Surfactant.jpg

Additional Considerations

The order of addition of components is vital in the manufacture of consumer products. In the production of detergents, a stringent mixing order must be followed to allow for intermediate **surface properties** which facilitate mixing, the **neutralization** of **surfactants**, and the incorporation of solids[4]. In the production of hand creams, each surfactant and component must be added sequentially to produce the required water-in-oil-in-water emulsion[7]. Perfumes, pigments, and other expensive ingredients must often be added later in the mixing process in order to maximize their effectiveness.

This seemingly simple tooth paste is likely a solid suspension containing several surfactants, medical ingredients, perfumes, and pigments. The rate and order of addition of each ingredient and the mixing conditions of this product were tightly controlled. (Accompanying text)

Source: http://brownandwhitefoods.com/images/tooth-paste.jpg.

Reactions can sometimes occur in the production of consumer products, such as **saphonication** in soap production, **polymerization** in the formation of gels, the neutralization of surfactants, and when controlling the acidity of a mixture. If insufficient mixing is delivered to the system, the product may be exposed to temperatures which cause degradation and unwanted reactions[8]. Additional mixing equipment may be needed following any change in rheology.

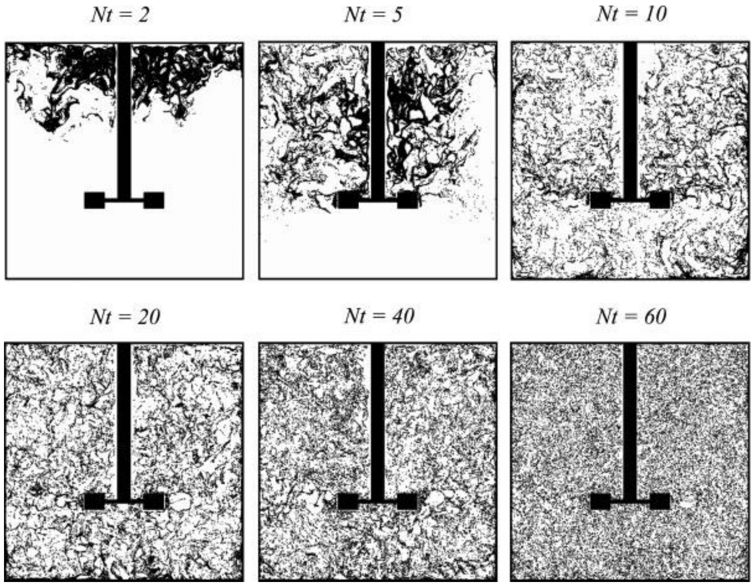
High product purity is often required with expensive consumer products such as cosmetics, and contamination is unacceptable; is important that mixing equipment be designed for easy cleaning. When dealing with abrasive solid suspensions, durable equipment should be selected and equipment replaced often since any impurities created through abrasion can result in contamination[6].

Perfumes, solvents, and other high-value additives may warrant mixing in a sealed vessel. Appropriate shaft sealing and vessel design is required to avoid product loss and recipe changes due to evaporation[8].

Batch processing is common when dealing with consumer products, since some intermediate products require long residence times. Due to the high capital costs of mixing vessels and stirrers, this equipment needs to be flexible and easy to clean[5]. Sometimes it is necessary to meet several mixing goals simultaneously. It would not be uncommon for a single stirred tank to contain 3 separate mixers, such as the combination of a wall scraper, an axial flow impeller to ensure good fluid circulation, and a high-shear impeller for emulsification or solid dispersion[3]. Such specialized mixing operations are often costly and inflexible.

Liquid Blending

Liquid blending is a mixing operation in which two or more **miscible** liquids are mixed together until a certain degree of **homogeneity** is achieved[9]. The amount of time required to reach the degree of homogeneity desired is known as the blend time (θ_B).



Progression of blending in a stirred tank; the concentration becomes increasingly uniform as the number of impeller rotations (Nt) increases. (Accompanying Text)

Source: 10

Liquid blending is a very important part of the consumer product industry. In the manufacturing of **perfume,** blending is required to dilute the concentrated perfume oils by **dissolving** them in ethanol[11]. Blending is also required at numerous stages in the production of **toothpaste**. For example, after adding the flavouring agents the contents are mixed under vacuum to produce the desired smoothness and homogeneity in the final product[12].

Blending may take place between high or low **viscosity** liquids. The flow regime of the system can be determined using the **Reynolds' number**, which is dependent of system geometry. If the liquids have low viscosities than the blending is not affected by the fluid **shear rates** and the mixing usually occurs in the **turbulent flow regime**. In comparison, for highly viscous fluids a certain shear force may be needed in order for uniformity to be reached. Mixing of viscous liquids typically occurs in the **laminar flow regime** and stagnation points, known as islands of unmixedness, may form[13]. If the fluid is **non-Newtonian**, cavern formation or rod climbing may result[9]. Since the mixing occurs at the equipment scale, blending is a macro-mixing scale process.

For liquid blending, jet mixed or agitated vessels are typically used. If the mixing is to occur in a pipeline, a tee mixer or **static pipe mixer** may be employed[9]. An agitated tank can be used for either laminar or turbulent flow. Laminar flow in a stirred tank occurs for **impeller Reynolds**

numbers below 10. Typically, an agitated tank using a **helical ribbon impeller** will be used for this application. The blend time can be estimated using[9]

$$\theta_B = \frac{896000}{N \cdot K_P^{1.69}}$$

where

N = impeller rotational speed (rps)

$$K_P = 82.8 \frac{h}{D} \left(\frac{c}{D} \right)^{-0.38} \left(\frac{p}{D} \right)^{-0.35} \left(\frac{w}{D} \right)^{0.20} n_b^{0.78}$$

h = helical ribbon impeller height (m)

c = helical ribbon impeller wall clearance (m)

p = helical ribbon impeller pitch (m per 360° rotation)

w = helical ribbon impeller blade width (m)

D = impeller diameter (m)

n_b = number of blades

Turbulent blending in tanks occurs when the **impeller Reynolds number** exceeds the turbulent to transition Reynolds number (Re_{tt})[9]

$$Re_{TT} = \frac{6370}{N_p^{1/3}}$$

For turbulent flow the blend time required to reach 95% homogeneity is given by [9]

$$\theta_B = \frac{5.2}{N \cdot N_P^{1/3}} \left(\frac{T^{1.5} \cdot H^{0.5}}{D^2} \right)$$

where

N_p = power number (dependent on impeller type)

T = tank diameter (m)

H = fluid height (m)

Static mixers are commonly used for both turbulent and laminar flow[9]. These take the form of pipe inserts which can be used to provide homogenous mixing in very short lengths of pipe.

Assorted static mixers for turbulent and laminar flow. Static mixers are often used in the consumer product industry due to high efficiency and reliability. (Accompanying Text)

Source: http://www.stamixco-usa.com/images/products/enlarge/P-06.0%29-Extruder-Mixing%28uagtr3%29.jpg

Liquid-Liquid Emulsions Sub-Entry

An **emulsion** is a system of two immiscible liquids in which one liquid (as the dispersed phase) is suspended in the form of small droplets in a second liquid (as the continuous phase).[14] Generally, one phase is presumed to be water or an aqueous solution whereas the other one is a water-insoluble substance such as mineral, animal or vegetable oil. Cosmetic emulsions can be classified into three types: water-in-oil (W/O), oil-in-water (O/W), and bicoherent (multiple emulsions) [14]. Multiple emulsions result when an emulsion is dispersed into an immiscible phase, an example being an O/W emulsion dispersed in a oil phase, or an O/W/O emulsion. The W/O system (an aqueous solution dispersed in oil) and the O/W system (comprised of aqueous droplets dispersed in an oil) predominate the consumer product industry. Some of the advantages of emulsions include efficient cleansing action, ease of application, and the ability to apply both water and oil-soluble ingredients at the same time[3]. Multiple emulsions also provide greater control and release of active ingredients, and provide attractive rheological properties[3].

A light oil phase (red) is being dispersed into the water phase. This stirring rate is insufficient for complete dispersion. (Accompanying Text)

Source: Handbook of Industrial Mixing (Reference 1)

An **emulsifier** is a surfactant used to stabilize an emulsion, occupying the interface between a droplet and the continuous phase[15]. Emulsifiers are **amphiphilic** molecules, containing both **hydrophilic** and **lipophilic** groups, which provide the molecule with some affinity for both the disperse phase and the continuous phase. Despite this property, any given emulsifier will be selectively soluble in either the oil or water phase.

An emulsion can be defined as either a macroemulsion or a microemulsion. The term "emulsion" usually refers to a liquid dispersion with a broad distribution of droplet diameters in the 0.01–100 μm range[3]. A **macroemulsion** ranges from 1-100 μm and is turbid and minimally stable[3]. A **microemulsion** has structural diameters in the 0.01-1 μm range and is clear, isotropic, and thermodynamically stable[16]. The formation of a clear polish is an application of a microemulsion. Microemulsions require a much higher level of emulsifier than macrosemulsions but can occupy 20–40% of the dispersed phase, compared to 1–5% of the dispersed phase for macroemulsions[16]. An emulsion with a wide drop size distribution or several peaks in the distribution is **polydisperse**, in contrast to **monodisperse** systems with a uniform droplet size.

Liquid-liquid emulsions can be prepared mechanically by using stirrers or other emulsifying machines. In mechanical emulsification, the interface between the two liquid phases is first deformed to such an extent that drops are produced[14]. These drops are usually too large, and must then be broken up into smaller ones. Shear and friction produced by liquids flowing past each other or by contacting with solid parts of the equipment reduce the liquid to smaller droplets. Impellers used in liquid-liquid dispersion include disk turbines, pitched blade turbines, propellers, hydrofoils, paddles, retreat curve impellers, among others[1]. Static mixers and various rotor stators (inline or otherwise) can also be used to produce emulsions. Small quantities of emulsifiers are often added in most of mechanical emulsion operations to provide stability and increase emulsion efficiency.[3]

Blending of Powders into Liquids

The blending of powders into liquids occurs in many places in the consumer product industry. The cosmetic, detergent, and paint industry all require the mixing of liquids and powders to create and maintain slurries[17]. For example, in the production of lipstick, solid pigment is dispersed in an oily liquid.

There are four possible process objectives for the blending of solids and liquids that can be applied to the consumer product industry[17]: suspending or resuspending the solids in the liquid; drawing down floating solids and incorporating them into the liquid; dissolving solid particles, either to a molecular level or merely to a desired size; mass transfer from solid to liquid or liquid to solid.

A slurry composed of solids suspended in a stirred tank, can be useful in the consumer product industry as a way to apply coatings, allow a larger surface area for reactions and mass transfer**,** dissolve solids, or many other processes. For simple solids (where the mixing is only affected by the solid properties of particle size, density, volume fraction, and size distribution), the Zwietering equation can be used to determine the impellor rotation speed that will just suspend the solid in the liquid[17].

$$N_{js} = S\,\nu^{0.1}\,{d_p}^{0.2}\,\left(\frac{g_{(\rho_s-\rho_l)}}{\rho_l}\right)^{0.45}\,X^{0.13}\,D^{-0.85}$$

Where:

N_{js} - impeller rotation, rps

S - Zwietering constant, function of impellor geometry, found in literature tables

ν - kinematic viscosity, m^2/s

g_c - gravitational acceleration, 9.81 m/s^2

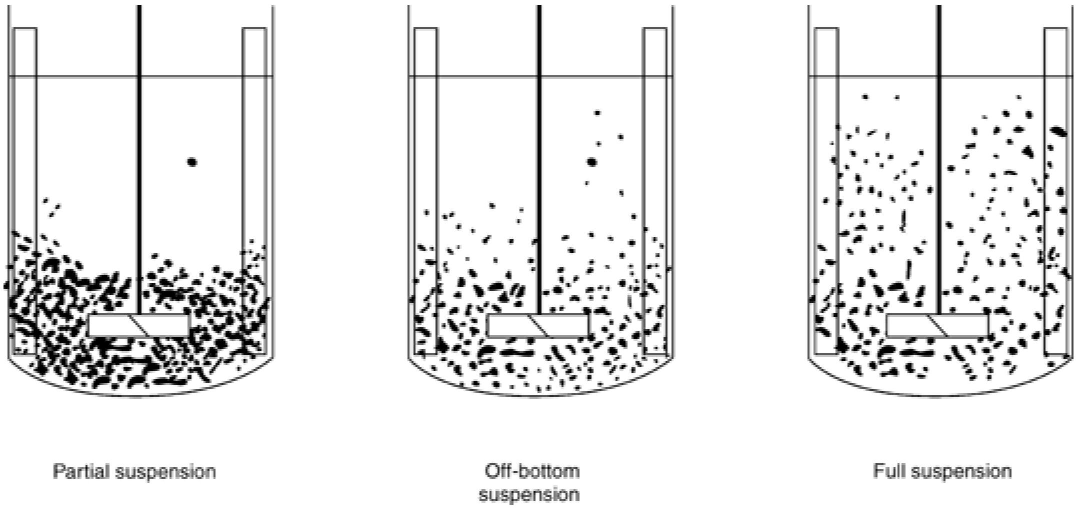
ρ - density, of solid and liquid, kg/m^3

X - mass % of suspended solids to liquid, kg solid/kg liquid

d_p - mean diameter of solid particles, m

D - impeller diameter, m

At N_{js} the solids are suspended in the fluid, but are not evenly distributed. Increasing N lifts the solid rich cloud higher. Figure 7 shows partial solids suspension at speeds lower than N_{js} , off bottom suspension at N_{js}, and full suspension at speeds greater than N_{js}.[18] Note that this correlation is limited to slurries that are from 2% to 15% solids by volume[19].



Examples of Solids Suspension at N less than N_{js}, at N_{js}, and more than N_{js} (Accompanying Text)

Solids that tend to float often need to be incorporated into a liquid mixture, and this presents a different challenge than solids suspension. Sometimes all that is required is to allow the liquid to contact the solid. The air in the particles is displaced; the particles sink and break apart[1]. This is not the case if the density of the solid is less than the liquid. Then, a down pumping impeller is needed to create a vortex on the liquid surface to draw down the solids and keep them there, so they can be broken up[1].

For solids with low density, a correlation is available to calculate the impeller speed required to draw down the solids:

$$N_{Fr} = \frac{N^2 D}{g_c} = 3.6 * 10^{-2} \left(\frac{D}{T}\right)^{-3.65} \left(\frac{\rho_l - \rho_s}{\rho_l}\right)^{0.42}$$

Some solids have strong attractive forces for each other and will form back into large clumps or **flocs** even after they are broken up. To maintain the dispersion of the solids in the liquids surfactants can be added to the process[17]. The surfactant will interfere with the solids particles and prevent them from clumping together. The choice of using a surfactant should not be taken lightly, as it can cause problems with processes or product quality.

The type of mixer used in a solid suspension depends on the required solid particle size distribution. Colloid mills, ball mills, and sand mills are often used to finely disperse solid particles[5]. Hydrofoil impellers can be used in stirred tanks to suspend solid particles and promote dissolution[1].

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