Emulsification technologies: classic versus new

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Emulsions

Emulsions are mixtures of fluids, which are mutually insoluble. The type of emulsion that is mostly used is an oil-in-water emulsion (O/W emulsion). In these emulsions, an oily phase is dispersed as micrometer-sized droplets in a continuous aqueous phase. Alternatively, in water-in-oil emulsions (W/O emulsions), the dispersed phase is formed by an aqueous phase and the continuous phase is formed by an oily phase.

Emulsions are essentially unstable (with the exception of micro-emulsions which will not be discussed here). Due to the density difference, the dispersed phase will cream or sediment, resulting in physical instability. To decrease the creaming and sedimentation velocity, two options are available, or a combination thereof. One is to add substances to increase the viscosity of the continuous phase, therewith slowing the process down. The second is to decrease the size of the dispersed droplets, resulting in a decrease of the ratio of gravity over friction with the continuous phase due to the increase in specific area, and therewith in a lower velocity. Besides this, there is a driving force to decrease the surface free energy, which results in coalescence. Eventually, the emulsion will separate into a watery layer and an oily layer. To prevent coalescence a surfactant / stabilizer is added to the emulsion. This substance adsorbs at the interface between the dispersed phase and the continuous phase, forming a barrier between the two phases, and therewith preventing droplet coalescence.

In spite of instability issues, emulsions are important in a vast array of industrial applications. Products such as paints, milk, sauces, bitumen and many pharmaceuticals and cosmetics are essentially emulsions. To control, or ultimately prevent, product instability, the oil droplets in e.g. fresh cow milk are broken into smaller ones during processing, to prevent phase separation, therewith increasing physical shelf life. This is called homogenization. For pharmaceutical emulsions, the droplet size is of even more importance. Usually the pharmaceutical active substance is dissolved in the dispersed phase. If the droplet size is not uniform, this implies that the substance will not be distributed evenly in the medication, and in each the patient. Besides this, the medication will not be administered evenly in time, therewith reducing the effectiveness of the dosage. Ideally, the emulsion droplets should be homogeneous in size, and the newer emulsification methods described in the second part of the presentation aim to achieve this using micro porous structures.

'Classic' emulsification methods

Usually emulsions are made from a premix emulsion, which is produced by mixing gently, followed by homogenization to further reduce the droplet size. In general, homogenization is an intense process:

it introduces a large amount of energy into the premix emulsion to break up the droplets into smaller ones. Examples of homogenization systems that are used in practice are:

- High-pressure systems (Figure 1, left), in which the premix is pushed through a small orifice at high pressure. Due to the high shear and extension rates in the orifice, the droplets break-up into smaller ones.
- Rotor-stator systems (Figure 1, middle), in which the premix is pushed through the space within a circular stator and rotor. Due to the shear and extension exerted by the rotor, the droplets break-up into smaller ones.
- Ultra sound systems (Figure 1c, right), in which the premix is placed in a vessel with an ultra sound device. Due to the intense turbulence caused by the ultrasound waves, the droplets break-up into smaller ones.

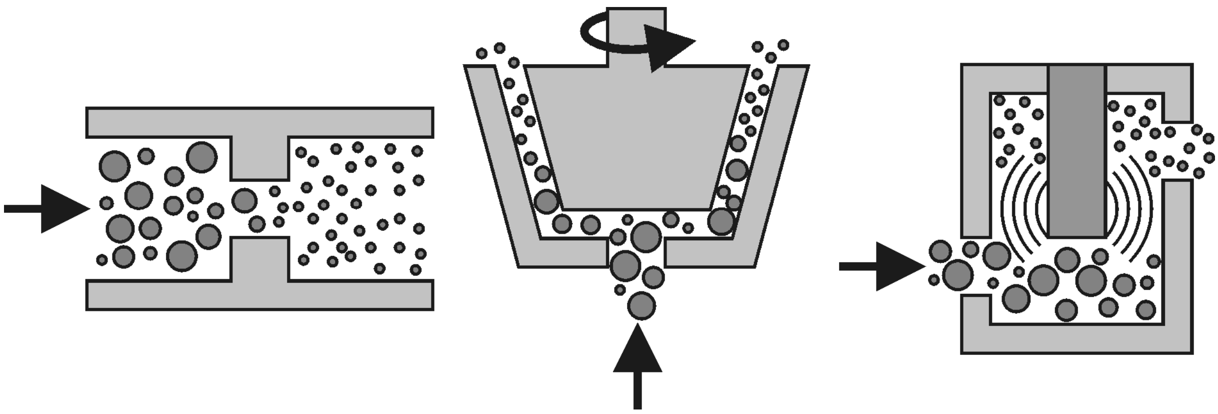

Figure 1. Schematic representations of the three traditional homogenization methods mentioned in the previous section.

In all of these systems the energy input is orders of magnitude higher then theoretically necessary[1]. Another disadvantage of these methods is the relatively large droplet size distribution they yield[2]. There have been many efforts to optimize the methods with respect to energy input and droplet size distribution, but the actual amount of energy that is used is still far from the theoretically needed minimum, and the droplet size distributions of the emulsions are still far from monodisperse.

Emulsification with micro-porous systems

Recently, new methods for emulsification, which use micro-porous systems, have received much attention in literature. Examples of these systems are:

- Membrane homogenization (Figure 2, left), as introduced by Suzuki and co-workers[3], is a method in which a premix emulsion is pushed through a porous membrane. In this membrane, the droplets break-up into smaller droplets resulting in a well-defined emulsion on the permeate side of the membrane.
- Cross-flow emulsification (Figure 2, middle), as introduced by Nakashima, is a method in which the to-be dispersed phase is pushed through a membrane (Nakashima et al.[4]) or a micro-engineered channel (Kawakatzu and co-workers[5]) into a larger channel where a cross-flowing continuous phase snaps the droplets off to form an emulsion with a narrow droplet size distribution.

- Microchannel emulsification (Figure 2, right), as introduced by Sugiura and co-workers[6], is a method in which the to-be dispersed phase is pushed through a micro-engineered channel onto a shallow terrace, where it has to assume a disk shape. At the end of the terrace, the to-be-dispersed phase falls into a deep well where it can assume the thermodynamically more advantageous spherical shape, and subsequently the dispersed phase breaks off and forms a droplet.

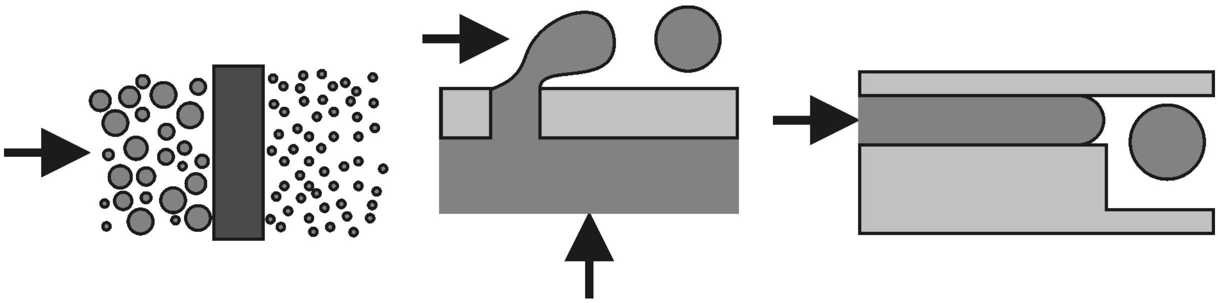

Figure 2. Schematic representations of the three emulsification methods based on the micro-porous systems described in the previous section.

For the methods described in Figure 2, higher energy efficiencies, and narrower droplet size distributions are reported compared to the previously mentioned traditional emulsification methods. However, not much is yet known about the actual underlying phenomena, and detailed knowledge on the droplet forming mechanisms is not available.

Outline of the presentation

This presentation will start with a brief overview of the classic emulsification technologies that were described before, and compare them based on the amount of energy they require. After this, the newer emulsification techniques will be discussed, and compared to the classic techniques. In the last part of the presentation, the latest results obtained at Wageningen University in the field of droplet formation mechanisms and development of new emulsification technologies will be shown. Amongst others, high speed imaging, and simulation results will be presented, and an outlook to future developments will be given.

References

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