**Controlled production of emulsions using membrane and microchannel technology**

This item was submitted to Loughborough University's Institutional Repository by the/an author.

**Citation:** VLADISAVLJEVIC, G.T., 2006. Controlled production of emulsions using membrane and microchannel technology. IN: Proceedings of the 38th Autumn Meeting of the Society of Chemical Engineering of Japan, Fukuoka, Japan. Paper J108.

**Additional Information:**
- This is an abstract.

**Metadata Record:** [https://dspace.lboro.ac.uk/2134/10669](https://dspace.lboro.ac.uk/2134/10669)

**Version:** Not specified

**Publisher:** Society of Chemical Engineering of Japan

Please cite the published version.
This item was submitted to Loughborough’s Institutional Repository (https://dspace.lboro.ac.uk/) by the author and is made available under the following Creative Commons Licence conditions.

For the full text of this licence, please go to:
http://creativecommons.org/licenses/by-nc-nd/2.5/
1. Introduction

Monodispersed emulsion droplets are advantageous in both fundamental study and practical applications. Two main manufacturing approaches for production of monosized droplets are: (a) direct drop-by-drop manufacture, and (b) passive droplet break up in a confined geometry. The typical examples of the first approach are: (i) direct membrane emulsification (ME) [1]; (ii) microchannel (MC) emulsification [2], (iii) direct generation of droplets in flow focusing microfluidic devices and in microfluidic devices with T-junctions [3], and (iv) nanoliter injection. The examples of the second approach are: (i) premix ME [4], (ii) droplet break up in MCs containing T-junctions or obstacles [5], and (iii) droplet break up in micromixers. This lecture aims to introduce the latest development on the utilization of the membrane and MC emulsification techniques to the controlled production of emulsions.

2. Membrane emulsification (ME)

In conventional direct ME (Fig. 1 (a-c)), fine droplets are created at the membrane-continuous phase interface by pressing a pure dispersed phase through the membrane. In order to ensure a regular droplet detachment from the pore outlets, shear stress is generated at the membrane surface, usually by recirculating the continuous phase along the membrane using a low shear pump (Fig. 1 (a)) [1] or by agitation using a magnetic stirrer or an impeller (Fig. 1 (b)). In rotating membrane systems [6], the droplet detachment is stimulated by rotating the membrane tube within a stationary continuous phase cylinder (Fig. 1 (c)). This can be particularly advantageous to the production of shear-sensitive particles. Suzuki et al. [4] implemented ‘premix’ ME, in which a preliminarily emulsified coarse emulsion (rather than a single pure dispersed phase) is forced through the membrane (Fig. 1 (d)) and the small droplets are formed by reducing the size of the large droplets in preexisting emulsions. When dispersed phase of the coarse emulsion wets the membrane wall, the process may result in a phase inversion, i.e. a coarse O/W emulsion may be inverted into a fine W/O emulsion and vice versa. One of the disadvantages of premix ME is the higher droplet polydispersity compared to direct ME. In order to improve the droplet size uniformity, a product emulsion is passed through the same membrane a number of times [8]. The repeated membrane homogenisation was originally developed for the production of multilamellar lipid vesicles (liposomes) using polycarbonate filters. The most commonly used membrane in direct ME is Shirasu porous glass membrane (SPG) developed by Nakashima et al. [1]. The span of particle size distribution in direct SPG ME is typically in the range of 0.25-0.45 and the ratio of the mean particle size to mean pore size is 3-4.

Fig. 1. Membrane emulsification methods and systems [7].

3. Droplet generation using microfluidic and microchannel (MC) array devices

The simplest microfluidic device for producing droplets is the T-junction (Fig. 2 (a)). The droplet-forming phase should not wet the channel walls at the junction, therefore...
hydrophobic T-junctions are needed to generate water droplets. When reversing the flow direction, T-junctions with differently sized exit channels will passively sort droplets according to size or break large droplets into smaller ones [5] (Fig. 2 (b)). Droplets may also be created using a microfluidic extension of Rayleigh’s approach, with two streams of one liquid flanking a stream of a second immiscible liquid and the combined two-phase flow is then forced through a small orifice (Fig 2 (c)) [87]. The pressure and viscous forces exerted by the outer fluid ultimately force the inner fluid to break into droplets, either in or just downstream of the orifice. Microfluidic devices can generate double and even triple emulsion droplets in a single step with a coefficient of variation in the dripping regime of generally less than 3 % and an entrapment efficiency of 100% allowing precision control over the outer and inner drop sizes as well the number of droplets encapsulated in each larger drop [9, 10].

In addition to soft microfluidic devices fabricated in elastomeric materials by soft lithography, parallel arrays of microgrooves fabricated in silicon single crystal by photolithography and anisotropic wet-etching processing have been developed and used for generation of uniform droplets by Kawakatsu et al. [2]. The grooved-type MC arrays can be fabricated with different geometries, e.g. with or without a terrace region and individuals MCs may be separated by partition walls on the terrace, as shown in Fig. 2 (d). Using deep ion etching (RIE), new ‘through-type’ MCs, which are vertical to the plate surface were developed and used for droplet generation by Kobayashi et al. [11] (Fig. 2(e)). The primary problem in straight-through MC emulsification is the difficulty in generating monodispersed emulsions when the viscosity of dispersed phase is less than 1 mPa s. To overcome this problem, an array of ‘asymmetric’ through-holes vertically fabricated on a silicon plate has recently been developed [12]. As shown in Fig. 2 (e), each asymmetric through-hole is composed of a narrow slit and a circular channel. The main advantage of silicon MC arrays in comparison with microfluidic devices with T-junctions and flow focusing devices is much higher productivity, due to large number of MCs on a single plate (in some cases over 100,000).

4. Production of solids from mono-sized droplets

Membrane and MC devices have also been adopted for the precision manufacture of functional solids. To date, several different types of particles have been successfully produced by incorporating use of various membrane and microfluidic devices in processes of polymerisation, gel formation, crystallisation, and molecular or particle self-assembly (Fig. 3). ME is more suited to the fabrication of less sophisticated particulates, such as solid lipid particles, gel microbeads, polymeric microspheres, silica particles, solder metal particles for surface mount technology, etc. Microfluidic devices allow more sophisticated particle designs to be created, such as polymersomes (polymeric vesicles), asymmetric lipid vesicles, colloidosomes, 3D colloidal assemblies, core-shell polymer microcapsules, particles with special optical properties, such as bichromal and discoid particles, etc [7].

---

**Table 3. Examples of Particulates Fabricated from Emulsion Droplets Through Membrane and Microfluidic Routes**

<table>
<thead>
<tr>
<th>3D Colloidal Assemblies</th>
<th>Lipid Vesicles</th>
<th>Polymerosomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="3D Colloidal Assemblies" /></td>
<td><img src="image2" alt="Lipid Vesicles" /></td>
<td><img src="image3" alt="Polymerosomes" /></td>
</tr>
</tbody>
</table>

Fig. 3. Examples of particulates fabricated from emulsion droplets through membrane and microfluidic routes.

5. References


---

*E-mail: gtvladis@afrodita.rcub.bg.ac.yu*