Entangled sciences: the art of microfluidic mixing and separation

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1 author:

Zhigang Wu
Uppsala University

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Preface

Entangled sciences: the art of microfluidic mixing and separation

Zhigang Wu
Huazhong University of Science and Technology, State Key Laboratory of Digital Equipment and Manufacturing, Wuhan 430074, People's Republic of China
E-mail: Zhigang.Wu@angstrom.uu.se

At the conjunction of interdisciplinary fields, we often struggle to express ourselves when we encounter society. As scientists, usually we can find the exact words to explain what we are doing and what field we are working in. However, working in mixing and separation opens up questions such as 'Will you not become confused or entangled with two such contrasting topics?' presented with a smile. Yes, we have to handle these two seemingly opposing issues since we are always trying to find what is beneath the surface. And the longer we spend in this field, the more beautiful connections we find.

In his plenary presentation at MicroTAS 2008, San Diego, when arguing that engineering is an art [1], Ottino showed us many beautiful pictures relating to mixing. Since I was working on soft inertial separation, I asked myself if separation was also an art? What were the connections between mixing and separation? According to my observations, there are quite a few.

Firstly, microfluidic mixing is categorized as being either active or passive, as is microfluidic separation, see figure 1. In microfluidic mixing, nearly all types of external actuation mechanisms, such as acoustic, electrical, piezoelectric, magnetic, thermal, and so on, can be used to disturb the flow and hence enhance the mixing. And in microfluidic particle separation, the same rule applies. Any actuation mechanism can be used as an external switch to deflect the selected particles for separation.

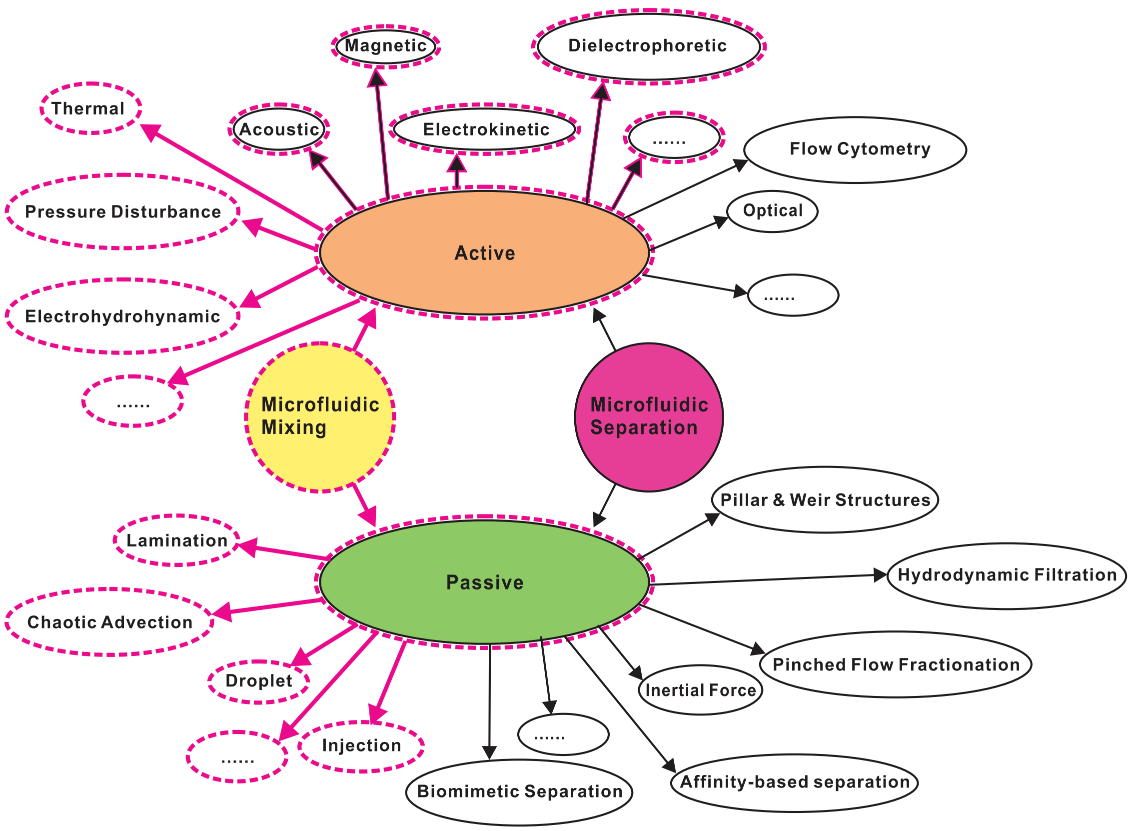

Figure 1. Categories of microfluidic mixing (dashed lines) and separation (solid lines).

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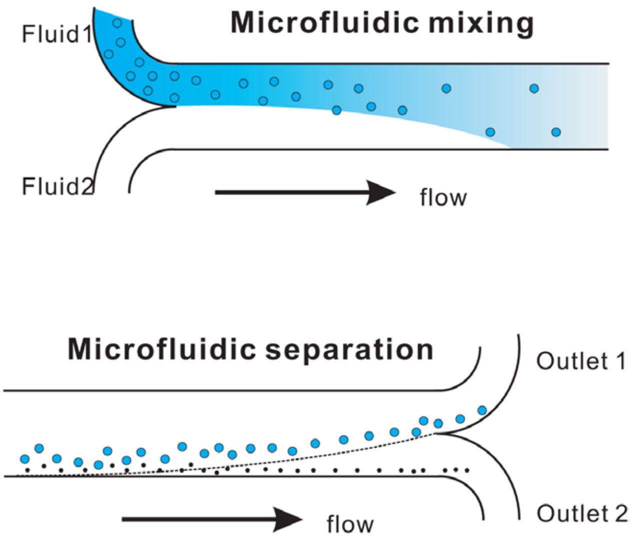

Figure 2. Movement of microfluidic mixing and separation: transvers migration.

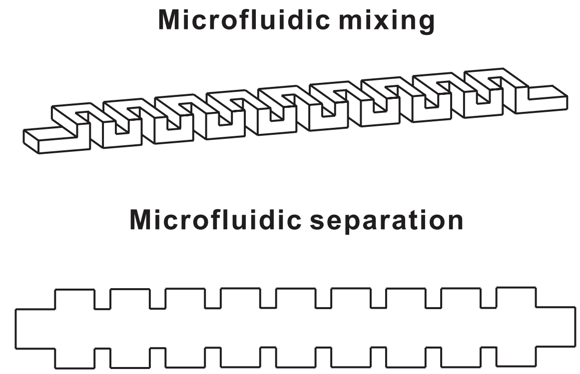

Figure 3. Strategy for microfluidic mixing and separation: iteration.

Secondly, the transport of the particles/molecules works in similar ways, see figure 2. In microfluidic mixing, the molecules from one source need to migrate transversely into another to achieve a homogeneous state. In particle separation, similar to the mixing process, one fraction of the particles should usually be deflected transversely to a separate track while the rest should be kept in the original. The slight difference is that in the latter only a fraction of the particles need be carefully controlled for transverse deflection or migration.

Thirdly, some general strategies are often used. To reach maximal performance, multiple iterations are often applied, e.g. figure 3. For instance, a typical approach for mixing is performance enhancement. In separation, a small transverse deflection is often not enough to separate the particles/cells of different sizes with a sufficient deflection distance. One typical amplifying technique to increase the distance is determination of the lateral displacement-based separation, which uses multiple iterations just like the mixing splitting–combining technique.

Fourthly, the flow state Reynolds number (Re) plays an important role in the mixing or separation process, see figure 4. Usually, Re determines which force is dominant. This is particularly important for passive mixing and separation, which often require a strong inertial force, especially a secondary force, to enhance the mixing or separation performance at a specific Re range. Some approaches meanwhile try to avoid a strong inertial force so as not to disturb their design.

Finally, several approaches have fundamentally the same design. Examples include cross-channel design, curved channels (figure 5), iterated expansion–squeezing channels, channels of various herring shapes, and asymmetrical focusing.

Returning to Ottino, I tend to believe that microfluidic mixing and separation are both kinds of art, which can be expressed in many formats. Although different in many aspects, they are intertwined in a beautiful entangled science.

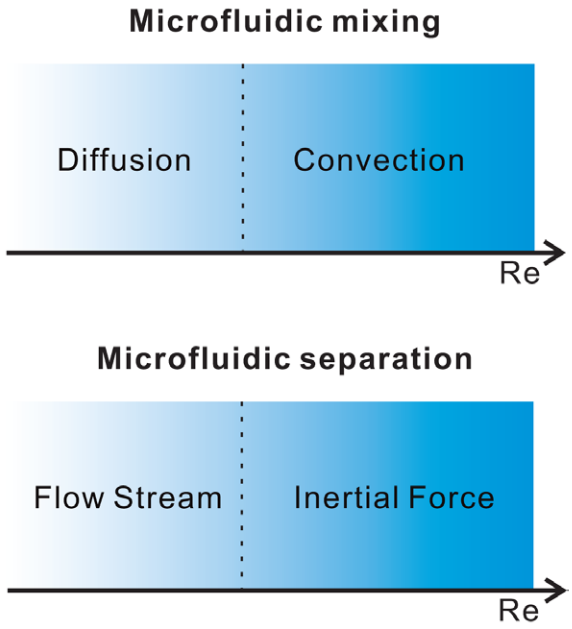

Figure 4. Microfluidic mixing and separation: flow states.

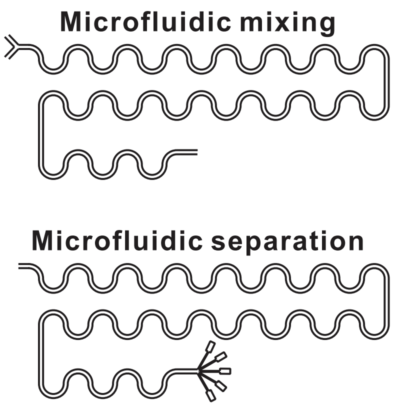

Figure 5. Microfluidic mixing and separation: specific design.

Reference

[1] Ottino J M 2008 Creativity in science and technology: examples from fluids, lesson from art *Proc. of the 12th Int Conf. on Miniaturized Systems for Chemistry and Life Sciences (MicroTAS 2008)* p 1338