Review

After two decades of development, microfluidics is now pushing back the boundaries to tackle a range of industrial challenges, including high-throughput experimentation, on-chip analysis, extreme conditions (pressure, temperature, etc.) and environmental footprint limitation. Microfluidics 2019 examined these topics in detail!

The program for this scientific conference was structured around three main formats: tutorials, four plenary sessions and the start-uppers debate. The tutorials focused on *Miniaturized on-line analysis, Novel microfluidic devices for fluid and material characterization* and *Microfabrication for extreme conditions*. The four plenary sessions were dedicated to *Fluid and flow characterization*, *Fluid separation and on-chip analysis*, *Synthesis and performance monitoring* and *New technologies for the environment and alternative energies*.

The major trends and improvements emerging from each format are summarized below.

Tutorials

Miniaturized on-line analysis *(N. Caillol, Axel'One, France)*

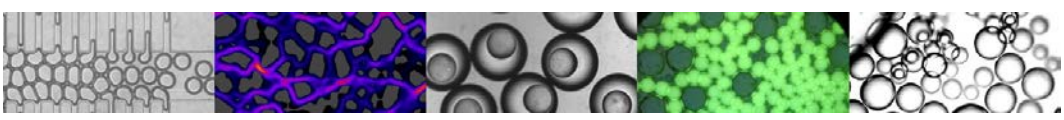
This presentation described the potential of online analytical techniques that can be adapted to applications in the field of microfluidics. It focused primarily on optical spectroscopy, covering the various technologies available (Raman, IR, UV-VIS, NIR), the different criteria for choosing and installing your equipment for online applications (quality, stability, cost, etc.), and data treatment options adapted as a function of signal quality and application monitoring targets.

Novel microfluidic devices for fluid and material characterization *(A. Lindner, ESPCI Paris, France)*

A. Lindner presented an overview of microfluidic designs and methods employed to study the various properties of fluids and materials. In fact, microfluidic devices do not only enable precise, easy control of flow geometries but can also be used to characterize material properties. Here we present a subjective overview of some recent microfluidic rheometer developments for the characterization of shear viscosities as well as normal stress differences or elongational viscosities. These devices rely on an intelligent channel design and innovative observation methods, including the onset of flow instabilities or birefringence. Material properties, such as Young's modulus, can be determined using in situ testing methods based on fluid-structure interactions, for hydrogel particles, biopolymers or microhelices.

Microfabrication for extreme conditions *(S. Marre, ICMCB, France)*

S. Marre presented the advantages of microfluidic chips capable of withstanding extreme pressure and temperature conditions for synthesis and processes or for studying flows in a porous media in actual geological conditions. To this end, he has developed Silicium-pyrex microchips that resist harsh conditions and have good chemical stability. Interfacing and fluid management were also explained. Finally, a number of examples were used to illustrate these developments.



Four plenary sessions

Fluid separation and on-chip analysis

α **Keynote lecture** *(R. Lammertink, Univ. of Twente, Netherlands)*

Rob Lammertink's group uses microfluidics to study membrane transport processes in detail. Concerning ion selective membranes, they have elucidated the dominant transport mechanisms, paving the way for improved ion separation processes by visualizing concentration profiles and fluid flows. They also studied the impact of gas-liquid and liquid-liquid interfaces in relation to membrane separation processes. Finally, an investigation of liquid-infused porous media with respect to fouling behavior was presented.

α **Other presentations**

This session examined fluid separation and on-chip analysis in greater detail. Molecule, fluid and particle separation have been studied in many fields. For instance, the separation of chiral molecules for pharmaceutical applications has been demonstrated using a microfluidic device integrating a chiral imprinted mesoporous platinum film under electrochemical potential control. Normal filtration with a PEGDA photo-synthesized membrane has been used to determine the equation of states of charged colloidal dispersions (e.g. nano-latexes or nano-silica), i.e., the relationship between osmotic pressure and colloid concentration. Moreover, hydrodynamic filtration is used to separate particles into different sized subpopulations. To optimize separation performance, a model has been developed to design the appropriate geometry. Finally, in the presence of a two-phase flow, it is known that the position of an unconfined droplet or bubble train in microchannels determines the mass or heat transfer process in the event of dissolution. Thus, a model has been developed to demonstrate that inertial and deformation-induced migration forces play a crucial role, as does surface stiffening due to surfactants.

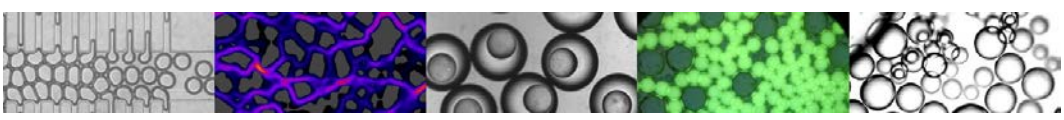
Fluid and flow characterization

α **Keynote lecture** *(D. Weitz, Harvard Univ., USA)*

D. Weitz presented his group's approach to the development of 3D microfluidic systems to investigate the fundamentals of two-phase flows in porous media. Their three-dimensional (3D) model systems make it possible to fully visualize the multiphase flow, in 3D, at pore scale resolution, using confocal microscopy and matching of refractive indexes. Finally, D. Weitz presented how they equip these systems with instruments to simultaneously visualize the flow and probe its bulk transport properties.

α **Other presentations**

A study of the impact of the inlet flow profile on channel flow stability following sudden expansion was performed by modeling. Studies of this type are important in order to understand phenomena such as the impact of a restriction on the nucleation rate in pharmaceutical crystallization processes. The impact of dynamic interfacial tension on droplet formation was then studied. The flow motion of particles in a fluid was subsequently experimentally observed and modeled: the results can be used for both the optimization and understanding of industrial applications and to determine the viscoelastic properties of the carrier solution. Lastly, understanding an analysis of immiscible two-phase flows and of coupled hydro-geochemical processes at the pore scale was performed using flow visualization in micromodels. Different factors were studied, including salinity.



Synthesis and performance monitoring

α **Keynote lecture** *(G. Kolb, Eindhoven Univ. of Technology, Netherlands)*

Gunther Kolb and Fraunhofer IMM have taken an important step towards the utilization of microchannels for industrial synthesis. Microchannel reactor fabrication and the associated fluidic simulation have been developed for optimization and scale-up purposes. Fuel processors for methanol, bioethanol, poly-alcohols, natural gas, LPG and diesel have been successfully developed for a connected fuel cell power range of up to 50 kW.

α **Other presentations**

During this session, participants were introduced to numerous examples of microsystems used for highly controlled working conditions and high-throughput operations. The microsystem applications illustrated ranged from the high-speed production of droplets to fast data acquisition for chemical reactions, flocculants and fuels, as well as highly controlled precipitation or nucleation.

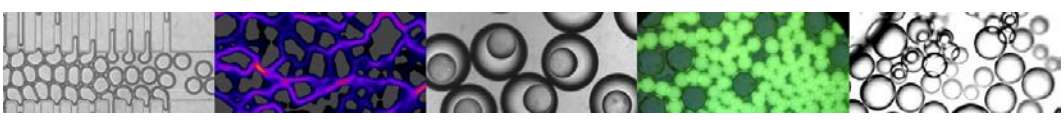
New technologies for the environment and alternative energies

α **Keynote lecture** *(D. Sinton, Univ. of Toronto, Canada)*

D. Sinton's group addresses the world's greatest fluid challenge: control of anthropogenic CO_2 emissions. D. Sinton presented the different approaches employed. Their early efforts were dedicated to the development of microfluidic technologies to understand the pore-scale effectiveness of the most established CO_2 utilization strategies in energy operations. They subsequently used microfluidics to measure the thermophysical properties of CO_2 mixtures. Concerning CO_2 conversion, D. Sinton presented the group's work to study hydrothermal processing of biomass on a chip. Lastly, D. Sinton described their CO_2 conversion project, marking a shift from the conventional microfluidics-for-data approach and employing microscale transport for the challenge of bulk conversion of CO_2 into fuels and feedstocks via renewable-energy powered electrocatalysis.

α **Other presentations**

The photocatalytic depolymerization of lignin is of significant interest to the pharmaceutical and fine chemicals industries. The development of a photocatalytic microreactor was presented and its performance tested. The production of energy through an osmotic engine composed of hydrogel particles was then presented and the synthesis of size-controlled microgel was carried out with a microfluidic device. Furthermore, CO_2 bioconversion within deep saline aquifers was studied via a high-pressure microfluidic approach.



Start-uppers debate

Three start-uppers, from newly created start-ups to entities addressing the international market, presented their activity and answered questions from the audience. Our guests were Laurent Boitard (CEO of MilliDrop), Lyderic Bocquet (Director of IPGG and founder of Sweetch-Energy) and France Hamber (CEO of Fluigent). Among the topics covered: questions dealing with legal and financial aspects, R&D difficulties, team management and recruitment, market identification, first client confidence and the future.

Participation highlights

Microfluidics 2019 brought together **100 scientists** from Europe, North America and Asia: **more than 18 nationalities were represented**! All of them - academics, industrial players and students – underlined the relevance of the conference for the *Microfluidics for chemistry and energy community*. **Microfluidics 2019 is unanimously recognized as the place to be for disseminating your newest research, learning from your peers and initiating collaborations!**

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