Scientific Report

ESF Exploratory Workshop on

Physics of micro- and nano-flows

Leiden, (The Netherlands), 8-12 June 2008

Convened by:

Lydéric Bocquet ①, Detlef Lohse ②, Federico Toschi ③ and
Patrick Tabeling ④

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② Faculty of Science and Technology, University of Twente, Netherlands
③ Istituto per le Applicazioni del Calcolo, Consiglio Nazionale delle Ricerche, Roma, Italy
④ LMM, Ecole Supérieure de Physique et de Chimie Industrielles, Paris, France

Co-sponsored by

Lorentz Center
“Physics of micro- and nano- flows”
Leiden June 9-12 2008

Organizers:
Lydéric Bocquet, Prof., University of Lyon
Federico Toschi, Prof., University of Eindhoven
Detlef Lohse, Prof., University of Twente
Patrick Tabeling, Dr., ESPCI, Paris

1. Executive summary

- The workshop took place in the building of the Lorentz Center, Leiden University. The Lorentz Center provides remarkably convenient facilities, with – in addition to the conference room -- the help of a local secretary, offices for all participants, WIFI with access to most scientific journal, and a very large discussion room. The scientific discussions strongly benefited from this facilities.

- A dinner has been organized, which has been appreciated by the participants and helped participant in getting acquainted.

- The workshop gathered ~30 researchers

- From the opinion of participants, the workshop provided an excellent opportunity to discuss the state-of-the-art of this developing field, and explore new directions and the future of this emerging domain.

As discussed below, there is an opportunity to develop an international network on these topics.

2. Scientific content of the event

During recent years, the pursuit of scale reduction inherent to nanotechnologies has been extended to the fluidic domain, with the very active development of micro-fluidics and now nano-fluidics. Such microscale “lab on a chip” devices are already widely used in biotechnological applications for target screening, for drug design, and for the analysis of small probes of biological material. However, increasing the density of fluidic operations on a chip even further, i.e. miniaturising fluidic devices more, leads to new questions and challenges, both from a fundamental and an application point of view. A key point is that future devices working at nano-scales cannot be thought on a basis of further scale reduction of existing devices working at larger scales: New solutions have to be found, taking the peculiarities of the small scales into account. This requires fundamental breakthroughs in their intrinsic operation and functionalities.
In this context, the aim of the workshop was to give an important contribution in the comprehension of flows at micro- and nano- scales and their potential couplings to the largest scales. We have gathered a community of experimentalists, theoreticians, computer scientists and technologists, working with different perspectives on fluid dynamics in very small systems and at interfaces. During the talks and accompanying discussions, we have explored the fundamental aspects of the physics of fluids at these scales, their modeling, and the new experimental tools and techniques, which have been specifically developed to assess the dynamics at the smallest scales.

During the workshop, talks and discussions have been organized around three themes:

- Micro- and Nano- flows
- New challenges in experimental fluid dynamics at small scales
- Modelling of fluids in small volumes

Round tables took place with the aim to controversially discuss some important subjects: slippage effects, their origin and implication in future nanofluidic devices; nanobubbles, the existence and control and fundamental understandings.

From the various talks and discussions among the participants, several scientific points have emerged:

- The microfluidic domain has now reached a level of maturation, where applications beyond “simple plumbery” starts to emerge, and which – as a key point – benefit crucially from the small scales involved (Strook, Weitz, Colin, Bocquet, ...). In other words, microfluidics is obviously not just a microscale downsizing of fluidic plumbery, but a clever use of specificity of phenomena occurring at the microscales has shown a very strong potential for future phenomena and applications. New applications are explored in this context, eg for desalinization, encapsulation, chemistry... It thus becomes clear that new microfluidic potentialities are being continuously invented, preparing for the future of this domain. New routes to develop nanofluidic systems are now being developed with emerging new routes with high potential. The new physical and chemical phenomena which occur at these scales are currently explored (Lemay, Riedo, Stein, Mugele, Tabeling)

- In parallel, there is a strong effort to develop fundamental understanding of fluid dynamics at the smallest scales, and involving complex – eg nanostructured – surfaces (Netz, Lohse, Vinogradova, Bazant, Squires, Bocquet, ...). The role of surface dynamics, surface nanoscale behavior, molecular effects, ... is now actively studied. In particular the recent development of new tools (computational, fundamental) has allowed to re-explore “old” phenomena (eg like electrokinetics), revisiting/reinventing their potential impact for micro and nano devices. This has driven new experiments in this context (Stein, Eijkel, Tabeling, etc.). This domain has therefore driven a strong back-and-forth interaction between experiments and theory.
A subject which attracted a lot of attention is the possible existence of surface nanobubbles (Attard, Craig, Lohse, Vinogradova). The discussions addressed both new experimental evidences and possible theoretical explanations.

Quite similarly to experimental microfluidics, simulations techniques have now reached a level allowing to go beyond the methodology level and adress the physical questions raised by the specific behavior at nano and micro scales (Yeomans, Pagonabarraga, Sbragaglia, ...). Computational techniques like Lattice-Boltzmann and phase-field models are employed to study questions involving complex multiscale dynamics connecting the behavior at microscales to phenomena occurring at nanoscales.

In parallel it is interesting to note that quite similar progress has been made for molecular simulations, e.g. Molecular Dynamics, which are now able to reach large scales (time and spatial) for ever more detailed and realistic models (Netz, Attard).

3. Content Assessment of the results, contribution to the future direction of the field

At the end of the workshop the organizers took several concrete actions towards shaping the field of fundamental micro- and nanofluidics in Europe:

1. In a plenary discussion we jointly explored the possibility to apply for a research network on the fundamentals of micro- and nanofluidics, in order to systematically keep a closer interaction amongst experts who participated to this ESF exploratory workshop.

2. A smaller group of scientists, namely the organizers of the workshop, met to agree on concrete actions to be taken towards a joint European proposal on the subject. Key groups for such a network were identified. Submission in 2008 was considered to be unrealistic because of lack of time. Submission in 2009 is a realistic option. One of the organizers of the present ESF network will coordinate this effort.

3. The coordinator Prof. Federico Toschi agreed to coordinate a submission of a joint European programme within the COST framework. This proposal (on Lagrangian aspects of particles in flow) has meanwhile been submitted. There is considerable overlap of the groups involved in the COST proposal and the groups present at the ESF meeting.

4. Toschi also agreed to setup a internet database for micro- and nanofluidics, comparable to the database he had already set up for turbulence within the International Collaboration for Turbulence Research, ICTR, see webpage http://www.ictr.eu/

5. Immediately after the ESF workshop the Lorentz Center workshop started. Several of the ESF workshop participants extended their stay also to the LC workshop while other joined. During the LC workshop several students also took advantage of the presence of senior researchers to interact.
4. Final program

Sunday 8 June 2008

Afternoon

19:30  Dinner at Restaurant Hotel hel Witte Huis Oegstgeest
      (Wilhelminapark 33, 2342 AE Oegstgeest, Tel: +31 (0)71 515 38 53)

Monday 9 June 2008

10.00-10.45  Coffee and registration
10.45-11.10  Lorentz Center Welcome by organizers
Presentation of the European Science Foundation (ESF)
Michel Mareschal (Standing Committee for Physical and Engineering Sciences)

Topic 1: New Challenges in experimental fluid dynamics at small scales
11.10-11.40  Serge Lemay (Delft University of Technology, NL)
11.40-12.10  Bruno Andreotti (Laboratoire Hydrodynamique et Mécanique Physique,
              ESPCI, Paris, FR)

12.30-14.00  Lunch Break

Topic 3: Micro- and Nano-flows
14.00-14.30  Vincent Craig (Dept of Applied Mathematics, Australian National University,
             AU)
14.30-15.00  Elisa Riedo (School of Physics, Georgia Institute of Technology, US)
15.00-15.30  Julia Yeomans (Rudolf Peierls Centre for Theoretical Physics, Oxford, UK)
15.30-16.00  Coffee Break
16.00-16.30  Phil Attard (School of Chemistry, University of Sidney, AU)
16.30-17.00  Annie Colin-Exterieur (CNRS-UMR 5258, Université de Bordeaux, FR)
17.00-17.30  Wine and Cheese party
17.30-18.30  Roundtable

Tuesday 10 June 2008

Topic 2: Modelling of fluids in small volumes
09.00-09.40  Roland Netz (Physics Department, Technical University Munich)
             Driven soft matter in nano-confinement
09.40-10.10  Joel Koplik (Institute for Physico-Chemical Hydrodynamics, City College of
              CUNY, New York, US)
10.10-10.30  Coffee Break
10.30-11.00  David Weitz (Department of Physics, Harvard University, US)
11.00-12.30  Informal discussions
Wednesday 11 June 2008

**Topic 1:** New Challenges in experimental fluid dynamics at small scales

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<th>Institution</th>
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<tr>
<td>09.00</td>
<td>Olga Vinogradova</td>
<td>Max-Planck-Institute für Polymerforschung, Mainz, DE</td>
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<td>09.40</td>
<td>Lydéric Bocquet</td>
<td>LPMCN, Université de Lyon, FR</td>
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<td>10.10</td>
<td>Coffee Break</td>
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<td>10.30</td>
<td>Patrick Tabeling</td>
<td>LMM, ESPCI, Paris, FR</td>
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<td>11.00</td>
<td>Derek Stein</td>
<td>Brown University, Atlanta, US</td>
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<td>11.30</td>
<td>Detlef Lohse</td>
<td>Twente University, Enschede, NL</td>
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**Topic 2:** Modelling of fluids in small volumes, ctd

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<tr>
<td>14.00-14.30</td>
<td>Mauro Sbragaglia</td>
<td>University of Tor Vergata, Rome, IT</td>
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<td>14.30-15.00</td>
<td>Martin Bazant</td>
<td>Department of Mathematics, MIT, US</td>
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Thursday 12 June 2008

**Topic 2:** Modelling of fluids in small volumes

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<tr>
<td>09.30</td>
<td>Ignacio Pagonabarraga</td>
<td>Facultat de Fisica, University of Barcelona, ES</td>
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<td>10.00</td>
<td>Abraham Stroock</td>
<td>Cornell University, Ithaca, US</td>
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<td>11.00</td>
<td>ShangJiong Yang</td>
<td>University of Twente, NL</td>
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11.20-12.30  Informal discussions
12.30-13.30  Lunch Break
13.30-14.00  Roundtable

**Topic 3:**  Micro- and Nano-flows

14.00-14.30  Jan Eijkel (University of Twente, NL)
14.30-15.00  Todd Squires (University of California, Santa Barbara, US)
15.00-17.00  Roundtable to discuss follow-up activities in particular concerning possible joint research activities and funding opportunities

17.00  End of ESF Workshop
5. Statistical information on participants (age structure, gender repartition, countries of origin, etc.)

We are not aware of the precise age of most participants. We can however state that a good balance between senior scientists (Attard, Weitz, Netz, Tabeling, Lohse, …) and more ‘junior’ scientists (Andreotti, Bazant, Colin, …) has been reached.

Gender repartition: Female: 5 / Male: 23

Countries of origin:
- Australia: 2
- France: 6
- Germany: 1
- Holland: 7
- Italy: 2
- Russia: 1
- Spain: 1
- UK: 1
- US: 7

6. Final List of Participants

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