Transport Phenomena at the Nanoscale

Personal Development:

I was awarded a Marie Curie Reintegration Grant following a three and a half years long PhD in Materials Engineering at Drexel University, Philadelphia, PA, USA. In January 2008 I was appointed a probationary Lecturer in the Department of Chemical Engineering at University of Bath, United Kingdom, and was awarded the Re-integration grant in September 2008. In conjunction with a PhD studentship provided by the University the IRG has been the basis for the creation of the Nanofluidics Transport Laboratory I direct at Bath. The IRG funds were initially used to purchase all the necessary equipment to start research activity in the Department. The first pieces of equipment purchased have been the used to perform exploratory work which has been at the basis of successful funding applications, including a First Grant with UK EPSRC awarded in 2009 and a 5-year UK Royal Academy of Engineering Research Fellowship awarded in 2010. In particular, thanks to the IRG funding, it was possible to develop the experimental setup necessary to synthesize and test novel ceramic membranes with controlled pore size in the nanometer range and carbon nanotube-based membranes for water separation and purification. The preliminary results obtained via the IRG funding have been a tremendous boost to my professional and academic career, allowing me to successfully pass probation in 2011 and become a tenured Lecturer in the Department of Chemical Engineering at University of Bath, UK.

Scientific Development:

The objectives of the IRG grant included studying if and how nanometre scale confinement affected the flow of liquids inside nanochannels. From our preliminary study in this area, a review on liquid imbibition in nanochannels was published.[1] Thanks to the IRG funds we have been able to perform water flow measurements in nanoporous alumina membranes (Figure 1). We have shown, for the first time, that liquid flow enhancement can be achieved also in hydrophilic nanochannels (Figure 2(left)).

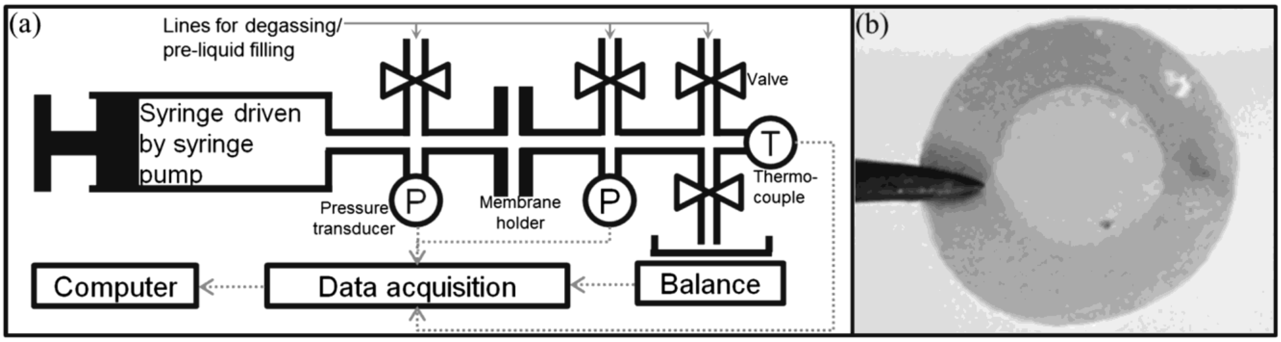

Figure 1. (a) Schematic of the setup built to perform fluid flow measurements in hydrophilic alumina nanoporous membranes, one of which is shown in (b).[2]

Following on these results I have been awarded a grant from the Royal Society to establish a collaboration with a mathematician in Italy to develop a theoretical model to explain this unexpected phenomenon. The model we have developed not only can explain the flow enhancement in alumina nanochannels but was capable of capturing experimental and molecular dynamics results of water flow in carbon nanotubes (Figure 2(right)).[3]

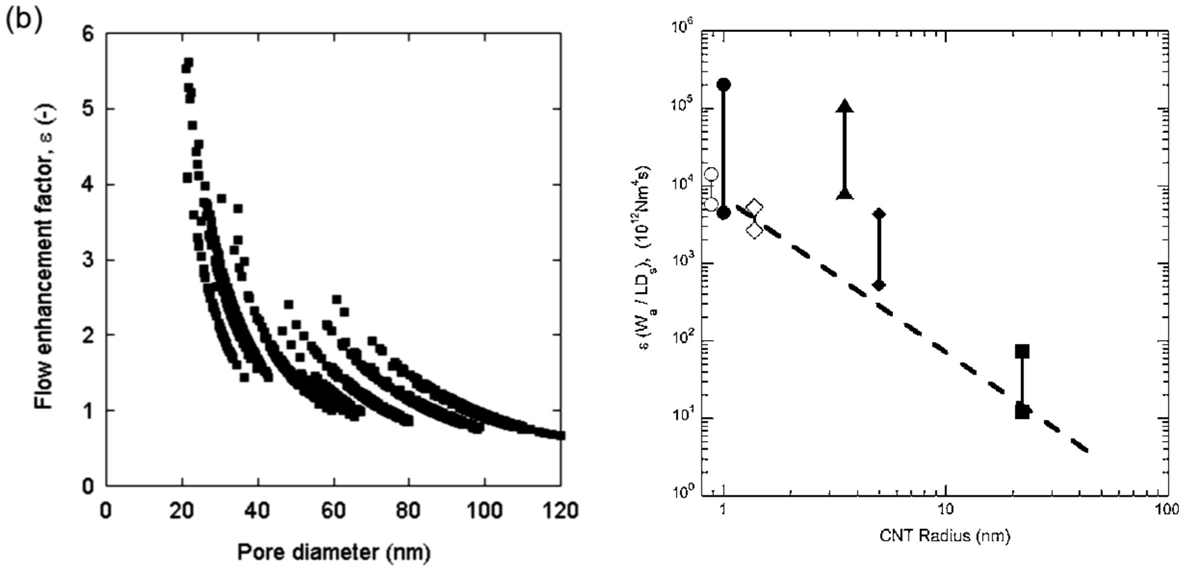

Figure 2. (left) Flow enhancement in hydrophilic alumina nanochannels showing the power law dependence of the enhancement on the nanochannels radius.[2] (right) Normalized flow enhancement as a function of carbon nanotube radius (dashed curve). The literature enhancement have been normalized for comparison: Circle Thomas and McGaughey (2009); filled circle Holt et al. (2006); diamond Thomas et al. (2010); filled triangle Majumder et al. (2005); filled diamond Du et al. (2011); filled square Whitby and Quirke (2007). The literature values (open symbols for MD and full symbols for experimental) are reported as a range between minimum and maximum possible values.[3]

The cumulative outcome of this research has significant potential to change the design of ceramic membranes used for the filtration of liquids. While polymeric membranes currently dominate the market for water filtration in general and desalination in particular, ceramic membranes could one day replace them due to higher mechanical and chemical resistance. Before this can happen, though, their transport properties (permeability and salt rejection) have to be significantly improved.[4] Our results show that it is possible to fabricate nanoporous alumina membranes with narrow pore size distribution in the ultrafiltration range with superior transport properties due to flow enhancement effects. In addition, these membranes are hydrophilic, with very low contact angle, a property that can be used to obtain low fouling membranes. We are now exploring further development of these membranes for potential commercial exploitation.
Results from the IRG-funded work and further development can be found online at the following address: www.bath.ac.uk/nanotech.

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References:
1. Bekou, S.; Mattia, D., Wetting of nanotubes. *COCIS* **2011,** *16* (4), 259-265.
2. Lee, K. P.; Leese, H.; Mattia, D., Water flow enhancement in hydrophilic nanochannels. *Nanoscale* **2012,** *4* (8), 2621-2627.
3. Mattia, D.; Calabrò, F., Explaining high flow rate of water in carbon nanotubes via solid–liquid molecular interactions. *Microfluid. Nanofluid.* **2012,** *13* (1), 125-130.
4. Lee, K. P.; Arnot, T. C.; Mattia, D., A review of reverse osmosis membrane materials for desalination--Development to date and future potential. *J. Membr. Sci.* **2011,** *370* (1-2), 1-22.