

# Direct measurement of liquid flow rate up to picoliter per minute

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The maturation of nanofluidics over the last two decades has benefited from significant instrumental development in order to measure physical quantities associated to flow and transport at the nanoscale. The measurement of electrical current, for instance, through a single nanochannel, such as an ion channel within a lipid bilayer can now be done with commercial apparatus. These developments contributed to the understanding of transport phenomena in nanopores related to various applications ranging from DNA sequencing to oil extraction and purification, but also water desalination and reversely electricity production by means of electro-diffusio-osmosis phenomena based on ion selective transport in nanopores.

In this framework, a central quantity that remains challenging to measure at the scale of an individual nanopore, is flow rate. The best commercial flow rate sensor gives the ability to measure flow rates of the order of 10 nL/min that remain three decades larger than those typically expected with water in a single nanopore of 100 nm diameter. A few approaches exist though to probe such small flow rates but indirectly and in specific configurations only[1].

To overcome these limitations we developed a simple versatile approach that allows one to perform direct liquid flow rate measurements with a detection threshold of the order of 1 pL.min<sup>-1</sup> [2]. This approach, that is the subject of a patent that will be submitted in the coming days, is applicable to any type of liquid and is not limited to the study of a specific nanofluidic system. This communication aims at describing the principle of the measurement method and the building of a demonstrative sensor based on this approach. The capabilities of the sensor are illustrated with the characterization of pressure driven flow through cylindrical micro-capillaries used as benchmark systems that can be easily calibrated. This demonstrative sensor is shown to cover three decades of flow rates ranging from 1 pL/min to 1 nL/min. The measure of flow rate through a single conical nanopore within a 1 micron thick silica membrane will be considered as a last example that opens new possibilities for the study of electro-osmosis in strong confinement.



Figure 1: Measured flow rate through calibrated capillaries (left), SEM picture of a nanopore (center) and theoretical velocity field in low Reynolds regime (right).

## References

- [1] Eleonora Secchi, Sophie Marbach, Antoine Nigués, Derek Stein, Alessandro Siria, and Lydéric Bocquet, *Nature*, 537(7619), 210-213, 2016
- [2] Preeti Sharma. *Coupled electro-diffusio-osmosis fluxes in a single nanochannel for energy conversion*, PhD thesis. Université Grenoble Alpes, 2017.