Master thesis : Bursting conditions of passive capillary valves and subsequent emptying dynamics in centrifugal microfluidic platforms

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Bursting conditions of passive capillary valves and subsequent emptying dynamics in centrifugal microfluidic platforms

Master's thesis — Master of Science in Ingeneering Physics
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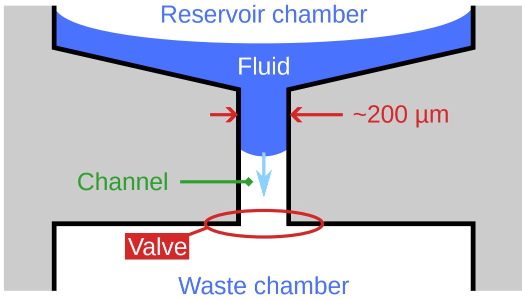
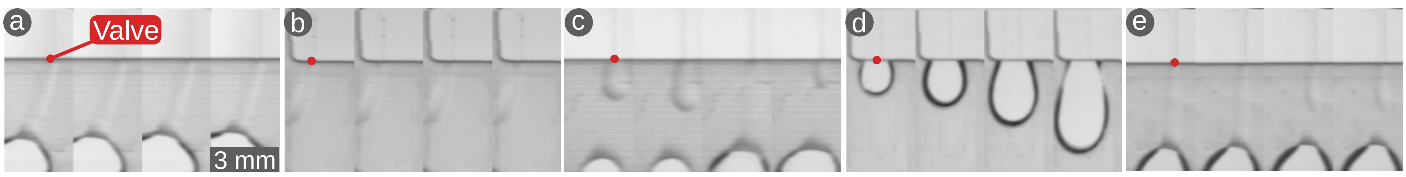
Fully-automated sample-to-answer biochemical assays are needed in intensive care units, e.g., for the real-time monitoring of antibiotic concentration in blood samples from patients whose physiological state may quickly vary. The Lab-on-Disk developed in the Medicare project offer a promising integrated solution to this request. A Lab-on-Disk is a centrifugal microfluidic platform that consists in a rotating disk that contains microchambers and microchannels. The liquids flow therein thanks to centrifugal forces and can be mixed together to perform the assays. For the robustness of the assays, liquids have to be regulated by valves. In particular, the passive capillary valve is the simplest to implement as it only consists in an abrupt enlargement of the channel geometry. This master's thesis aims at identifying the bursting conditions of a given valve and at characterizing the emptying dynamics of the reservoir upstream once the valve opens.



Thanks to a first set of experiments, which consisted in performing a ramp on the angular frequency, we could identify the bursting pressure of a given valve. The latter is shown to follow a Laplace law, considering a curvature proportional to the valve width, which was varied from 0.1 to 0.6 mm. The proportionality coefficient is independent of the angular acceleration in the tested range [100, 1000] RPM. The contribution from the interface in the reservoir chamber to the pressure balance is demonstrated significant and should be considered in the computation of the bursting pressure. The main source of uncertainty is identified as the time discretization due to the video recording.

In a second set, we performed a pulse on the frequency to trigger the valve, followed by a steady frequency plateau during which the reservoir chamber emptied. The properties of the fluid interfaces were measured by computer vision. High-resolution videos of the experiments were processed by the Medicare HUB software developed as part of the master's thesis. Five emptying scenarios have been identified and characterized on the basis of the behaviour of the liquid beyond the valve. That includes: (a) the liquid is shaped as a jet that goes down to the bottom of the waste chamber in a straight way, (b) the same jet is deflected by the Coriolis force and attaches to a lateral wall in the waste chamber, (c) the liquid drips from the valve in a aperiodic sequence of released droplets, (d) the liquid accumulates in a single growing droplet at the outlet of the valve and, (e) the fluid stops flowing such that the valve closes back before the reservoir chamber is fully emptied. Each of these scenarios are linked to features of their emptying curves, i.e., the time evolution of the interface radial position in the reservoir chamber. A phase diagram is presented to discriminate between them on the basis of two dimensionless numbers. The first number accounts for the centrifugal forces, the other is equivalent to a Bond number and accounts for the interface deformation by the centrifugal forces. Lastly, an analytical model is presented to reproduce the experimental emptying curves. The model captures the experimental emptying curves with great accuracy for a Bond number greater than unity. By contrast, a Bond number close to unity implies too much variation in the capillary forces, which invalidates the model hypothesis.



Overall, this work allows a better understanding of the bursting conditions of a capillary valve and is a first but significant step in the characterization of its emptying dynamics. It results in two recommendations for applications that require some robustness and predictability of capillary valves. To go further in the study of capillary valves, emphasis should be made on a systematic analysis of the emptying scenarios. Additional experiments are required to refine some regions of the phase diagram or to explore new ones. It is important to consider all the events that can occur during the emptying as they can strongly influence the flow rate, as highlighted by discontinuities in the emptying curves. Eventually, studies can be performed on the pulse operation itself to identify some reliable bursting conditions.