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Abstract

When the size of fluidic devices is scaled down, inertial effects start to vanish such that the governing equation becomes linear. Some microfluidic devices rely on the non-linear term related to the inertia of the fluid, and one example is fluid rectifiers (diodes) e.g. related to some micropumps. These rectifiers rely on the device geometry for their working mechanism, but on further downscaling the inertial effect vanishes and the governing equation starts to show symmetry properties. These symmetry properties reduce the geometry influence to the point where fluid rectifiers cease to function.

In this context it is natural to look for other sources of non-linearity and one possibility is to introduce a non-Newtonian working fluid. Non-Newtonian properties are due to stretching of large particles/molecules in the fluid and this is commonly seen for biological samples in “lab-on-a-chip” systems. The strength of non-Newtonian effects does not depend on the device size. Furthermore a non-Newtonian working fluid removes symmetry properties such that geometry influence is reintroduced, and indeed non-Newtonian effects have been used in experimentally realized microfluidic rectitifiers[1].

The rectifiers in [1] have the simplest thinkable non-symmetric geometry, but the relation between the geometry and the corresponding working behavior is non-intuitive. This indicates that we will be able to enhance the performance of these devices by changing the design. For this purpose we use the method of topology optimization, which is a kind of design optimization where nothing is assumed about the topology of the design. We will apply a high-level implementation of topology optimization using the density method in a commercial finite element package[2].

However, the modeling of non-Newtonian fluids remains a major scientific challenge, but progress continuous and it is now possible to model systems in a parameter regime where actual devices work.
Presently we have implemented a state-of-the-art model of a non-Newtonian fluid and used this model for topology optimization of a non-Newtonian rectifier. In this way we have found designs that are topologically different from previously experimentally realized non-Newtonian rectifiers.

Non-Newtonian microfluidics is not at all restricted to rectifiers. The project outlook thus relates to optimization of bistable fluid devices, as experimentally demonstrated in [3]. Due to the non-intuitive nature of non-Newtonian microfluidics, there is even the possibility of finding new devices with the help of topology optimization: That is rather than improving existing devices, we can imagine a novel device, then define an objective function and finally investigate the feasibility of the device idea using topology optimization.

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