Pumping Ferrofluid With Only Liquid

May 3, 2022

Robert L. Read

Abstract

Currently this is very preliminary. This is an attempt to design a pump that can efficiently pump ferrofluid with no moving parts except the ferrofluid and two blobs of an immiscible, incompressible fluid, such as water. Eliminating moving parts allows miniaturization and potentially fabrication as a chip. A miniature pump could be used for cooling a chip and for "lab on a chip" applications. The proposed design uses two permanent magnets and seven controllable electromagnets. The design was developed from considering the minimal topological connection of fixed chambers. It has four distinct phases, each phase having a distinct magnetic configuration.

Keywords: ferrofluid pump

1 Introduction

Ferrofluid can be manipulated by electronically controlled magnetic fields to exert force on fluids[1, 2, 3]. This makes it possible to build pneumatic or hydraulic devices, perhaps on very small scales, such as a single chip[4, 5], to miniaturize fluid handling. This has been proposed for biomedical purposes[6] that would use water or body fluids, although this paper reports only on experiments done with air. Miniature pumps and valves could be used to make a "lab on a chip" (LOC) or even to heat or cool different chip areas.

2 Related Research

A number of papers report on ferrofluid pumps, focusing in particular on micropump and lab-on-a-chip applications[3, 7]. Many of these papers use a version of mechanical valve not based on passive ferrofluid, even though they move a ferrofluid bolus with a magnetic field. For example, a corrugated silicone micro valve[4, 8] has been reported. Other researchers use active valves, which require synchronization with the ferrofluid plug to form a pump, such as [9], which describes an active *T-Valve* with a moving ferrofluid plug, and [10] describes a complete fluid pump with valves that use active control of a ferrofluid bolus. At least two additional kinds of active valves, a *well valve* and *Y-valve*, have been described[11]. Active control is possible because the action of the plunger or bolus may be synchronized with the opening and closing of the valves. Nonetheless a passive valve would be simpler and less expensive, and would not require knowledge of the timing of the plunger.

An interesting functional micropump in which the moving ferrofluid bolus merges with a fixed ferrofluid valve and then separates on each pumping cycle has been described[5].

An interesting devices induces a flow directly in ferrofluid with no moving parts, presumable based on the rotation of clumps of ferrofluid [12].

3 The Idea

There is no known way to directly move a mass of ferrfluid which is immersed in ferrofluid. The idea of moving a ferrofluid plug or bolus which is bouneded by air or water via electromagnets turned on or off is well known. A slight inversion of this idea is to use two boluses to trap a blob of water. The water thus remains a separator. In the diagrams below it is represented as a “W”, and the ferrofluid as an “F”. The separator allows us to move the bolus slightly. In order to create a pump, we need to recycle this separator, rather than moving it once, as in a piston.

If we combine this with the idea of a moving bolus “picking up” some ferrofluid and then dropping some of that ferrofluid, we can have a two circulating water blobs and two circulating ferrofluid plugs. One ferrofluid plug, which is moving from the inlet to the outlet, is larger. The other plug is smaller, and merely separating the water plugs as it is returned.

If we reduce this to a minimal configuration, we have a circle of seven

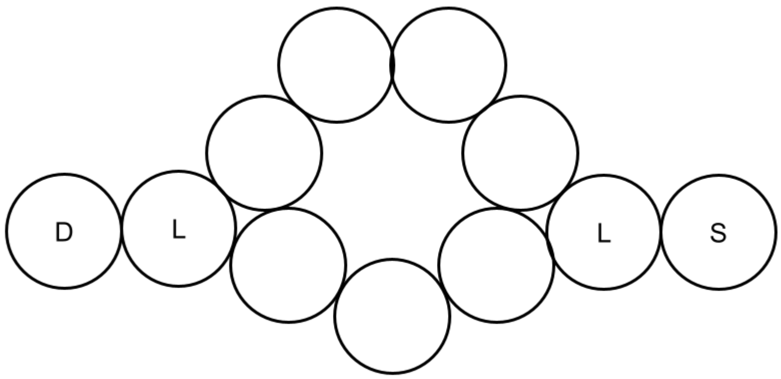

Figure 1: The Pump Schematic

regions of equal size. The inlet and the outlet prevent the water blobs from escaping by having permanent magnets in place. The water blobs can never displace these locks, represented by “L” in our diaggram. The inlet of the pump has an inexhaustible supply of ferrofluid represented as a source (“S”). The outlet is represented as a drain “D”.

The water plugs must always be kept separated by ferrofluid plugs. However, these plugs can pull fluid from the source and push it into the drain if so driven by the changing magnets in the seven dynamic regions. By cycling through four configurations as depicted, we can move ferrofluid from the source to the drain.

4 A Simple Test Apparatus

It is easy to source permanent magnets and difficult to source electomagnets with the precise shapes neede for this project. A test apparatus using only

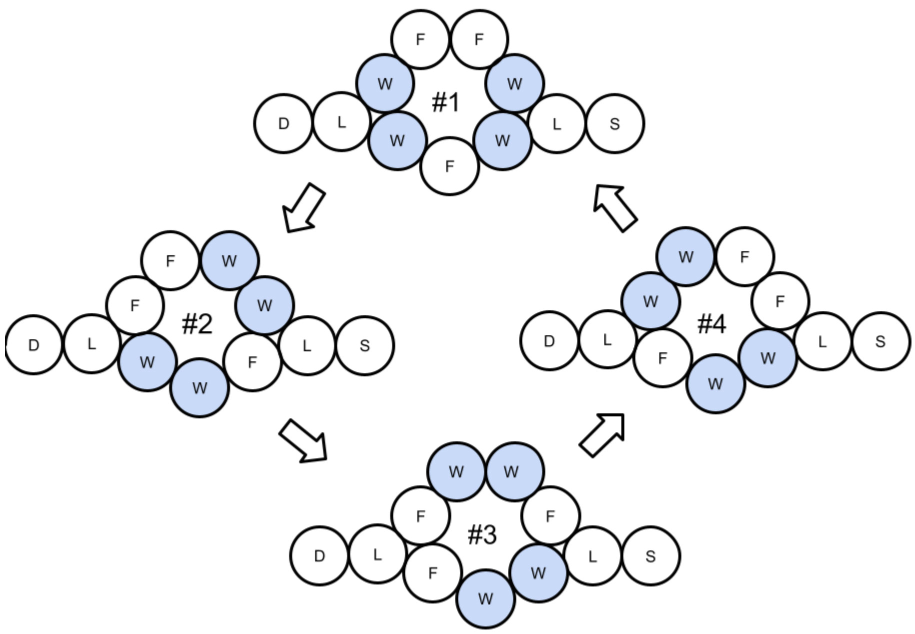

Figure 2: The Pump Schematic

permanent magnets moved by hand to match the 4-stroke cylce of the pump should allow us to test the hypothesis that this pump will work and measure flow on a per-cycle basis. This approach will postpone the need to develop the electromanets.

We therefore propose to make 3D printed apparatus that has cages for permanent magnets which can be moved into the pump ring and out of the pump ring to simulated turning an elctromagnet on and off. These cages are necessary because strong permanent magnets tend to want to fly into each other and must be carefully constrained. We believe we can furthermore make handles which we can glue to the magnets with hot-melt glue to make the motion of the magnets easier to effect. We suspect that the magnest will stay in place when in the ring, and have to held when out of the ring, which may require three hands or some dextrous holding.

5 Conclusions

6 TODO

Study this: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.719.4343&rep=rep1&type=pdf

7 Acknowledgements

This paper was an outgrowth the the Passive Ferrrofluid Check Valve (PFCV) [13] reported by Veronica Stuckey and Robert L. Read. Veronica Stuckery 3D printed some of the apparatus.

References

References

[1] I Torres-Díaz and C Rinaldi. Recent progress in ferrofluids research: novel applications of magnetically controllable and tunable fluids. *Soft matter*, 10(43):8584–8602, 2014.

[2] Madhusree Kole and Sameer Khandekar. Engineering applications of ferrofluids: A review. *Journal of Magnetism and Magnetic Materials*, page 168222, 2021.

[3] Arzu Özbey, Mehrdad Karimzadehkhouei, Sinan Eren Yalçın, Devrim Gozuacik, and Ali Koşar. Modeling of ferrofluid magnetic actuation with dynamic magnetic fields in small channels. *Microfluidics and Nanofluidics*, 18(3):447–460, 2015.

[4] Christophe Yamahata, Mathieu Chastellain, Heinrich Hofmann, and Martin AM Gijs. A ferrofluid micropump for lab-on-a-chip applications. In *Techn. Digest Eurosensors XVII, The 17th Europ. Conf. On Solid State Transducers*, number CONF, 2003.

[5] Anson Hatch, Andrew Evan Kamholz, Gary Holman, Paul Yager, and Karl F Bohringer. A ferrofluidic magnetic micropump. *Journal of Microelectromechanical systems*, 10(2):215–221, 2001.

[6] Trevor Michelson, Joshua Rudnick, Joshua Baxter, and Reza Rashidi. A novel ferrofluid-based valve-less pump. In *ASME International Mechanical Engineering Congress and Exposition*, volume 59445, page V007T08A009. American Society of Mechanical Engineers, 2019.

[7] Meng-Chun Hsu, Ahmed Alfadhel, Farzad Forouzandeh, and David A Borkholder. Biocompatible magnetic nanocomposite microcapsules as microfluidic one-way diffusion blocking valves with ultra-low opening pressure. *Materials & design*, 150:86–93, 2018.

[8] Christophe Yamahata, Mathieu Chastellain, Virendra K Parashar, Alke Petri, Heinrich Hofmann, and Martin AM Gijs. Plastic micropump with ferrofluidic actuation. *Journal of microelectromechanical systems*, 14(1):96–102, 2005.

[9] A Menz, W Benecke, R Perez-Castillejos, JA Plasza, J Esteve, N Garcia, J Higuero, and T Diez-Caballero. Fluidic components based on ferrofluids. In *1st Annual International IEEE-EMBS Special Topic Conference on Microtechnologies in Medicine and Biology. Proceedings (Cat. No. 00EX451)*, pages 302–306. IEEE, 2000.

[10] Bruno Ando, Alberto Ascia, Salvatore Baglio, and Nicola Pitrone. Ferrofluidic pumps: a valuable implementation without moving parts. *IEEE*

Transactions on Instrumentation and Measurement, 58(9):3232–3237, 2009.

[11] Herb Hartshorne, Christopher J Backhouse, and William E Lee. Ferrofluid-based microchip pump and valve. *Sensors and Actuators B: Chemical*, 99(2-3):592–600, 2004.

[12] Leidong Mao, Shihab Elborai, Xiaowei He, Markus Zahn, and Hur Koser. Direct observation of closed-loop ferrohydrodynamic pumping under traveling magnetic fields. *Physical review B*, 84(10):104431, 2011.

[13] Veronica Stuckey and Robert Read. A novel passive ferrofluid one-way (check) valve.