Novel Passive Ferrofluid Check Valve

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Abstract

This work focuses on a novel passive ferrofluid check valve. The structure is free of mechanical moving parts and is based on a ferrofluid plug in a narrow channel.Check valves, also known as one-way valves, are devices that allow fluids to move in only one direction primarily to prevent backflow in the system. The valve returns to stasis (closes) under the influence of a static magnetic field when the pressure on the ferrofluid is less than the magnetic forces of the ferrofluid itself. Here, we present a simple design for a passive, normally closed ferrofluid check valve consisting of a unique channel-and-chamber geometry, a bolus of ferrofluid, and a static magnetic field. The flow is determined only by the force differential between the pressure of the fluid in the channel and the magnetic force of the ferrofluid at the intersection of the channel and the chamber. Small pumps and valves enable flow management in microfluidic systems. A novel passive ferrofluid check valve is presented. The valve consists of only a unique channel-and-chamber geometry, ferrofluid, and a stationary magnetic field. The flow is determined only by the inlet and output pressure, and the magnetic field is completely static. The prototype valve and experimental setup are explained and performance of the valves cracking and collapse pressure reported. This initial design can be used for microfluid handling and lab-on-a-chip applications.

Additionaly we present a theory of operation based on energy minimization and compare predicted performance to actual performance.

1 Introduction

This article is a brief report on an initial but functioning design of a passive ferrofluid check valve (PFCV) that has no moving parts except for the ferrofluid bolus itself, which is stationary in normal operation. By passive, the authors mean a check valve that functions without changes to the magnetic field affecting the bolus, whether that field is induced by a permanent magne t or an electromagnet. That is, the flow is determined purely by the difference between the inlet port pressure and the outlet port pressure. To our knowledge, no passive ferrofluid check valve has been previously reported, despite being an active area of research and despite such a valve having significant advantages for operation and especially fabrication over valves with moving parts.

A fundamental component of such devices is the check or one-way valve. Two check valves on either side of a chamber whose volume can vary creates a positive displacement pump. A perfect check valve opens or cracks with minimal pressure on the inlet side and sustains maximal pressure on the outlet side before collapse, allowing fluid to flow in only one direction. Following [Ref 7] we call the maximum pressure differential the valve can resist in the direction it is intended to check or block (from outlet to inlet) the sustainable or collapse pressure.

2 Theory and Background

This research posits that a ferrofluid confined to a thin channel followed by an open area can function effectively as a check valve. Check valves are passive, one-way valves which prevent the backflow of liquid. There is a minimum differential upstream pressure, known as cracking pressure, between the inlet and outlet that will operate the valve. Check valves operate under the assumption posited below in

$$|\vec{F_m}| \geq P_f * A \tag{1}$$

where $|\vec{F_m}|$ is the magnitude of the force exerted by the ferrofluid, P_f is the pressure of the fluid against the valve, and A is the surface area of the ferrofluid plug in contact with the transport fluid in channel. This leads to cracking pressure, which is when the pressure of the fluid against the ferrofluid exceeds the magnetic force of the ferrofluid defined below as P_c in

$$P_c > \frac{A}{|\vec{F_m}|} \tag{2}$$

In the system presented in this research the substance will flow through the ferrofluid plug when the cracking pressure is exceeded resulting in a pressure release and preventing the backflow of fluid into the system. Check valves have applications in microelectronics and medical devices. The valve presented in this research can be adjusted by changing the magnetic field, and thus the force exerted by the ferrofluid. This research focuses on exploring, both theoretically and experimentally, the simplest case of a static magnetic field.

A cylindrical neodimnium magnet of *insert strength and dimensions here* was selected for the purposes of this experiment, and a T-shaped valve containing a bolus of ferrofluid at the center of a cylindrical magnetic field. *Fig 1 of system mock up*

Ferrofluids is a colloidal mixture of nanoscale ferromagnetic particles suspended in a carrier fluid (typically an mineral oil or other organic solvent). A surfactant coats each particle to prevent the particles from clumping together, maintaining the homogenous colloidal mixture as a fluid. The magnetica attraction of tiny nanoparticles is weak enough to allow the Van der Waals force to prevent magnetic clumping, and typically do not retain magnetization in the absence of an externally applied magnetic field[1]. Ferrofluid in the presence of an external magnetic field will produce the force of many dipoles interacting with one-another and can be summarized using Equation (3)[2].

$$F_{ff} = \int_V \mu_0 \overset{\rightarrow}{(\vec{M} \cdot \nabla)} \vec{H} dV + \Sigma_n \oint_S \frac{\mu_0}{2} (\vec{M_n})^2 dS \oiiint \tag{3}$$

where $\vec{M}$ is the magnetization of the ferrofluid in an applied magnetic field, $\vec{H}$is the applied magnetic field, and $\vec{M_n}$ is the magnetization upon upon each ferrofluid particle due to one another. The first volume integral takes into account how the applied magnetic field will change across the volume of the ferrofluid, and the second surface integral only looks at the surface of each particle affecting one another. These can be evaluated in a case-by-case basis for each applied magnetic field.

References

[1] Voit, W.; Kim, D. K.; Zapka, W.; Muhammed, M.; Rao, K. V. (21 March 2011). "Magnetic behavior of coated superparamagnetic iron oxide nanoparticles in ferrofluids". MRS Proceedings. 676. doi:10.1557/PROC-676-Y7.8.

[2] Rosensweig, R. E. (2013). Ferrohydrodynamics. United States: Dover Publications.