Flow of Magneto-Rheological Suspensions in Microchannels

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Abstract

This experimental study focuses on the flow and characterization of a magneto-rheological (MR) material through a microchannel. MR flow in microchannels can potentially be used as a microvalve in microfluidic and MEMS devices. Flow is controlled by injecting MR material through the microchannel via a syringe at a controlled adjustable rate. The pressure drop of the flow is measured across a length of tubing with internal diameters ranging from 150 μm to 750 μm. A magnetic field is applied perpendicular to the microchannel flow and is controlled by adjusting input current from 0 to 2 A. The results show a significant pressure drop for different magnetic field strengths. It is observed that wall surface roughness has an effect on the flow pressure drop.

The DAQ system consists of a National Instruments (NI) SCXI-1200 controller interfaced to LabVIEW on the computer. DC power supplies are required to create the magnetic field for the electromagnet and power the pressure transducer and NI controller. A MR material, prepared at the University of Nevada’s (UNR) Chemical Engineering Department, can be mixed with more than 90 wt% solids loading of commercially available carbonyl iron micropowder. This MR material eliminates the problem of particle settling by keeping the particles suspended indefinitely. The iron micropowder chosen for this study is the HQ grade from BASF with particles ranging in size from 0.5 to 2.2 μm in diameter. Figure 2 shows an SEM image of a fused silica microchannel with an inside diameter (ID) of 100 μm. Inside the microchannel there are deposits of the UNR MR material that remain after previously being driven through the microchannel.

The magnetorheological (MR) effect is observed when a magnetic field is applied. This effect is characterized by a change in the flow properties of MR materials when subjected to magnetic fields. The MR effect is often observed in suspensions of magnetically soft particles into liquids such as silicon oil or water, the flow behavior of MR fluid through microchannel is similar to a particle-laden or a complex microfluid handling systems for chemical analyses, consisting of separation capillaries, coolers of macro devices, and propulsion engines.

Introduction

The miniaturization of devices to the micro and nano scale level is the current trend in many fields of study. The characterization of MR fluid and its accompanying devices at the microscale are generally well understood. In contrast, there has been limited research published on ER and MR fluid characteristics at the micro scale level. When fully understood, this research could be extended to many applications from microfluidic sensors and valves to complex microfluid systems in chemical analyses, consisting of separation capillaries, coolers, macro devices, and propulsion engines.

Experimental studies of MR fluids at this micro scale level introduce a new arduous challenge. Because MR fluids are suspensions of magnetically soft particles into liquids such as silicon oil or water, the flow behavior of MR fluid through microchannel is similar to a particle-laden or a granular flow. Studies have shown that with particle laden flows, the ratio of the particle diameter to the channel diameter must be about 1.3 for clogging to occur [1]. However, from the experiments that we have conducted, this rate does not seem to hold true with MR suspensions. Theoretical studies of particle laden or two phase flow in microchannels do not take into account the effects of particle agglomeration, settling, and tubing diameter transitions that can result in clogging. This challenge is compounded further as the iron particle size decreases. While an MR with nanosized particles may flow through the microchannel, the change in pressure drop when a magnetic field is applied is insignificant.

Experimental Setup

Specialized equipment for this experiment was required due to the precision of the low volume flow rates and the high pressures that would be measured. A schematic of the experimental setup is presented in Figure 1a. The MR material delivery comes from a syringe driven by a highpressure programmable syringe pump. As the fluid exits the syringe, it transitions into stainless steel tubing and components that allow for the connection of the pressure transducer. The microchannel test section starts at the exit of the pressure transducer. An electromagnet with a gap perpendicular to the microchannel is located in the middle of this test section and is capable of producing a magnetic field density of 0.56 Tesla at 2 Amps of input electric current as shown in Figure 1b. The MR material exits to atmosphere pressure at the end of the test section.

Figure 1a: Schematic of the experimental test setup.

Figure 1b: PEA of the MR microchannel valve.

The pressure drop measurements across the microchannels, the syringe pump could be programmed to deliver a profile changing volume flow rate for microfluid internal diameters down to 250 μm as the input current was adjusted. For microchannels smaller than this, a constant flow rate was used and adjusted manually to obtain the on- and off-state pressure drop for different magnetic field strengths. The microchannels used in this study were commercially available. The 250 μm and larger ID microchannels are constructed from 316 stainless steel or polyether ether ketone (PEEK).

Figure 2: SEM image of a 100 μm ID fused silica microchannel with UNR MR Material deposits.

Figure 3: Shear stress vs. shear rate for a 80 wt% BASF HQ carbonyl iron powder MR suspension in 1 mm gap of a shear rheometer.

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Figure 4 shows the data from 750 μm microchannels. The surface roughness of stainless steel and PEEK microchannel types are 64 and 2.3 microinches RMS, respectively. Notice that the pressure drop is independent of these two materials at this diameter. Although the larger channels are not considered to be microchannels, it is interesting to see how the data change as the channel diameter becomes smaller. At 250 μm there is a noticeable difference between the two materials when the magnetic field is applied as shown in Figure 5. As the microchannel diameter decreases, the flow rate must also be reduced so that the pressure rating of the various components in the experimental setup is not exceeded.

Figure 4: Pressure drop vs. flow rate across 750 μm ID channels, 5 cm in length.

Figure 5: Pressure drop vs. flow rate across 250 μm ID channels, 5 cm in length.

Stainless steel or PEEK microchannels smaller than 250 μm are not readily available, so fused silica capillary tubing with a PEEK outer coating (PEEKsil™) was obtained with the same 5 cm lengths. The pressure drop across a 5 cm length of 150 μm PEEKsil tubing is shown in Figure 6.

Figure 6: Pressure drop vs. flow rate across 150 μm ID PEEKsil channel, 5 cm in length.

Summary and Conclusion

It has been demonstrated that an MR suspension can be formulated that will flow through microchannels. Possible applications for this technology include microavalves and various other MEMS type of applications. The pressure drop along the microchannel is affected by the surface roughness of the microchannel. The Herschel-Bulkley flow model can be adapted to predict the pressure gradient for the MR material flowing through microchannels.

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References
