Microfluidics Innovation Center

Application Note

VISCOUS LIQUID FLOW RATE MEASUREMENT

https://www.microfluidics-innovation-center.com/application-notes/viscous-liquid-flow-rate-measurement

Contents

Introduction

In microfluidic systems, the viscosity of working fluids is a key parameter that influences flow behavior. At the microscale, inertial forces are negligible (low Reynolds number regime), and viscous forces dominate the flow dynamics. As a result, fluid viscosity directly affects flow rate and shear stress distributions within microchannels and pressure drops across microfluidic setups. This can influence the overall stability of the flow and efficiency of microfluidic processes (mixing, separation, particle focusing, etc), affecting inflow particle detection and droplet formation, highlighting the need for accurate flow rate measurements for applications involving viscous liquids.

Our new Galileo flow rate sensor comes calibrated for use with a range of liquids of different viscosities, suitable for applications requiring measurement and/or control of viscous liquid flow rates. The Galileo flow rate sensor is designed with a base and snap-in cartridge. The flow path is contained entirely within the cartridge, which can be swapped to measure different flow rate ranges, or when it is important to avoid cross-contamination between experiments. Our sensor also features a unique clogging alert light to notify the user that the measurement reading is drifting or if the sensor is fully blocked.

This application note demonstrates the technical performance of our Galileo flow sensor with viscous liquids at flow rates of 0.5-50 µL/min, assessed by gravimetric analysis. Glycerol was selected as a test liquid due to its well-characterized and easily tunable viscosity. Here, we tested the Galileo flow sensor with dilutions of 20-80% (v/v) glycerol in water. Hexadecane was also tested as its viscosity closely matches that of glycerol 40%. Glycerol 40% approximates the viscosity of whole blood (commonly reported in the range of 3.5-5.5 mPa.s [1]), making it an option to control particles in suspension, while hexadecane has applications in emulsion formation.

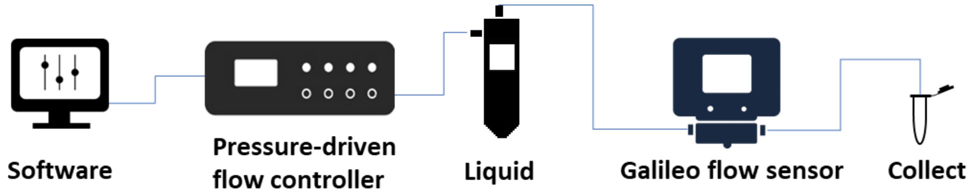
Applications

Microfluidic applications of the Galileo flow rate sensor for viscous liquid flow rate measurements include:

- Flow focusing (e.g. for imaging flow cytometry)
- Droplet formation and stability (e.g. cell encapsulation, single or double emulsions, nanoparticle formation)
- Cell or particle manipulation
- Controlled mixing

Setup

Galileo flow rate sensor



In this setup, a pressure-driven flow controller was used to drive liquids of different viscosities through a microfluidic setup. The Galileo flow rate sensor was connected inline to monitor the flow continuously. An Eppendorf tube was placed at the outlet to collect the liquid for analysis.

Materials

HARDWARE

- Flow controller (e.g. pressure-driven OB1 MK4 with one 0-2000 mbar channel, Elveflow)
- Galileo flow rate sensor (0-30 µL/min and 0-480 µL/min cartridges; Note: other ranges are available)
- Tubings (PTFE, 1/16” outer diameter; OD), fittings and reservoirs
- Scale (Mettler Toledo XSR225)

CHEMICALS

- Glycerol dilutions (20%, 40%, 60% and 80% v/v in water)
- Hexadecane

Quick Start Guide

Instrument connection

1. Connect a pressure-driven flow controller to an external pressure supply using pneumatic tubing, and to a computer.

2. Turn on the pressure controller and open the software.

3. Install and calibrate the pressure controller following the manufacturer's instructions.

4. Click the Galileo flow sensor cartridge into its base.

Tips from the expert. Insert the cartridge with the label side up. A light click should be felt as the magnetic connectors between the base and cartridge make their connection. If the magnetic connection is successfully completed, the "Connect" indicator on the LCD screen should turn green within a few seconds. If connection is not properly established, the Cartridge indicator will remain red. If so, remove and replace the cartridge in the slot.

5. Connect the Galileo base to a computer (USB type C-to-type C or USB type C-to-type 2). Open the Galileo software and click "Connect Galileo" on the interface.

6. Select the working liquid from the dropdown menu and click "Apply".

Tips from the expert. The Galileo base has been configured for liquids of different viscosities during calibration by the manufacturer. Contact us for configuration options.

Setup preparation and filling

1. Connect the liquid reservoir caps to the pressure controller with pneumatic tubing.

2. Connect the reservoir to the Galileo flow sensor cartridge inlet with 1/16” OD tubing.

3. Connect a collection vial to the end of the setup, e.g. Eppendorf tube.

Tips from the expert. Ensure the end of the tubing reaches to within 1mm of the bottom of the vial. Arrange the setup next to an analytical weigh balance. Place the connected Eppendorf tube directly on the balance plate for higher precision gravimetric analysis.

4. Fill the system until liquid reaches the outlet of the tubing connected to the Eppendorf vial. Note, the Galileo flow rate sensor should be used with a maximum pressure of 3 bar. A pressure alert light is visible on the sensor display; red indicates an over-pressure event.

Tips from the expert. With our lowest range cartridge, full filling might take upwards of several minutes, during which time, the “Status” alert light will show orange until the sensor is full of liquid. To fill faster, select a pressure near the upper range of your pump.

Experiment

Gravimetric analysis provides a direct measurement of flow by tracking mass accumulation over time, making it particularly useful for benchmarking flow performance in microfluidic setups.

Each Galileo flow sensor test was performed for a one-hour collection period. The total mass of the collected liquid was determined by weighing the collection reservoir before and after liquid collection. Mass was converted to volume using equation 1.

Equation 1: $\text{density} = \text{mass} / \text{volume}$

Flow measurement by gravimetric analysis

1. Start the flow by adjusting the pressure to reach the target flow rate. Flow for 3-5 minutes to ensure the system is stable.

2. Click "Start Acquisition" in the Galileo software, and select a location and name for the log file.

3. Start timing the flow rate: simultaneously read the exact starting weight of the reservoir on the precision balance and start a timer. Also note the precise real time to cross-reference with the flow sensor log file during analysis.

Tips from the expert. Note that the presence of some liquid in the base of the tube before starting the timed flow experiment is beneficial to minimise the effect of hanging or partial droplets, especially at very low flow rates.

4. Continue to flow for desired time, e.g. 1 h. Simultaneously stop the flow and the timer.

5. Click “Stop acquisition” in the Galileo software.

6. Weigh the full reservoir on the precision balance and record the value.

7. Clean the system thoroughly by flushing with water, then ethanol and air. Store the Galileo flow sensor dry when not in use.

Results

Viscosity of liquids tested in this application note

The Galileo flow rate sensor was programmed during manufacture with viscosity data for different liquids (measured using a Lovis 2000 ME rolling and falling ball viscometer, Anton Paar, between 10-40°C), and the liquid names were added to the dropdown menu in the software interface. Viscosities of the test fluids used in this experiment are shown graphically (Fig. 1), while detailed viscosity and density values are also given in Tables 1 and 2 (Appendix 1).

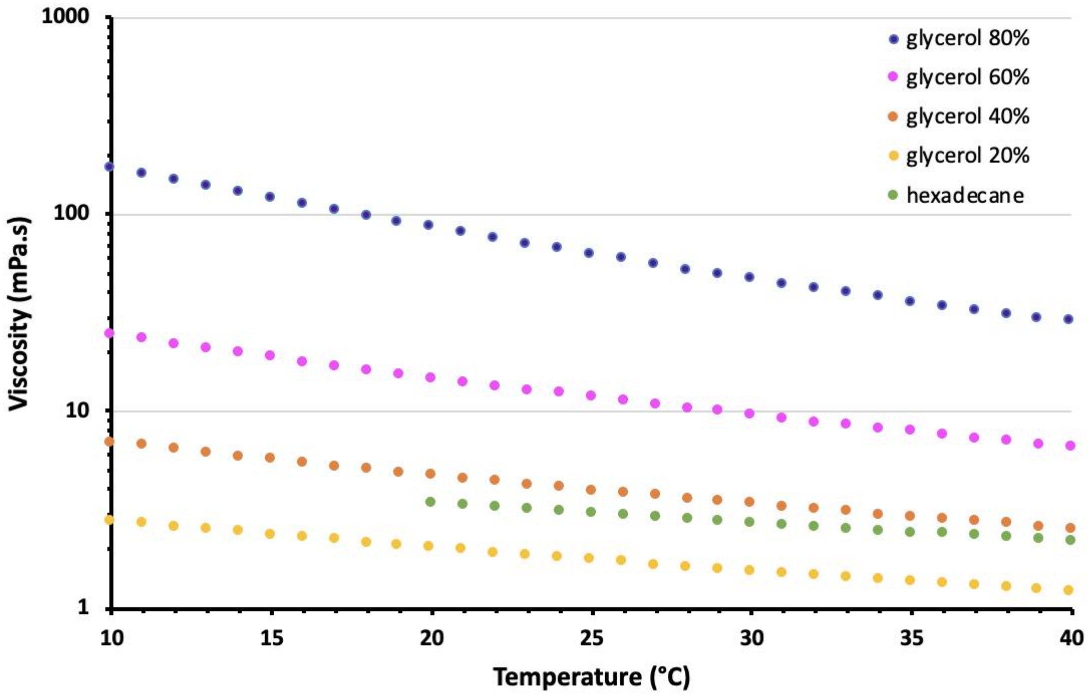


Figure 1. Reference viscosity of liquids in this test (10°C to 40°C). As the melting point of hexadecane is about 18°C, its reference viscosity was measured from 20°C to 40°C.

Flow sensor performance with viscous liquids

The Galileo flow sensor was tested for accuracy with liquids of different viscosities using two Galileo cartridges of ranges 0-30 µL/min (Galileo-1) and 0-480 µL/min (Galileo-2), where the full working range is defined for pure water. Galileo-1 was tested here at flow rates of 0.5, 2.5 and 10 µL/min. Galileo-2 was tested at flow rates of 10, 20 and 50 µL/min. The accuracy of the Galileo flow rate sensor with viscous liquids in the flow rate range of 0.5-50 µL/min was determined using the gravimetric method (Fig. 2, 3). Accuracy is presented as the percent difference of the calculated average flow rate from the expected flow rate provided by the sensor.

The average flow rate was calculated from the measured liquid mass, corrected for average fluid density, over the given collection time. The average fluid density per test was calculed, accounting for temperature. The expected flow rate was determined by averaging the instantaneous flow rate readings from the Galileo flow rate sensor.

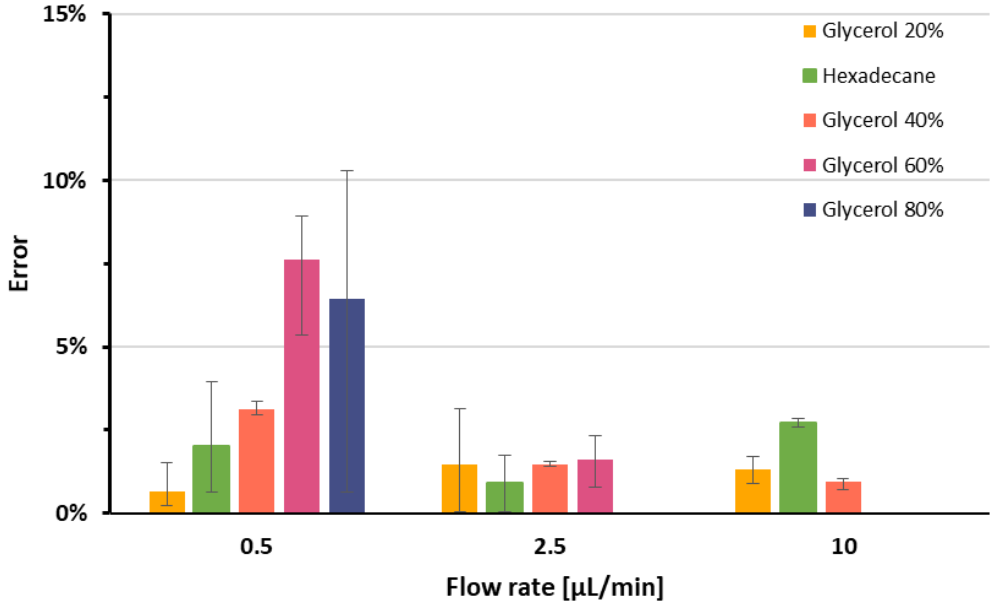


Figure 2. Error of viscous liquids in the Galileo flow rate sensor (Galileo-1; 0-30 µL/min range).

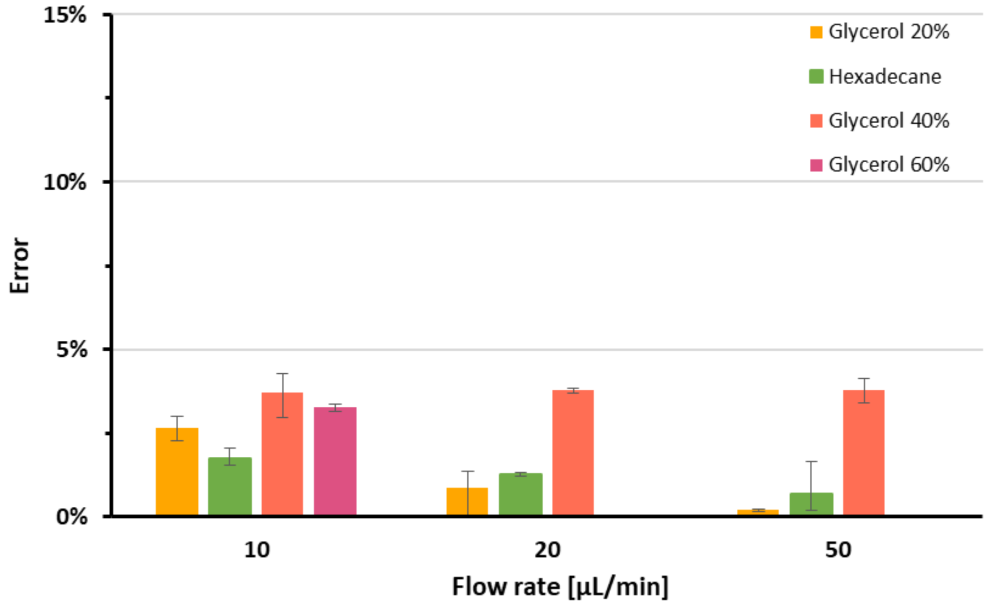


Figure 3. Error of viscous liquids in Galileo flow rate sensor (Galileo-2; 0-480 µL/min range).

The Galileo flow rate sensor performed reliably for a variety of viscous liquids. Specifically, flow rate measurement error was within 5% across flow rates of 0.5-50 µL/min for viscous liquids in the range of 2-5 mPa·s, and within 10% error for substantially more viscous liquids at the lowest flow rates tested per cartridge, making the Galileo flow sensor a suitable option for use in microfluidic applications utilizing viscous liquids.

Use-case application of viscous liquid flow rate measurement

An application of viscous liquid flow rate measurement and/or control is shown for microfluidic droplet generation (Figure 4). In this setup, water-in-oil (W/O) droplets were generated using hexadecane as the continuous phase and water as the dispersed phase, within a cross-junction microfluidic channel.

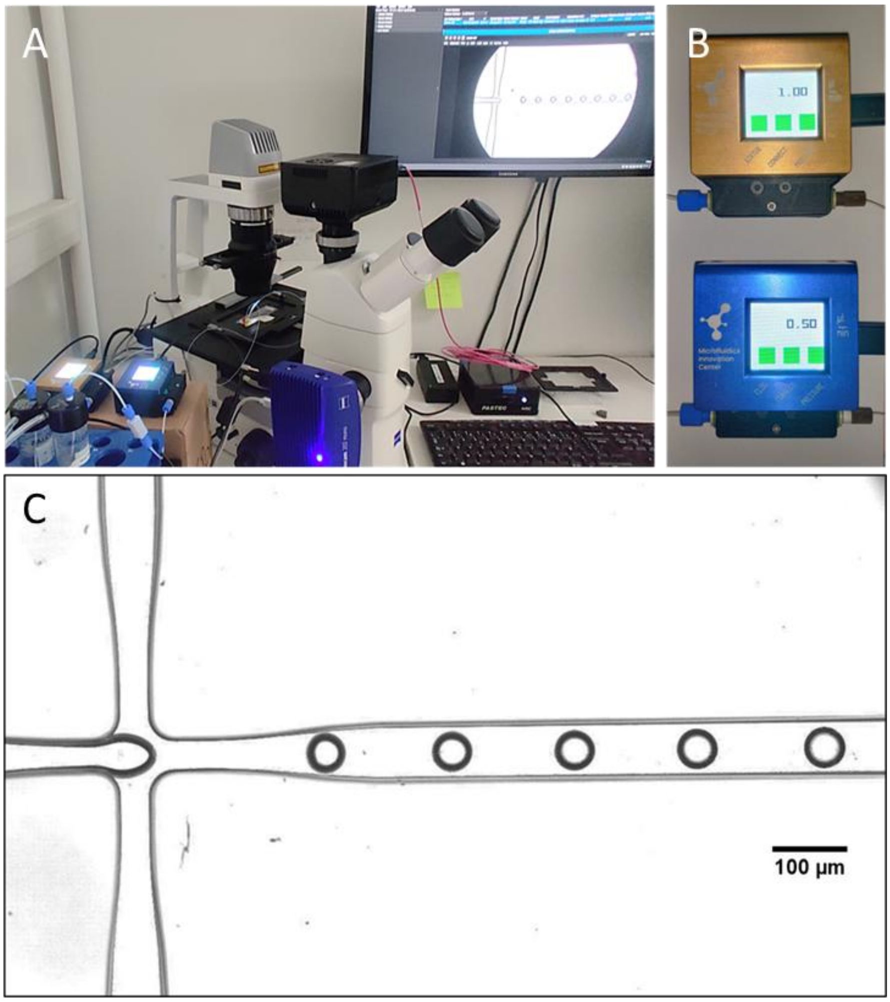


Figure 4. W/O droplets generated in a cross-shaped channel microchip. A: Setup of the droplet generating process. B: Galileo flow rate sensors provide separate real-time flow measurements for hexadecane (in yellow) and water (in blue). C: W/O droplets were generated using hexadecane as the continuous phase and water as the dispersed phase.

Appendix 1

Table 1. Viscosity of liquids tested in this application note (Instrument uncertainty 0.5%).

Temperature [°C]	Viscosity [mPa·s]				
	Hexadecane	Glycerol 20%	Glycerol 40%	Glycerol 60%	Glycerol 80%
10.00		2.760	6.995	24.589	172.390
11.00		2.668	6.710	23.279	160.095
12.00		2.583	6.441	22.050	148.683
13.00		2.498	6.186	20.925	138.450
14.00		2.419	5.945	19.870	128.685
15.00		2.343	5.717	18.897	119.983
16.00		2.272	5.501	17.961	111.775
17.00		2.203	5.297	17.100	104.625
18.00		2.137	5.100	16.285	98.210
19.00		2.073	4.916	15.532	91.464
20.00	3.414	2.013	4.743	14.823	85.600
21.00	3.331	1.956	4.577	14.145	80.460
22.00	3.252	1.901	4.417	13.515	75.340
23.00	3.175	1.848	4.266	12.918	70.868
24.00	3.101	1.797	4.123	12.359	66.577
25.00	3.030	1.749	3.989	11.832	62.533
26.00	2.962	1.702	3.859	11.337	58.945
27.00	2.896	1.658	3.736	10.867	55.426
28.00	2.831	1.615	3.618	10.427	52.230
29.00	2.770	1.574	3.504	10.004	49.391
30.00	2.710	1.535	3.397	9.610	46.716
31.00	2.652	1.496	3.294	9.235	44.250
32.00	2.596	1.460	3.195	8.878	42.015
33.00	2.542	1.425	3.100	8.539	39.836
34.00	2.491	1.391	3.012	8.223	37.807
35.00	2.440	1.358	2.925	7.919	35.846
36.00	2.390	1.327	2.842	7.628	34.135
37.00	2.343	1.296	2.763	7.356	32.512
38.00	2.296	1.267	2.687	7.097	30.948
39.00	2.249	1.239	2.613	6.849	29.531
40.00	2.206	1.212	2.543	6.612	28.534

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Table 2. Density of liquids tested in this application note.

Temperature [°C]	Density[g/cm³]				
	Hexadecane	Glycerol 20%	Glycerol 40%	Glycerol 60%	Glycerol 80%
10.00		1.0597	1.1183	1.1717	1.2223
11.00		1.0595	1.1179	1.1711	1.2216
12.00		1.0592	1.1175	1.1706	1.2210
13.00		1.0589	1.1170	1.1700	1.2204
14.00		1.0586	1.1166	1.1695	1.2198
15.00		1.0583	1.1161	1.1689	1.2192
16.00		1.0580	1.1157	1.1684	1.2186
17.00		1.0576	1.1152	1.1678	1.2179
18.00		1.0573	1.1147	1.1672	1.2173
19.00		1.0570	1.1143	1.1667	1.2167
20.00	0.7734	1.0566	1.1138	1.1661	1.2161
21.00	0.7727	1.0563	1.1133	1.1655	1.2155
22.00	0.7720	1.0559	1.1128	1.1650	1.2149
23.00	0.7713	1.0555	1.1123	1.1644	1.2142
24.00	0.7706	1.0552	1.1119	1.1638	1.2136
25.00	0.7699	1.0548	1.1114	1.1633	1.2130
26.00	0.7692	1.0544	1.1109	1.1627	1.2124
27.00	0.7685	1.0540	1.1104	1.1621	1.2117
28.00	0.7678	1.0536	1.1099	1.1615	1.2111
29.00	0.7671	1.0532	1.1093	1.1609	1.2105
30.00	0.7665	1.0528	1.1088	1.1604	1.2099
31.00	0.7658	1.0524	1.1083	1.1598	1.2092
32.00	0.7651	1.0520	1.1078	1.1592	1.2086
33.00	0.7644	1.0515	1.1073	1.1586	1.2079
34.00	0.7637	1.0511	1.1067	1.1580	1.2073
35.00	0.7630	1.0507	1.1062	1.1574	1.2066
36.00	0.7623	1.0502	1.1056	1.1568	1.2060
37.00	0.7616	1.0498	1.1051	1.1562	1.2054
38.00	0.7609	1.0493	1.1045	1.1556	1.2047
39.00	0.7602	1.0489	1.1040	1.1550	1.2041
40.00	0.7595	1.0484	1.1034	1.1544	1.2035

References

[1] Nader, E. *et al*. Front Physiol. (2019) 10:1329. doi: 10.3389/fphys.2019.01329

Acknowledgements

This application note is part of a project that has received funding from the European Union's Horizon research and innovation program under projects:

HORIZON-EIC-2022-TRANSITION-01, grant agreement no. 101113098 (GALILEO),

HORIZON-MSCA-2022-DN-01, grant agreement no. 101119729 (NEXTSCREEN), and

HORIZON-MSCA-2022-DN-01, grant agreement no. 101119956 (DarChemDN).