DIRECT DIFFERENTIAL MICRO CORIOLIS MASS FLOW SENSOR TO DETECT THE EFFICIENCY OF A PRECONCENTRATOR SYSTEM

J. Groenesteijn[1*], H. Zhang[1], R.M. Tiggelaar[1], T.S.J. Lammerink[1], J.C. Lötters[1,2], J.G.E. Gardeniers[1] and R.J. Wiegerink[1]

[1]MESA+ Institute for Nanotechnology, University of Twente, THE NETHERLANDS
[2] Bronkhorst High-Tech BV, THE NETHERLANDS

ABSTRACT

We have designed and fabricated the first direct differential micro Coriolis mass flow meter (MFM). The direct differential nature of the sensor allows for accurate measurement of small differences between large flows. The differential measurement is achieved by fabricating two parallel, mechanically coupled micro-channels. By applying the two mass flows in opposite direction, the detected mass flow is proportional to the difference in Coriolis force on the two channels. We demonstrated this sensing principle by detecting the amount of water evaporated from a solution by a pre-concentrator.

KEYWORDS: Coriolis, Differential Mass Flow Sensor, Pre-Concentrator

INTRODUCTION

To increase the sensitivity of a micro-NMR detection setup and reduce the measurement time, the concentration of analyte in a mass limited sample is often increased by using a pre-concentrator. However, the established setups required for precisely validating the efficiency of the pre-concentrator are limited due to their intrinsic low sensitivity and long response time. Integration of a micro-pre-concentrator and a microfluidic sensor capable of measuring the performance of the pre-concentrator would make active control of the pre-concentrator possible to ensure optimal performance of a micro-NMR detection setup. In this paper, we present a direct differential micro Coriolis mass flow sensor for fast, accurate measurement of small differences between large flows. Experiments have been done to demonstrate the operating principle of the sensor and to measure the difference between the fluid flow into and out of the pre-concentrator which offers the possibility to monitor the evaporation efficiency of the pre-concentrator.

THEORY

A Coriolis MFM operates by measuring the Coriolis force due to mass flow through a vibrating tube. In [1] we presented a MFM with a full-scale range of 20 mg/min and an accuracy better than 0.2 mg/min. However, this sensor was only capable of measuring a single flow. In this paper, we present a new measurement principle in which the sensor tube is exchanged by two parallel tubes allowing the direct measurement of a differential flow. The tubes are mechanically coupled, but have separate fluidic paths. Figure 1 schematically shows the working principle. The tubes are actuated in torsion mode around axis ω_{am}. A mass flow Φ_{mx} inside the tubes will induce Coriolis forces that excite the swing vibration mode, leading to a vibration amplitude proportional to the mass flow. Here the subscript x is used to indicate channel 1 or 2. When the mass flow through each tube is in opposite direction, this will induce Coriolis forces in opposite direction generating a total Coriolis force only depending on the difference in mass flow, thereby independent of common flow, described by equation (1).

$$|\overrightarrow{F_{Ctot}}| = -2L(|\overrightarrow{\Phi_{m1}}| - |\overrightarrow{\Phi_{m2}}|)|\omega_{am}| \quad (1)$$

The fabricated chip is shown in Figure 2. The pre-concentrator is based on evaporation of solvent by means of a porous hollow fiber. The fiber consists of a hydrophobic material (polypropylene, PP Q3/2), which means that water will not penetrate the porous walls. An nitrogen gas flow along the fiber will decrease the partial pressure outside the fiber, resulting in evaporation of the water, increasing the concentration of the solution. Figure 3 shows a photograph of the pre-concentrator [2].

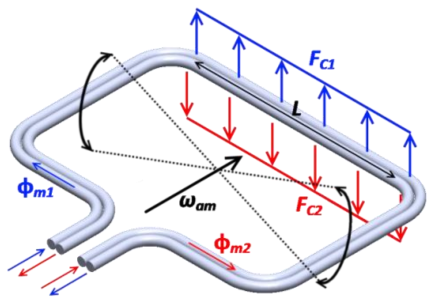

Figure 1: Schematic overview of the principle of operation of the direct differential micro Coriolis mass flow sensor. The mass flows Φ_{mx} will cause Coriolis forces F_{cx} in opposite direction (x=1,2 indicates the channel).

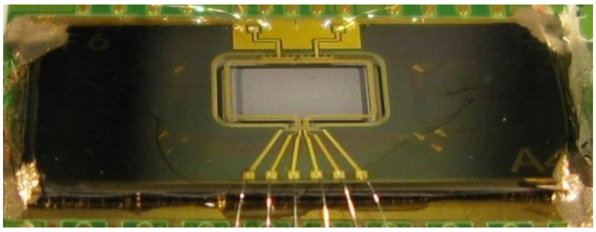

Figure 2: Photo of the fabricated differential micro Coriolis mass flow sensor mounted on a PCB.

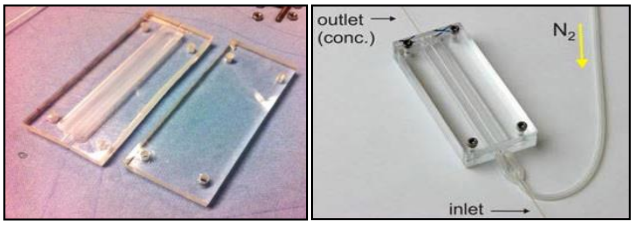

Figure 3: Left: the two parts of the polymethylmethacrylate (PMMA) fiber holder with a flow chamber in the bottom part. Right: The fiber holder with a fiber mounted in it. The in- and outlet of the fluid path is shown, as well as the N_2 flow inlet.

EXPERIMENTAL

Measurements were performed with and without pre-concentrator. The first measurements, without pre-concentrator, are used to demonstrate the sensor's capabilities to measure a differential flow. The used setup is shown in Figure 4. During the measurement, one flow is generated by a syringe pump. By connecting the outlet of the first channel (denoted by "B" in Figure 4) to the inlet of the second channel (denoted by "C" in Figure 4) it is ensured that $\Phi_{m1}= \Phi_{m2}$ and measurements can thus be done with zero differential flow and varying common flows. In this case, a differential flow can be generated by opening the proportional valve such that $\Phi_{m1}–\Phi_{diff} =\Phi_{m2}$. By connecting outlet "B" to fluid connection "D", an identical flow would flow through the sensor in the same direction ($\Phi_{m1}= -\Phi_{m2}$) resulting in a sum flow which measures the same flow twice. During these measurements DI water is used.

The second measurement series uses the setup shown in Figure 5 and is used to measure the evaporation rate of a phenol red solution with an initial concentration of 5.5 µM, in a porous-fiber pre-concentrator. During these measurements, ϕ_{m1} is a fluid flow generated by a syringe pump. The pre-concentrator is connected between the outlet of the first channel and the inlet of the second channel, such that Φ_{m2} is the fluid flow with increased concentration. The measured differential mass flow is then the amount of evaporated water. The increase in concentration, R, and thus the efficiency of the pre-concentrator, is calculated by using equation (2), where Φ_{pump} is the infuse rate of the pump and $\Phi_{differential}$ is the measured differential flow.

$$R = \frac{\Phi_{pump}}{\Phi_{pump} - \Phi_{differential}} \qquad (2)$$

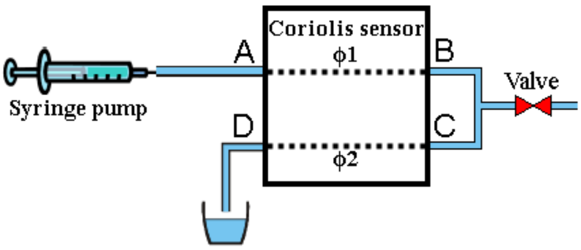

Figure 4: Measurement setup to demonstrate the operation of the differential micro Coriolis mass flow sensor. A fluid flow is generated by a syringe pump and a differential flow can be applied by controlling the proportional valve.

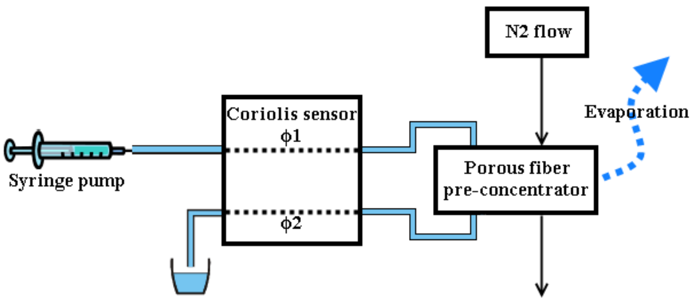

Figure 5: Measurement setup for using the differential microCoriolis mass flow sensor to detect the efficiency of a porous-fiber pre-concentrator.

RESULTS AND DISCUSSION

Figure 6 demonstrates the operating principle of the sensor. Here, the differential flow is measured with a closed valve. The measurements show that the common mode flow is effectively rejected by a factor of approximately 200. Figure 7 shows the sensitivity of the sensor to a differential flow when the proportional valve is opened. The sensor shows a linear response to the measured mass flow corresponding to the Coriolis measurement principle indicated by equation (1).

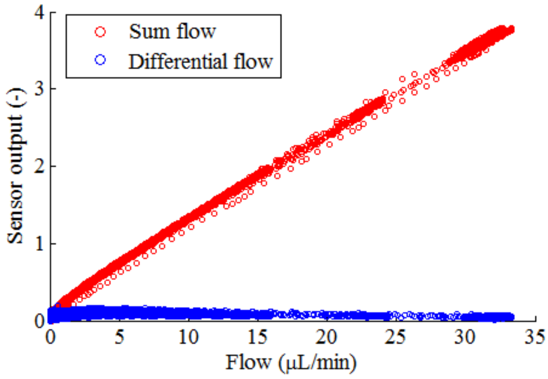

Figure 6: Measurement results when identical flow is applied either in the same direction (sum flow) or opposite direction (differential flow) while the valve is closed. The zero-difference differential flow demonstrates the sensors insensitivity to a common flow.

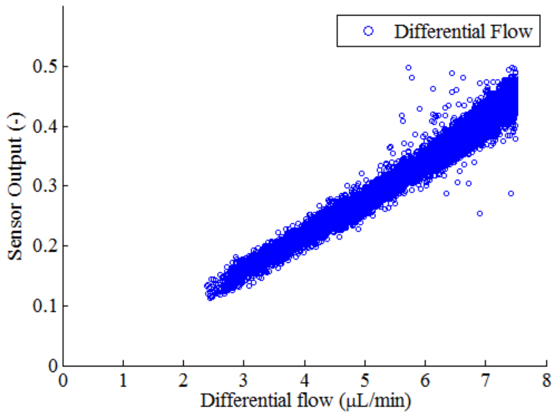

Figure 7: Measurement results of an applied differential flow. The differential flow was applied by a syringe pump.

Figure 8 shows the results of experiments performed using the setup in Figure 5. The increase in concentration is shown as a function of fluid flow for different nitrogen flows through the pre-concentrator. The highest measured increase in concentration is at a fluid flow of 5 µL/min and a N_2 flow of 5 L/min. The concentration is increased by a factor of 18.7 to 103 µM. The graph shows that the efficiency increases at lower fluid flow and higher nitrogen flow.

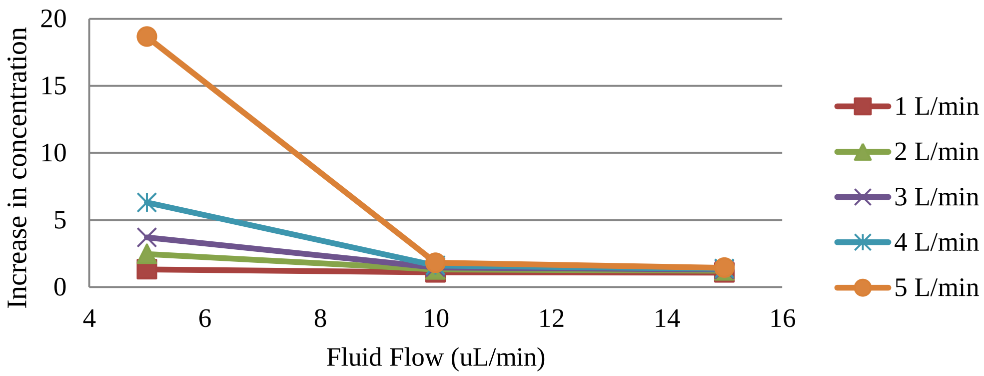

Figure 8: Calculated increase in phenol red concentration as a function of the input flow for different nitrogen flows.

CONCLUSION

We have designed and fabricated a direct differential micro Coriolis mass flow sensor and demonstrated its usefulness in measuring the efficiency of a porous-fiber pre-concentrator. The sensor showed a common flow rejection ratio of approximately 200. The concentration was increased by a factor of 18.7, confirming the validity of the integration of the sensor with a pre-concentrator. Since this basic platform functions properly, the next step will be to integrate the sensor with an on-chip pre-concentrator which enables active control of the concentration and can be further implemented in a micro-NMR detection system.

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REFERENCES

[1] J. Haneveld, T.S.J. Lammerink, M.J. de Boer, R.G.P. Sanders, A. Mehendale, J.C. Lötters, M. Dijkstra and R.J. Wiegerink, "Micro Coriolis mass flow sensor with integrated capacitive readout", J. Micromech. Microeng. 20, no. 12 (2010): 125001.

[2] J. Bart, "Stripline-based microfluidic devices for high-resolution NMR spectroscopy" PhD-thesis University of Twente, 2009.

CONTACT

*J. Groenesteijn, tel +31-534894373; j.groenesteijn@utwente.nl