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# Flow Sensor Ignoring Fluid Characteristics by Means of a Parallel Wire

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## Abstract

***A sensor that measures flow time employs a flow parallel wire (FPW) with a central tap. Upstream of the sensor is where you'll find the heater. Half-bridging the upstream and downstream halves of the FPW causes a significant output peak whenever a heat pulse travels through the FPW. The qualities of the fluid have no effect on the time it takes to generate the heat pulse and record the peak maximum.***

## Introduction

Nearly 30 years ago, it was demonstrated that the time of flow (TOF) between the generation of a heat pulse and the arrival of this pulse to a sensor could be used to determine the flow velocity of liquids [1]. The possibility of measuring flow independently of the fluid's characteristics was explored [2, 4]. However, empirical evidence demonstrated that the calculated duration of flow was still a variable dependent on the medium [3]. It was hypothesized that the heat transition time between the heater and fluid, and the fluid and the sensor, would vary depending on the fluid's heat conductivity and viscosity.

As a first step toward mitigating the influence of heat transition, we monitored the maximum temperature flow time, t, between two sensor wires installed downstream of a heater (refer to Fig. 1a, sensor A). This manner, the temperature difference between the fluid and the two wires shouldn't affect the reading, and the temperature difference between the fluid and the heater shouldn't affect the reading, either. As illustrated in Fig. 2, we combined the upstream and downstream sections of a flow parallel wire (FPW) to form a half bridge as an alternate approach. The objective was to generate an output signal whose zero-crossing occurs at the instant the pulse of heat reaches the wire's central tap. In the experiments, we used water, ethanol, and two kinds of oil. Tab demonstrates how noticeably different the fluids' properties are.

Table 1. Fluid properties

| Properties | Measured Fluids | | | |
|---|---|---|---|---|
| | Water | Ethanol | Oil 1 | Oil 2 |
| Density ρ [kg/m³] | 998 | 790 | 809 | 857 |
| Viscosity η [mPa s] | 1.0 | 1.2 | 3.25 | 49.3 |
| Heat conductivity λ [W/(m K)] | 0.598 | 0.165 | 0.15 | 0.15 |

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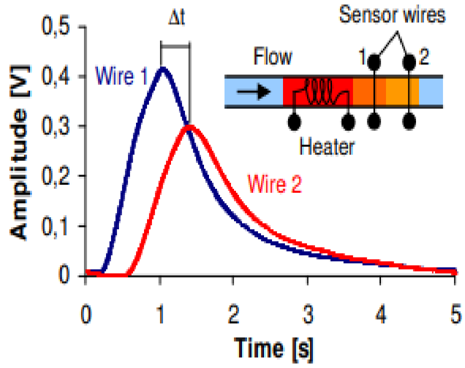
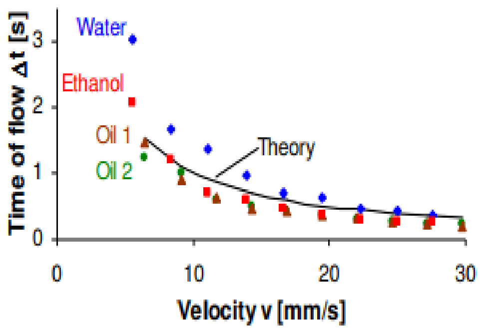
## 2. Sensors and Measurements

The heater in each sensor was a copper coil 8 mm long, with a 100 m wire and an 800 m coil diameter. The 2 A current pulses that lasted for 100 ms were what powered the heater. A syringe pump was used to create the flow. The sensor wires were fabricated from 17.5 m gold wire, and the flow channel was machined from 1mm x 1mm polymethylmethacrylate.



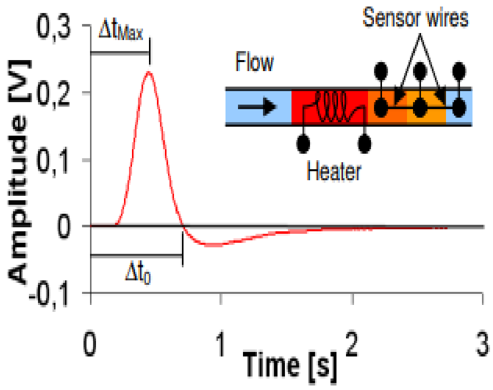

(a)



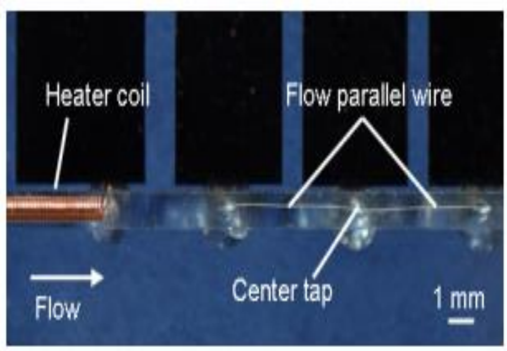

(b)

*Fig. 1. (a) Water, ethanol, and two oil curves measured using sensor A's two sensor wires across the channel.*

Flow time between sensor A's two wires was still a function of fluid characteristics (refer to Fig. 1b). Calculations show that the flow time increases significantly when water is present. The upstream and downstream sections of Sensor B were joined to form a half bridge, and its sensor wire, measuring 10 mm in length, was oriented parallel to the flow in the middle of a 55 mm long flow channel (Fig. 2 a and b). Figure 2a depicts the signal at the output. The maximum tax and zero crossing t0 of the bridge output were measured from the end of the heater pulse.



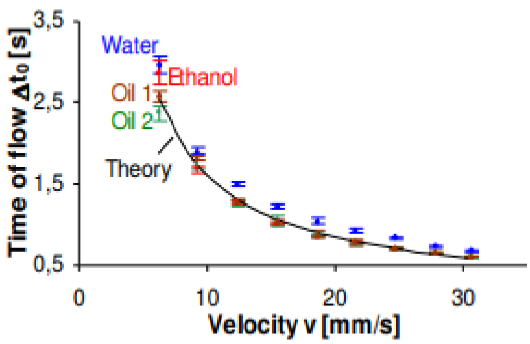

(a)




(b)

*Fig. 2. a) Sensor B with two sensor wires running parallel to the channel; b) an open-topped photograph of Sensor B.*

Sensor B's defining curves are less dependent on fluid parameters than Sensor A's defining curves. In Fig. 3a and b, the mean flow velocity is shown against the zero-crossing time t0 and the maximum time tax. The figures show the mean value and standard deviation of five values recorded after each measurement was performed four times.




(a)

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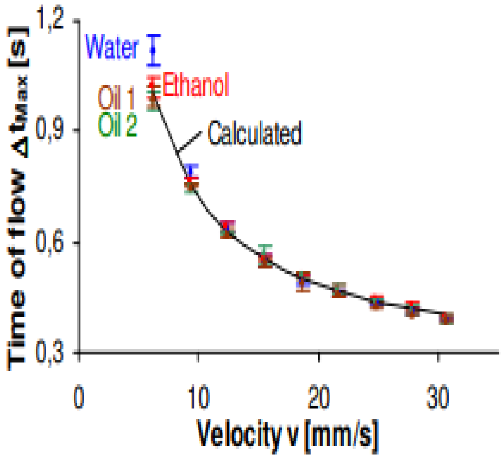
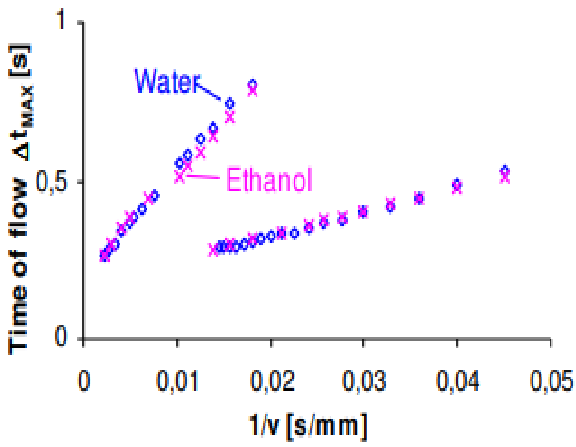


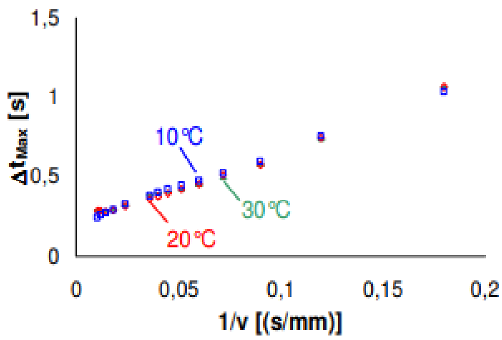

(b)

***Fig. 3 (a) Flow time t0 for various fluids (sensor B); (b) Flow time tax for various fluids (sensor B).***

For low flow velocities, tax appears to be just a very weak effect of fluid characteristics, and t0 departs from the other curves by only around 10% for water. This is surprising given the large differences between the fluids' viscosities (Table 1) and heat conductivities (Table 1). Two FPWs are positioned 4.5 and 45 mm downstream of the heater, and their maximum operating times, tax, are shown against the inverse of the flow velocities in Fig. 4a. By using two FPWs, a wider flow range of around 0.01 to 0.5 m/s may be measured. Water was used in a climate chamber at three different temperatures to analyse sensor B's temperature cross sensitivity. As can be observed in Fig. 4b, the measured time of flow is only marginally affected by the ambient temperature.




(a)




(b)

***Fig. 4. Sensor B's temperature sensitivity for water (a) and ethanol (b) at their respective maximum flow rates***

## 3. Conclusions

Using a sensor wire oriented perpendicular to the flow channel to measure the transit duration of a heat pulse yields a characteristic curve that is only a weak dependence of the fluid characteristics and temperature. As a result, the FPW enables fluid-composition-independent flow measurements.

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