A simple, low-cost downhole flow logging system

Stephen M. Sellwood[1], David J. Hart[2], and Jean M. Bahr[1]

[1]University of Wisconsin – Madison, [2]Wisconsin Geological and Natural History Survey, University of Wisconsin – Extension

Abstract

Measurements of fluid flow in a well or borehole provide valuable information about the adjacent formations, including the presence of permeable features such as fractures, the presence of aquitards, and whether flow is upward or downward. Borehole flow data in groundwater wells are typically collected with mechanical spinner, heat pulse, or electromagnetic flow meters. These instruments provide excellent data, but can be expensive to purchase, and in the case of the spinner flow meter, can require significant data analysis.

We have developed a simple, economical method for measuring flow in groundwater wells. The equipment consists of an electric heater that induces a heat pulse into the water column, and a submersible temperature measurement device. The heater consists of a 2000 watt cartridge heater, shrouded in a perforated steel housing, and attached to electrical cable. The heater runs on a 2000 watt generator. Temperature measurements can be made with a variety of instruments designed to measure water temperature. We used a combined water level, temperature, and conductivity meter with a flat tape to measure depths. The total cost of the heater was $639 and the cost of our water level/temperature/conductivity meter was $1,361 for a total cost of $2,000.

The method consists of setting the temperature measurement device in the well at a known distance from the heat source and measuring the time required for the heated water to reach the measurement point. The elapsed time between onset of heating and the first measured temperature change at the temperature device is used to calculate fluid velocity in the well.

We tested the equipment and the method in a previously-studied well and found the results to be in good agreement with previous flow measurements at the site. Laboratory tests were conducted to determine practical upper and lower limits of effective flow measurement using this system. The simple design, ease of analysis, and low cost and availability of components make this system an effective and economical tool for measuring fluid flow in wells and boreholes.

Experiment Description

The Goal: Heat a discrete region of water in the test well, then measure the time required for the heat to travel a known distance.

Experiment Procedure:

- Set up inlet and outlet for upward or downward flow
- Measure steady state flow rate
- Set heater in well to known depth (depth measured from center of heater)
- Set temperature measurement probe to know depth in the well (above heater for upward flow measurement, below heater for downward flow measurement)
- Run heater for 1 minute
- Record temperature change with time as reported by the temperature measurement probe
- Distance divided by the time of arrival of the heat slug is the measured flow velocity

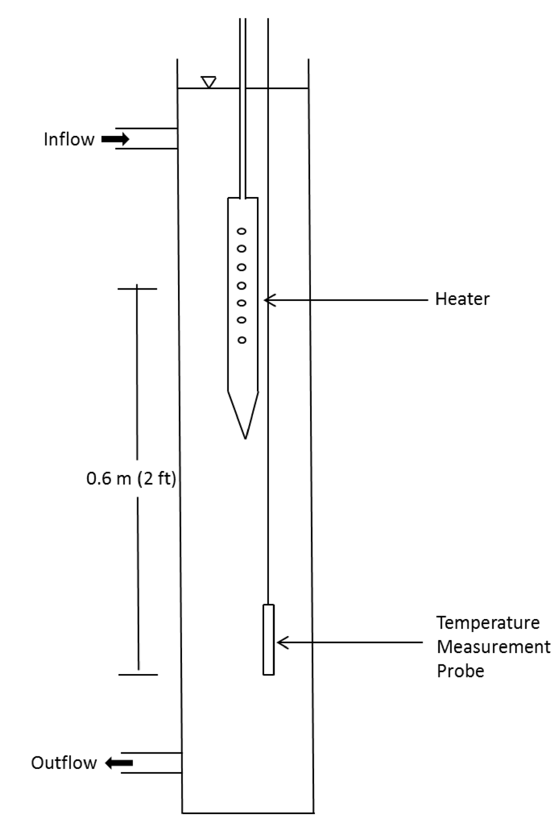


Figure 1 – Experimental setup for downward flow configuration.

Experiment Equipment

The Heater

- 2,000 watt cartridge heater element
- Stainless steel perforated shroud
- 10 gauge (30 amp) grounded, wet environment electrical cord

Figure 2a – Photo of heater showing shroud and electrical cord on a spool.

Figure 2b – Photo of heater deployed in test well.

Temperature Probe

- Solinst TCL Meter*
- Temperature range: -15°C to 25°C
- Reports temperature to 0.1°C

Figure 2c – Water level electric tape with temperature and fluid conductivity probe.

Figure 2d – Digital display of fluid conductivity and temperature.

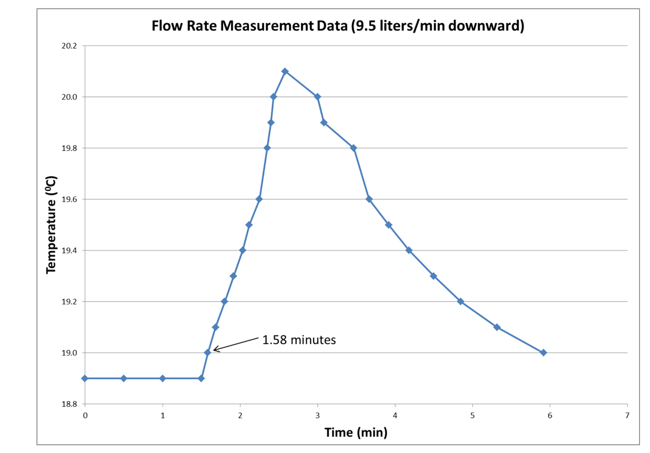
Experiment Well

- Diameter 0.15 m (6 inch) PVC
- Inflow and outflow valve controlled

Figure 2e – Experimental well setup with downward flow configuration.

*Brand names not endorsed by authors

Results



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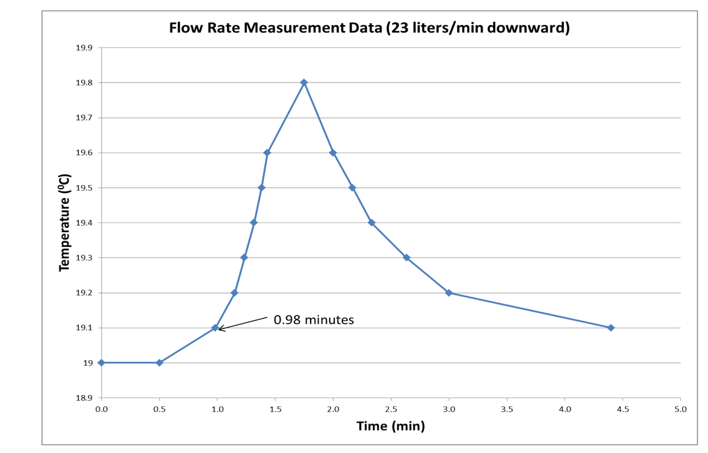

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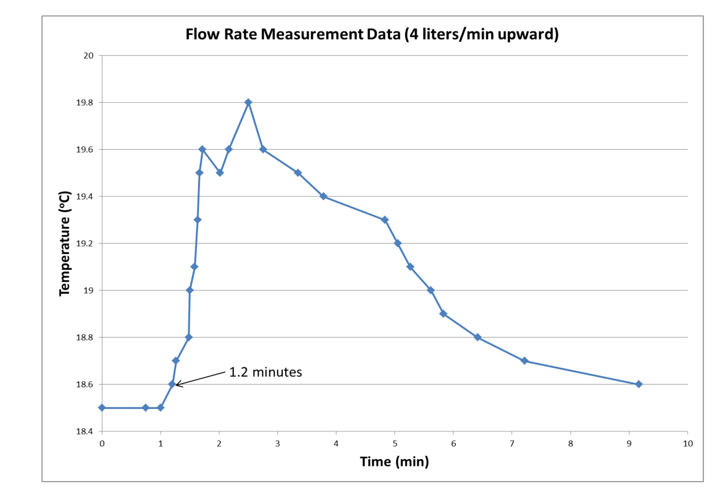

c.

Figure 3a-c – Graphs of temperature versus time for three individual heating experiments. Figure 3a shows data collected for a downward flow rate of 9.5 liters/minute (2.5 gpm). Figure 3b shows data collected for a downward flow rate of 23 liters/min (6 gpm). Note the shorter arrival time for the higher flow rate. Figure 3c shows data collected for an upward flow rate of 4 liters/min (1 gpm). Note the apparent double peak possible due to convection of the water column.

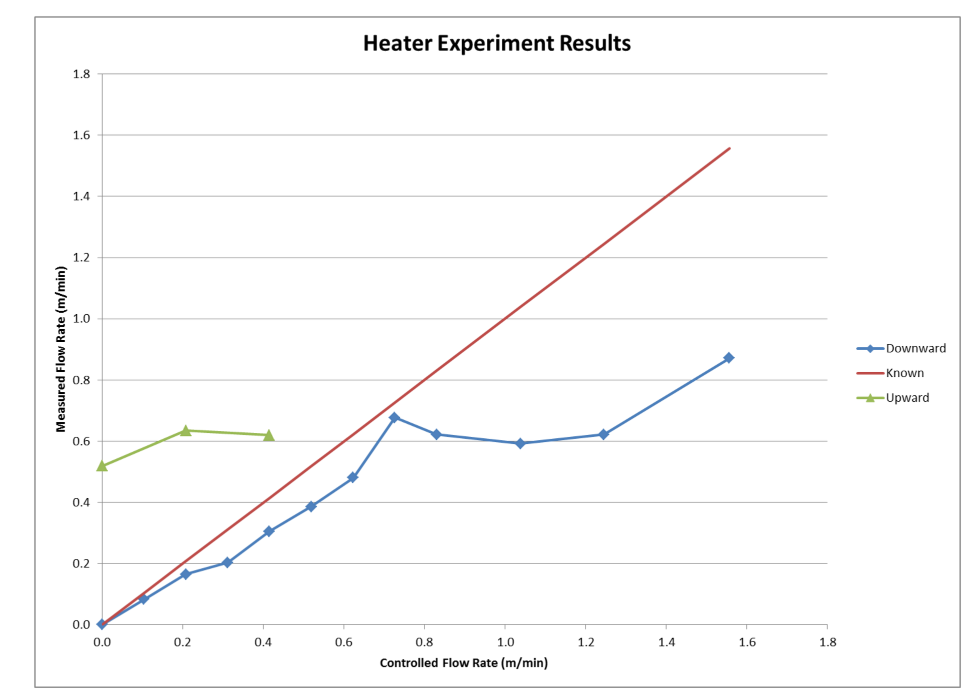

Figure 3d – Graph of measured flow rates versus control flow rate. Red line indicates 1:1 ratio for reference. Downward flow measurements are shown in blue. Note all measured downward flow rates were less than the actual control rate. Upward flow measurements are shown in green. Note all measured upward flow rates were greater than the actual control rate, including apparent upward flow measured in a no-flow condition. This is likely due to convection currents that set up near the heater as depicted in Figure 3e.

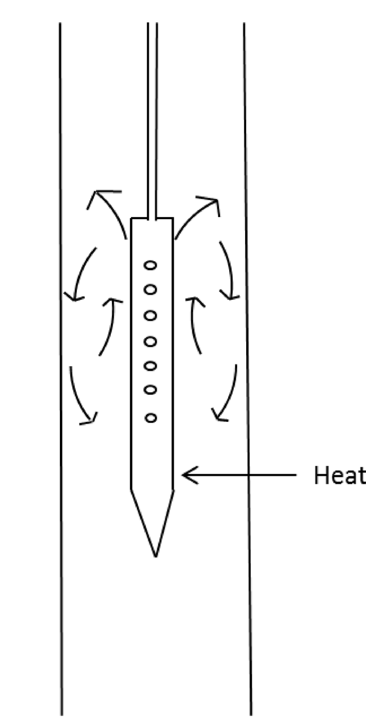

Figure 3e – Schematic of convection currents believed to develop near the heater.

Conclusions

- The electric heater is an effective way to warm water at a discrete level in a well
- Convection in the near-heater region causes apparent upward flow and, as a result, the method overpredicts the magnitude of upward flow. A possible solution may be to increase the distance between the heater and the temperature probe
- The method underpredicts the magnitude of downward flow
- The method is effective for confirming downward flow and relative changes in downward flow
- With additional study of the nearfield convection, the method setup might be improved, and a correction factor could possibly be determined so that accurate flows are measured
- Future research will focus on using fiber optic temperature sensing for simultaneous temperature measurement over the borehole length

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