# Calibration of Heat Pulse Sensors for Soil Water Matric Potential

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## Introduction

- This poster presents the results of a laboratory study for calibration of heat dissipation sensors to measure soil water matric potential.
- A new function is presented to describe the sensor response over a wide range of matric potentials.
- Use of the new function with calibration data from only the tensiometer range to describe sensor response over the entire useful range is evaluated.

## Description of heat dissipation method

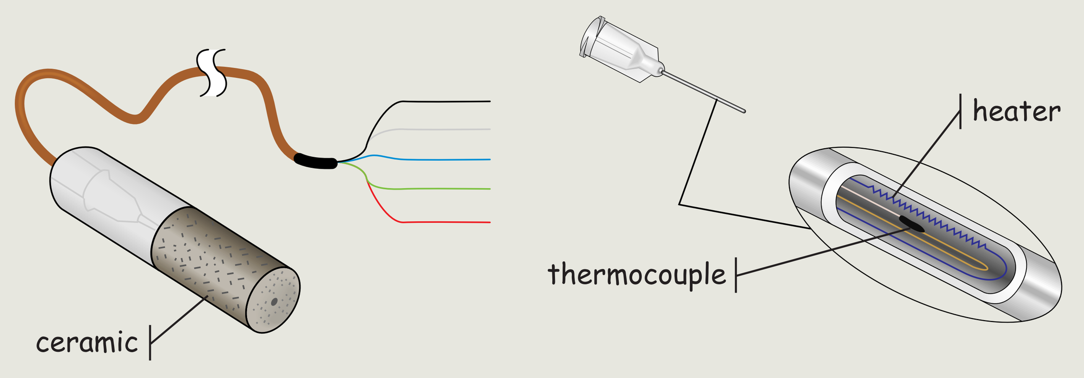


Figure 1. Heat dissipation sensor illustration.

- Heat transfer away from the heater depends on thermal conductivity of the porous ceramic which depends on water content of the ceramic
- Water flux between soil and ceramic under matric potential gradient changes water content of ceramic
- Heat transfer is characterized by measuring change in temperature during heating and empirically relating this to matric potential

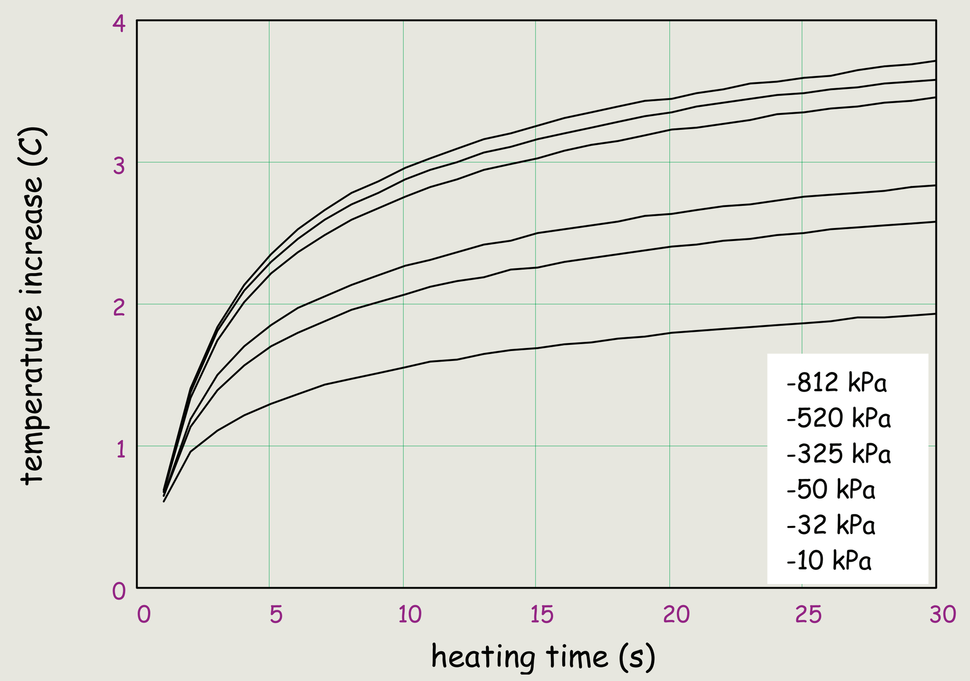


Figure 2. Typical response during heating.

## Description of study measurements

### Evaporation tray construction

Covered bottom of tray with small gravel then fine screen filter
Ground, air-dried soil added to mid-depth then saturated from bottom
Saturated sensors then placed on surface

Soil saturated as added to fill tray

A UMS T5 Mini Tensiometer was inserted into the center of the tray with ceramic cup at sensor depth.

Small ceramic discs of same material as sensors were buried during construction and dug out later for chilled mirror psychrometer measurement

Figures 3-5. Calibration tray construction and setup.

## Response calibration functions

### Three parameter function

Flint et al. (2002) proposed the following equation as a calibration function. This function was chosen based on the distribution of collected calibration data and the available methods for estimating the fitted parameters.

$$\psi = \psi_o \left( T^{*\,\frac{1}{m}} - 1 \right)^{\frac{1}{n}}$$

with: $\Psi =$ matric potential
$\Psi_o =$ air entry value of ceramic
$T^* =$ dimensionless temperature increase

$$T^* = \frac{\Delta T_{dry} - \Delta T}{\Delta T_{dry} - \Delta T_{wet}}$$

m and n are fitted parameters

### Proposed calibration function

- The response of the heat dissipation sensor is described by the change in thermal conductivity with water content.
- Thermal conductivity with water content and water retention were determined for the sensor ceramic.
- Using this information with the heat transfer equation for a line source showed a power function response of changing temperature during heating over the matric potential range.
- Combining these relationships, a version of the Brooks and Corey equation was derived to relate matric potential, $\Psi$, to normalized temperature change, $T^*$.

The proposed calibration function is: $\psi = \dfrac{(T^*)^{-1/\beta}}{\alpha}$

With $\alpha$ = 1/(the minimum tension for response of the sensor) and $\beta$ a fitted parameter related to the slope of the response curve.

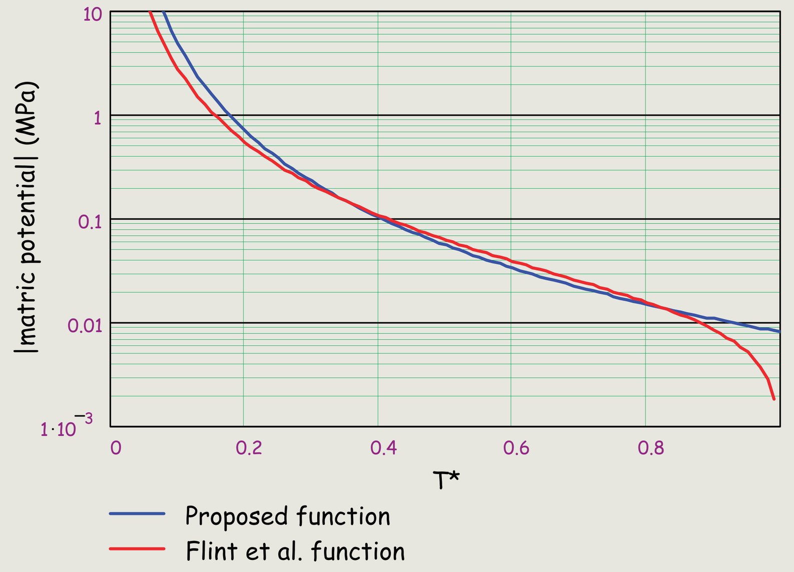


Figure 6. Calibration functions.

## Calibration Measurement Results

### Data collection method

Beginning at saturation, the soil was allowed to dry by evaporation from the top surface in incremental steps. At each calibration point the tray was covered to stop water loss after the evaporation period.
Sensors were monitored to determined equilibrium throughout the tray.

The tensiometer provided water potential from saturation to about -0.07 MPa (elevation of laboratory 1400 meters).

For the water poential range -0.2 Mpa to -1.5 Mpa, a Decagon WP4 Dewpoint Potentiameter was used to measure ceramic discs buried near the sensors and soil peds from near the sensors.

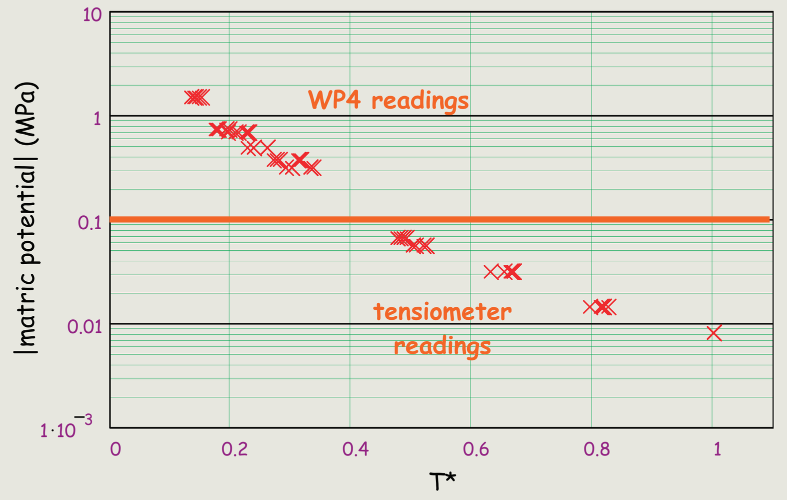


Figure 7. Calibration data collected with tensiometer and dewpoint potentiometer.

## Fitting data for calibration function

The following functions were used for parameter estimation of the Flint et al. calibration equation (left) and the proposed calibration equation (right).

$$\sum_{j=0}^{k-1} \frac{\left[ 2 \cdot \left| y_j - \psi_o \cdot \left[ (x_j)^{\frac{-1}{m}} - 1 \right]^{\frac{1}{n}} \right| \right]}{\left[ y_j + \psi_o \cdot \left[ (x_j)^{\frac{-1}{m}} - 1 \right]^{\frac{1}{n}} \right]} = 0 \qquad \sum_{j=0}^{k-1} \frac{\left[ 2 \cdot \left| y_j - \frac{(x_j)^{\frac{-1}{\beta}}}{\alpha} \right| \right]}{\left[ y_j + \frac{(x_j)^{\frac{-1}{\beta}}}{\alpha} \right]} = 0$$

The left-hand-side of the above fitting equations were used to compare the data fits.

Data were fitted using the following conditions

1. all parameters fitted to all data (tensiometer and WP4 measurements)
2. all parameters fitted to only tensiometer data
3. fixed $\Psi_o$ and $\alpha$ using all data
4. fixed $\Psi_o$ and $\alpha$ using only tensiometer data

During evaporative drying from saturation, the soil water tension when the sensor first responds is used for $\Psi_o$ and $1/\alpha$. This is sometimes referred to as bubble pressure.

## Results

- Figure 8 shows the results for conditions 3 and 4.
- Conditions 3 & 4 provided excellent fits to the data for both forms of the calibration equations with no difference for soil conditions drier than -0.010 Mpa.
- For the proposed equation, there is no difference in the fitted calibration equation whether all data is used or only tensiometer data.
- The Flint et al. equation provided poor results when only tensiometer data used.

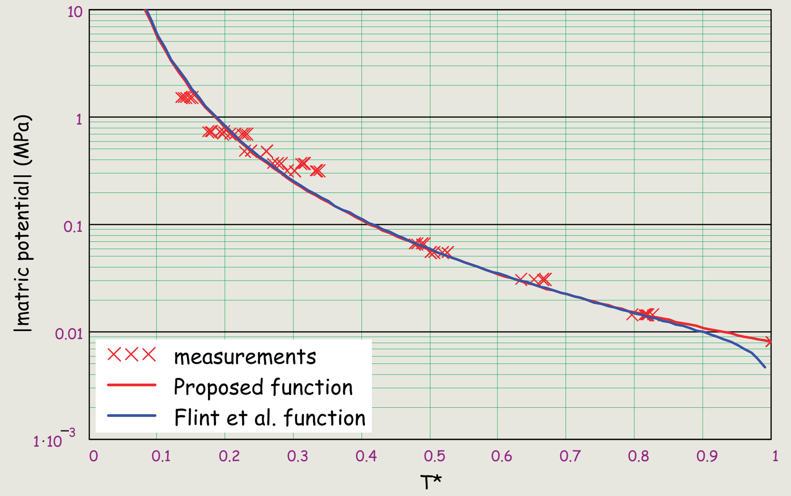


Figure 8. Fit of all data to both calibration functions.

## Conclusions

- Calibration of heat dissipation sensors for the entire useful range can be obtained by using data from only the tensiometer range when data is fitted to the proposed equation and $\alpha$ is set to the inverse of the bubble pressure.
- The Flint et al. calibration function also provides good calibration results though the more complicated form of this equation is not necessary. Additionally, the equation introduces an anomaly at the wet end since the sensor will never sorb water beyond the bubble pressure during wetting.
- Careful tensiometer measurements for calibration can alleviate need for other methods that are labor intensive and expensive.

## References

A. L. Flint, A.L., G. S. Campbell, K. M. Ellett, and C. Calissendorff. 2002. Calibration and Temperature Correction of Heat Dissipation Matric Potential Sensors. Soil Sci. Soc. Am. J. 66:1439–1445.