Modelling of a Dual-Probe Heat-Pulse Soil-Moisture Sensor using COMSOL®

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Introduction

A sensor is developed using the Dual-Probe Heat-Pulse (DPHP) technique to measure moisture content in soil. The DPHP sensor has two probes, a heater element and a thermocouple, placed 3 mm apart. The heater element includes a Nichrome wire wound on a copper wire and placed inside a stainless steel tube. The heater and the thermocouple are encapsulated in a casing made of Verowhite material (ABS) using an epoxy resin (Araldite) to bind them together. These sensors were fabricated and calibration test was conducted in laboratory conditions before deploying it in the field. To quantify and verify calibration results, FEM simulations were carried out using COMSOL Multiphysics® by simulating the model of the sensor in its soil environment. Also, from experimentation it was found that there was reduction in ΔT at higher moisture content due to inappropriate placing of the heater element, thereby affecting the performance of the sensor. To optimize the design of the sensor, FEM simulations was done for different sensor designs.

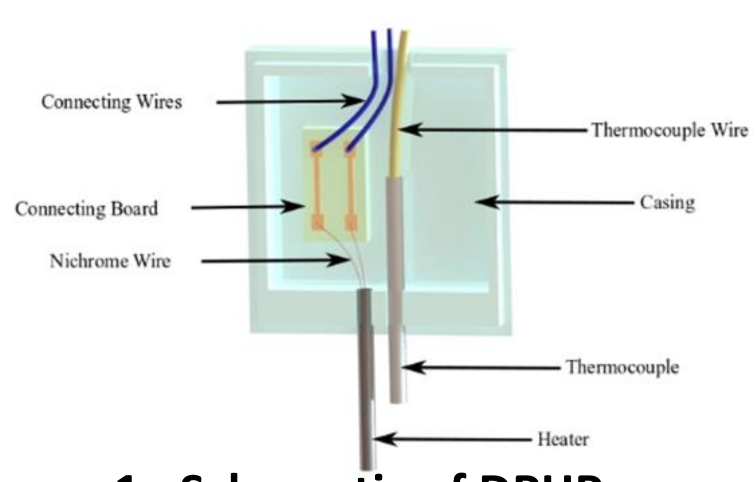

Figure 1. Schematic of DPHP sensor

Methods and Materials

The assembled sensor was modeled in COMSOL Multiphysics® by choosing the actual geometry of the prototype and appropriate materials as shown in Table 1. The *Joule Heating* interface was incorporated to simulate the supply of constant 3.3 V to the heater element for a desired time duration of 120 s, for which time-dependent study was incorporated. To model different soil conditions, soil densities and moisture content, *Heat Transfer in Porous Media* interface was used. For different soil densities, moisture content was varied in steps of 5% from 0 to 25% through parametric sweep. The initial temperature for all domains was set at 298 K. The maximum rise in temperature (ΔT) at a distance of 3 mm was obtained through point evaluation. The maximum rise in temperature (ΔT) is a function of volumetric heat capacity which in turn is related to volumetric moisture content. Furthermore, FEM simulations were carried out by varying the projection length of the heater element inside the sensor casing. The sensor design which results in maximum temperature rise and maximum heat flow through the soil across the moisture content is chosen for fabrication of sensor. Heat flux through the individual domains of the sensor (Soil, Verowhite, and Araldite) is evaluated by finding the surface integral of heat flux in x-direction on a normal plane created by union of sub domains across the entire model as shown in Figure 4.

Table 1. Material properties.

Material	Cp (J/(kg K))	ρ (kg/m³)	k (W/(m K))
Nichrome	450	8400	11.3
Stainless Steel	460	8000	16.2
Copper	385	8933	401
Red Soil	800	1200	0.22
Araldite	600	1170	0.22
Vero white(ABS)	1340	1170	0.06

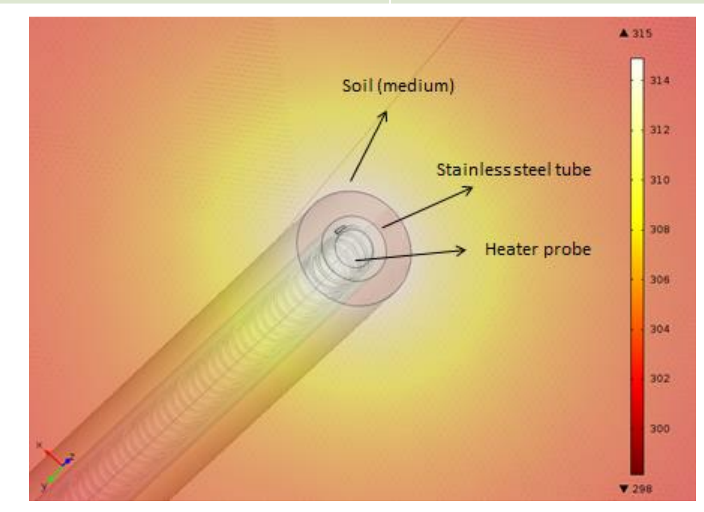

Figure 2. Model of the heater element

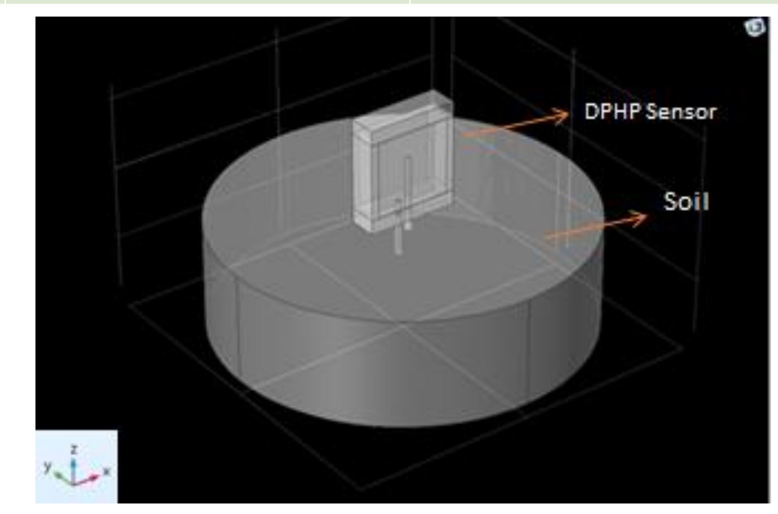

Figure 3. Model of the sensor in its soil environment

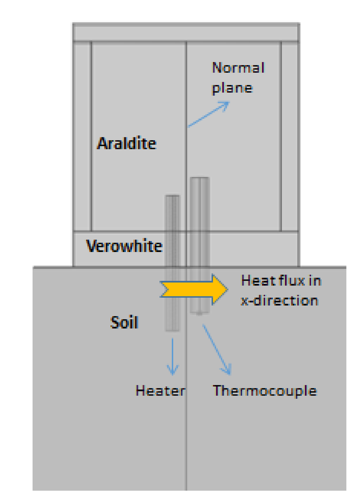

Figure 4. Heat flow in different domains of the DPHP Sensor

Results

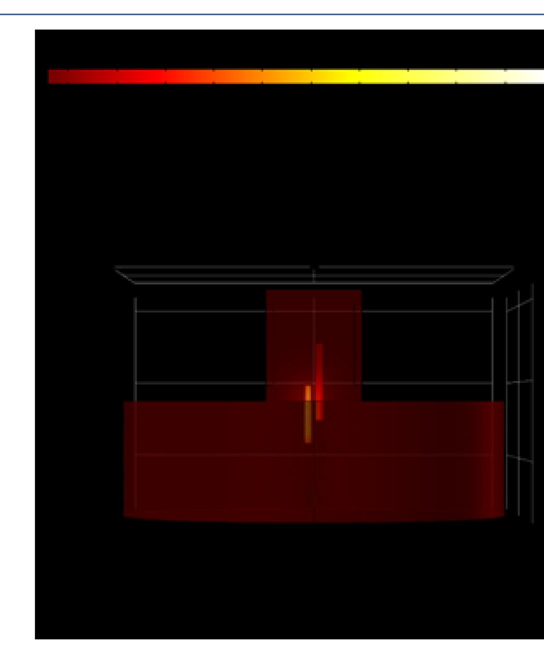

Figure 5. 3D Temperature plot

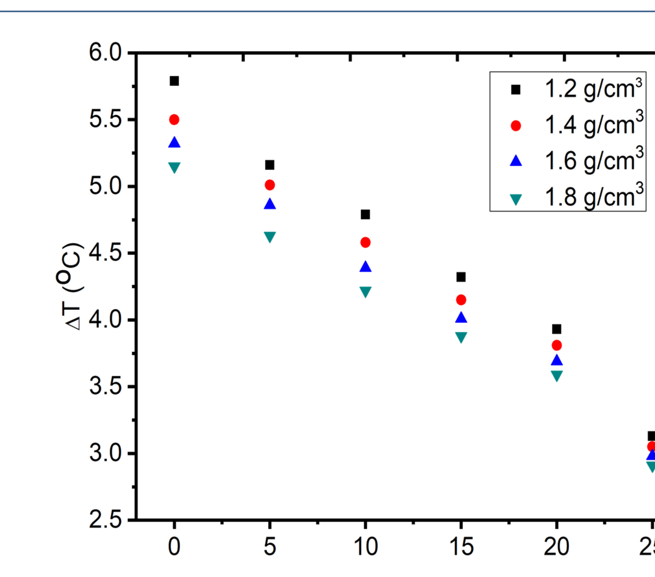

Figure 6. Plot of ΔT vs moisture Content for different soil densities

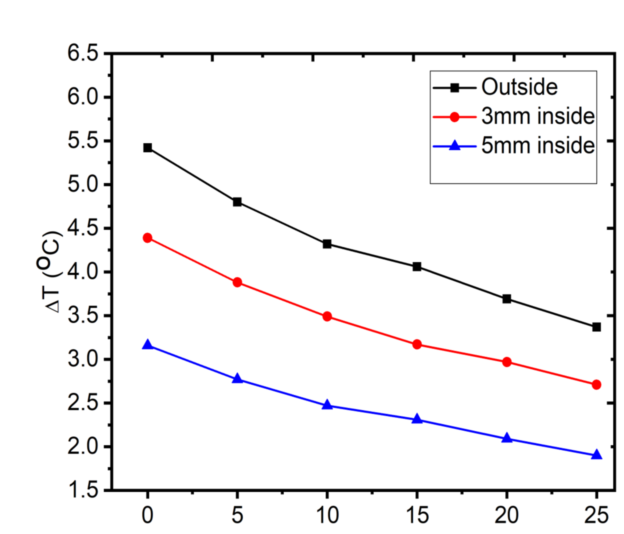

Figure 7. Plot of ΔT vs moisture content for different sensor design.

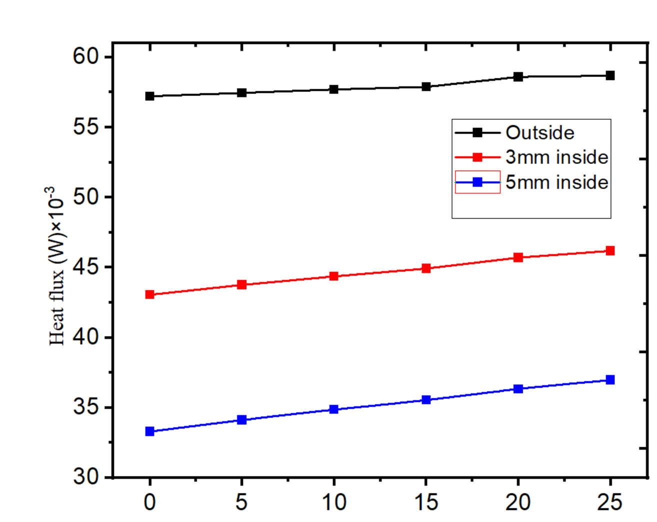

Figure 8. Plot of Heat flux vs moisture content for different sensor design.

Conclusions

- The design of the sensor with the entire heater element outside the epoxy resign gave higher temperature rise and higher heat flux in soil across the varying moisture content. Hence, this design was chosen for the construction of sensors fabricated.
- This research could serve as the design guideline for the manufacturing of DPHP soil-moisture sensors with optimal performance.

References

1. Jorapur, Nikhil, et al. "A low-power, low-cost soil-moisture sensor using dual-probe heat-pulse technique." *Sensors and Actuators A: Physical* 233 (2015): 108-117.
2. Valente, A., et al. "Modeling, simulation and testing of a silicon soil moisture sensor based on the dual-probe heat-pulse method." *Sensors and Actuators A: Physical* 115.2-3 (2004): 434-439.
3. COMSOL Multiphysics®, Heat Transfer module User guide, www.comsolcom(2013).

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