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Using a penetrator to measure the thermal diffusivity of loose granular materials in an atmosphere

M. D. Paton (1, 2), S. F. Green (1), A. J. Ball (1) and J. C. Zarnecki (1)
(1) PSSRI, Open University, UK (2) Finnish Meteorological Institute, Helsinki, Finland (mark.paton@fmi.fi)

Abstract

The nature of surface-atmosphere interactions on bodies is poorly characterised and would benefit from in situ measurements. Penetrators have the potential to deliver instruments, such as thermal sensors, to investigate the subsurface of a regolith. Laboratory experiments are described that use a penetrator to deliver a film heater into analogue planetary regoliths in the atmosphere of Earth. The design of a penetrometer for making thermal measurements in loose granular materials in an atmosphere is discussed.

1. Introduction

Measuring subsurface thermal properties of porous material such as a planetary regolith can help characterise the subsurface and to understand the environment on and above the surface e.g. [1]. This is important for determining climate stability and atmospheric physics in general. These properties are also useful for calibration of remote sensing techniques. Penetrators are ideal tools for delivering thermal sensors into the subsurface. They can also include other instruments such as accelerometers for determining the strength of the subsurface and some microscale information on the physical properties of the regolith.

2. Method

A penetrator, with dimensions based on those used for cone penetrations tests (CPT) was built in house at the Open University for thermal measurements. A foil heater was wrapped around a hollow shaft made of glass reinforced plastic pultrusion with a wall thickness of 3 mm and a shaft diameter of 38 mm. The foil heater doubled as a heater and a temperature sensor. The temperature was measured during heating by a circuit using the heater as one resistance element in a bridge. The signal was amplified using an opamp and read into a computer using an ADC11 10 bit analogue to digital converter.

The penetrator was dropped into three analogue regoliths of known properties using a specially constructed test rig that used a novel method using weights to control the impact dynamics [2]. The speed during impact and depth were calculated from measurements made by a shaft encoder mounted on the test rig.

Thermistors, shown in figure 1, were used to measure the radial heat flow from the film heater at increasing distances. These sensors also allowed the initial temperature of the target to be determined.

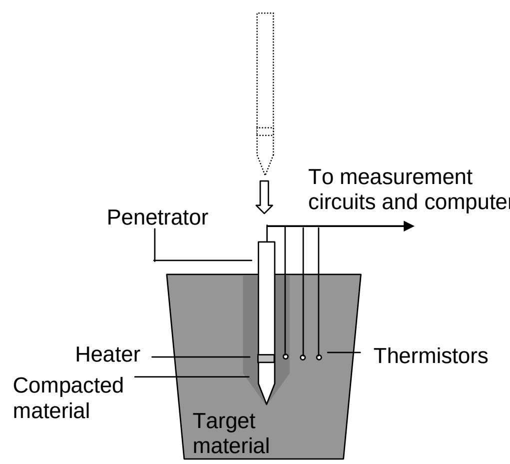

Figure 1: Diagram of penetrator, target and thermal sensors.

To determine the thermal diffusivity of the analogue regolith a numerical thermal model [3] was applied. The thermal diffusivity in the model was varied until it matched the data received from the film heater and the thermistors. A discrete form of the heat equation, equation 1, was initially used for determining the thermal diffusivity.

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + S \quad (1)$$

where is ρ is the bulk density, c is the heat capacity, r is the radial distance from the centre, z is the depth, k is the thermal conductivity and S is heat production.

3. Results

To assess the effect of compaction around the penetrator on the thermal measurements, two types of experiments were conducted into three different samples. The initial parameters of the experiments are shown in table 1. Sample type a is where the penetrator impacts the target (see figure 1). Sample type b is where a penetrator is first placed in the bucket and then the target is poured in around it.

Table 1: Initial parameters for the experiments

Sample	Sensor depth / cm	Impact speed / m s^{-1}	Target temperature / °C
1a	8	0.82	24.2
1b	8	-	24.3
2a	8	1.18	24.8
2b	8	-	24.8
3a	12	0.55	25.8
3b	12	-	25.2

Figure 2 shows the temperature difference between the model and the laboratory measurements of the penetrator standing in the free atmosphere of Earth. The blue line (top) is the difference in temperature between measurements using the film heater and the thermal model using equation 1. The red line (bottom) is the difference in temperature using a thermal model that considers convection and radiation losses from the heater. If convection is considered inside the hollow shaft then the difference is reduced even further.

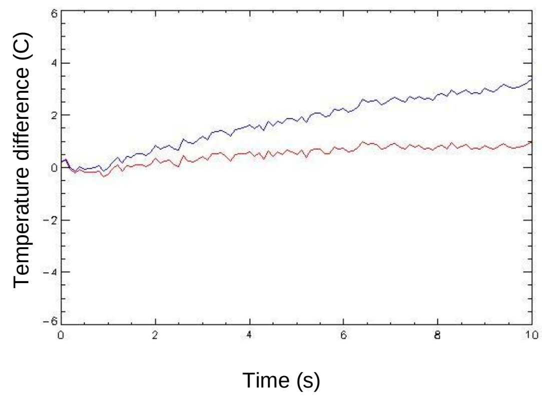

Figure 2: Difference between measured and modelled temperatures

4. Conclusions

Although a penetrator design is fixed by its primary function certain considerations need to be made when making thermal measurements in an atmosphere. To avoid possible difficulties correcting convection effects in a poorly characterised atmosphere it is recommended that the internal volume of the penetrator be filled in with a material to inhibit convection or that the shaft walls are thickened or a less powerful heater is used.

References

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