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Discussions Geoscientific Instrumentation Methods and Data Systems

Interactive comment on "A penetrator for making thermal measurements in a gas-filled planetary regolith" *by* M. D. Paton et al.

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Dear Referee #1 here are the responses to your technical comments:

The numbers in brackets are just reference to a working word document of the paper.

P112/L17 suit(e)

Corrected text (P3 L14).

P112/L20 MUPUS PEN penetration depth is max. 35 cm! However the thermal sensors on the Philae anchors (MUPUS ANC-T) may be as deep as 2.5m

Corrected text. (P3 L17)

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P113/L5ff It is mentioned twice that it is easier to thermally isolate a sensor mounted on the outside. One of this instances would be enough.

Agreed, corrected and removed second instance. (P4 L4)

P113/L10ff No objection to the authors statement here. He is certainly right. A side comment at this place is that for technical purposes it is practically impossible to perfectly isolate the thermal sensor from the main body and thus a really thorough calibration of the whole system has to be ensured.

Agreed. Care was taken with the calibration of the sensor. We used an environmental oven and tests in the laboratory to calibrate the system and its components as described in Paton (2005).

P114/L1ff I'm not entirely happy with the wording "thermal penetrator" which could be confused with a device thermally penetrating into the surface like e.g. a melting probe. This should rather be phrased as "penetrating thermal sensor" or suchlike.

Agreed, a more judicious choice of words is really required. I have removed the word thermal in the case where the text is referring to non-thermal aspects and added "fitted with a thermal sensor" when discussing the penetrator in relation to thermal measurements.

P116/L5 dependant / dependent Might be british / american language variant. However, according to the internet dependant should be used for persons only.

Corrected spelling.

P118/Eq 1 permeability is here denoted as K whereas on P117/L9 it is denoted as k, please use the same variable name everywhere, especially as k is used for the thermal conductivity later on.

Agreed, corrected text. (P7 L8)

P119/L15ff It might be of interest to the readers context that k/(rho c) is the thermal

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diffusivity.

Agreed. Reviewing the text we have to decided to introduce the diffusivity in the principal physical parameters as this is discussed in the paper but not explained. (P7 L24)

P119/L16ff The term rho*c is the volumetric heat capacity and should be named that way instead of "product of density and heat capacity".

Updated text. (P9 L11)

P120/L6 The shaft of the penetrator is a glass reinforced plastic tube manufactured by pultrusion. However, a material like this might have anisotropic thermal properties because of the production process. This should be discussed with one or two sentences.

Updated text. (P9 L27)

P127/Sect6/L13ff I am not sure if I agree to that conclusion; the temperature profile looks like the usual equilibrium curve between heat flow and heat production for this kind of probes. Is there a substantial deviation from an exponential heating curve which might substantiate the author's assumption?

Yes it does look like a normal equilibrium curve. However precisely for this reason we have plotted the temperature difference between the compacted and loose sample to show how they differ to examine to results in more detail.

The temperature measurements in figure 11 seem to be within the resolution limit of the measurement system. I'm not sure the conclusion drawn is fully valid. What is the error bar on the measurements or can the authors bring more arguments for their interpretation.

The fluctuations are around the measurement error for the film heater which is 0.07 K. (P13 L28 & P38 L4)

The fluctuations might be due to convection inside the hollow body and along the outer surface of the body. However, I doubt that fluctuations of about 0.2-0.3 K as shown

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for the heater would propagate from the inner walls through the penetrator body, the glue and the highly insulating Kapton back to the heater without dissipating along the penetrator shaft in axial direction. I would rather assume the fluctuations are due to effects outside the penetrator, and/or fluctuations in the measurement setup.

A 10 bit bridge ADC system and a Heater with a resistor tolerance of 10% (MINCO 5228 Datasheet) is not that accurate to go into great details of interpretation when the total difference between two measurements (different sample preparations and setup) is about 0.6-0.8% in absolute values and <0.09% for the fluctuations (in fig 11b). Compare with figure 14 and 15 of Hütter & Kömle 2012 doi:10.5194/gid-2-23-2012 a paper which is also in the discussion phase of the GI Journal parallel to this paper!

P128/L6ff Again the accuracy of the measurements make any interpretations of temperature differences rather meaningless since the whole measurement system can not resolve it. For all practical purposes in fig 12 the temperatures are within the intrinsic resolution of the system. What has not been discussed here is the influence of the thermal resistance between heater and sample material. I would agree with the author that an impacted sample should have a higher thermal resistance but that would result in a temperature increase of the heater for impacted samples that is higher than actually measured here.

Yes we agree your analysis is probably a correct one. While fluctuations in temperature inside the penetrator may play a role the fluctuations observed in the temperature difference are close to the measurement uncertainty ($\sim$0.1 K for the temperature difference). However these fluctuations are still of interest because their sudden and common time of occurrence for both samples suggests some phenomena related to the increasing temperature of the sensor.

Thanks very much for pointing out the paper by Hütter and Kömle, “Performance of thermal conductivity probes for planetary applications”. The paper explains the measurement issues regarding axial flow and contact resistance rather elegantly. It also

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clearly identifies the correct application of such probes.

According to Hütter and Kömle contact resistance is important at ambient, low vacuum, conditions. A change in contact resistance changes the characteristics and length of the transient period and causes a constant temperature offset at later measurement times. It may be that the changes in the contact resistance plays a significant role with our results and needs to be considered.

We would like to update our text quoting the measurement uncertainty of the instrument (Paton, 2005). We will also update the analysis of the results with a discussion of contact resistance and provide alternative explanations (i.e. measurement setup issues) for the fluctuations seen in the temperature differences.

Updated text (P15 L30)

P129/ No objections now, to the spatial relocating of the thermistor positions for modelling (in fig 13 and 14). The nice fit is justifying this assumption in a more plausible way than just tweaking model parameters. However, why should a thermistor in a impacted sample move closer to the centre instead away from it? As pointed out by the author there is room for improving the accuracy of the thermistor localisation during sample preparation, as difficult this may be for large samples. It would be nice though, to provide in fig 13 and 14 some numbers the author used for the thermal conductivity of both samples or at least the diffusivity if the conductivity is impractical.

The temperature sensors may have moved closer to the centre as were inserted after the impact. As they are pushed in the thermistor rods were kept at a constant distance from the shaft as they entered the target. However the rods were not completely stiff and the thermistors could have been deflected one way or another as they penetrated the target. Updated text to make this clearer (P18 L30).

P131/Sect7 I would prefer the usage of the wording "thermal probe for space applications" instead off "spacecraft penetrator" seeing in my imagination a penetrator ripping

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through the innards of spacecraft subsystems tearing a hole all the way through to the solar panels and shortening the mission lifetime substantially.

Agreed. Changed spacecraft penetrator to thermal probe and provided the spacecraft context later on in the sentence. (P19 L26)

PT132 I agree to the general conclusions of the author concerning the diffusioncon-vection model. However, assuming the benefit of filling the interior of a thermal probe with foam, which is thermally conducting as well, would outweigh the inhibition of con-vection inside the tube is not straightforward. This will be a matter of the environment (Mars or airless object) and thorough design to purpose including thermal modelling.

Yes agreed. However for this case there would be less leakage of heat into the interior of the penetrator if it is filled with a low conductivity foam or insulation material.

P133/L24 Kömle instead of Komle

Corrected text (22 L3).

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