THERMOPHYSICAL BEHAVIOUR OF LUNAR ANALOGUES UNDER SIMULATED LUNAR ENVIRONMENT. K. Durga Prasad, Vinai K., Rai, and S.V.S. Murty , Physical Research Laboratory, Ahmedabad 380009, India (durgaprasad@prl.res.in)

Introduction: The lunar surface, in particular the upper most porous layer of few cm, exhibiting a complex thermophysical behavior is not well understood so far. The principal reason for this is the interdependence of various physical properties and their effect on heat exchange within the medium and the extreme temperature and vacuum conditions of the Moon. The thermo physical behavior of lunar soils show significant dependence on various physical parameters viz. grain size, porosity, composition [1]. Further, when the grain sizes are of the order of few microns and when the environment is hard vacuum as in the case of the top surficial layer (few cm) of the Moon, the soil exhibits an unconventional behavior. Such a behavior has not been systematically studied so far, particularly for lunar soils. Therefore, an effort has been made to systematically investigate this behavior using lunar analogous soils. Here we present some of the preliminary results from this study.

Samples: Samples returned from the Moon are limited and are site specific and do not represent global diversity. In this scenario, a first-hand global understanding of lunar thermophysical behavior can be obtained only by conducting laboratory experiments on analogous samples in a simulated lunar environment. Terrestrial analogous soils representating samples for both mare and highland soils have been identified within India for carrying out these studies. Basaltic rocks from Dhinodhar area of Kutch, Gujarat have been identified as suitable Mare analogues. On the other hand, Anorthosite rocks from Sithampundi of Tamilnadu were selected as representative samples for lunar highlands. Details of the samples are presented elsewhere [2]. The chemical composition of the analogous samples were derived using X-ray Fluorescence technique and compared with that of lunar samples and other simulants like JSC[2].

Experimental Setup and Methodology: A chamber that can simulate temperature and vacuum conditions close to that of surface of the Moon has been custom-designed, fabricated and tested [3]. Experiments to understand thermophysical behavior conducted on analogous samples inside this chamber can mimic the experiments as conducted on the lunar surface. For this purpose, the sample with desired material, grain size/stratigraphy under investigation is placed inside a cylindrical sample holder made of Teflon with a copper plate at bottom. Details about experimental setup is described in [4]. Using the experimental setup, the temperature profile within the sample is measured as a function of depth and time. Thermophysical properties are then derived from these temperature measurements as given in equations 1, 2 and 3, to infer the thermophysical behavior of the soil sample under investigation.

a) Thermal Gradient (DT): The temperature gradient between two points Z_1 and Z_2 within the sample is given by the equation

$$DT = (T_2-T_1)/Z \rightarrow \quad (1)$$

Where T_1 and T_2 are temperatures at points Z_1 and Z_2 respectively and Z is the distance between the two points Z_1 and Z_2

b) Heat Flow: Heat flow is dependent on the bulk thermal conductivity of the sample and calculated from temperature gradient as given by equation

$$Q = DT * \lambda \rightarrow \quad (2)$$

Where 'DT' is the temperature gradient and 'λ' is the bulk thermal conductivity of the sample.

c) Thermal Diffusivity (κ): The thermal diffusivity of the sample is calculated using amplitude decay method given by the equation 5.4 (Adams et al., 1976).

$$D = \frac{(Z_2 - Z_1)^2 \pi / P}{[\ln(T_1) - \ln(T_2)]^2} \rightarrow \quad (3)$$

where T_1 and T_2 are the temperatures at sample heights Z_1 and Z_2 from the heat source and 'P' is the period or time of measurement in seconds

Figure 1: Designed Sample holders with and without perforations.

Results and Discussion: Using basalt samples of various grain sizes, experiments were conducted to study the dependence of thermophysical parameters on various properties like ambient pressure, grain size, composition, stratigraphy of the sample. Ambient pressure and grain size, both showed a significant dependence on the thermophysical behaviour within the sample. Under high vacuum conditions (<10^{-3} Torr), the heat flow was extremely sluggish while the same happened to be dominant in the case of low vacuum, lower grain size exhibiting slower heat flow and vice-versa. Under vacuum conditions, heat flow had a direct dependence on grain size with smaller grain size exhibiting slower heat flow and vice-versa.

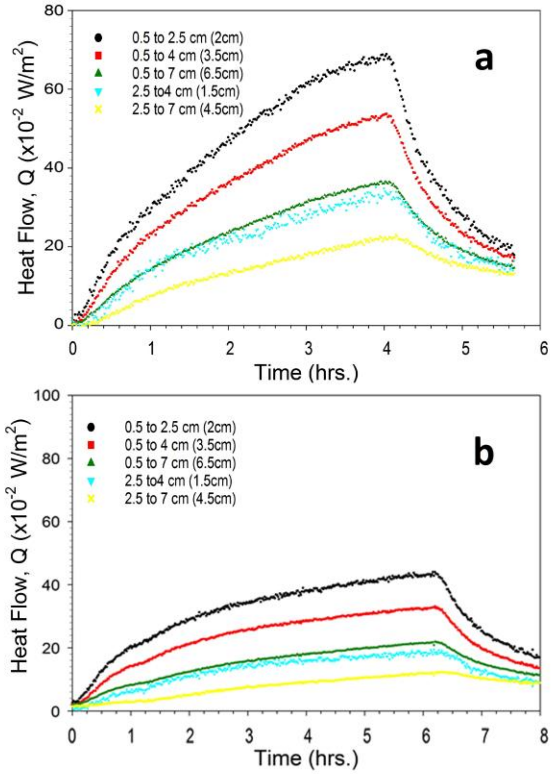

Figure 2: Comparison of heat flow with (a) Sample cup without perforations (b) Sample Cup with perforations

Although the dependence of various parameters was studied, the role of interstitial gases and composition is discussed here. The effect of grain size and porosity is discussed in [4].

a) Effect of Vacuum and role of interstitial pore fluids: It was observed during experiments that pore gases have not been evacuated completely as seen from the time taken for achieving desired vacuum level and also a spill-over of the sample in the area around the sample holder. To address this issue, another sample holder with slanted perforations along the walls has been fabricated to ensure out gassing of pore gases, without sucking the fine grained material. Both the sample holders with and without perforations are shown in figure 1. The heating experiment was carried out in both the cases using 100 µm Basalt sample and at a vacuum level of $1x10^{-4}$ Torr. It was found that for a given length of time, the temperatures and heat flow attained by the sample kept in sample holder without perforations is larger than that of the one in the holder with perforations. These results indicate the effect of trapped gases in pore spaces which have not been able to completely get evacuated resulting in a poorer vacuum and high heat flow. These pore gases also participate in heat transfer in the form of convection within the pore spaces of the sample and therefore do not represent realistic lunar conditions which needs to be taken care while carrying out all such experiments.

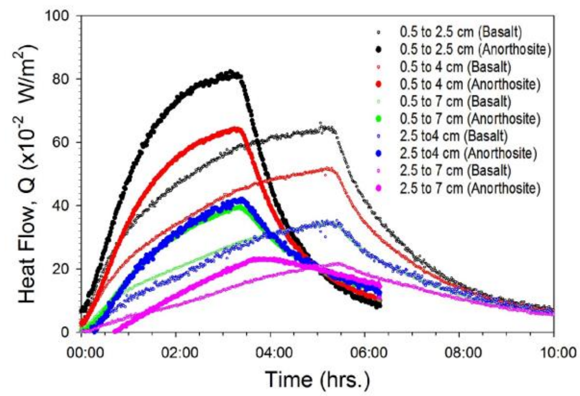

Figure 3: Comparison of heat flow profile during heating for Basalt and Anorthosite samples

b) Effect of Composition: The two main compositional rock types present on the Moon are Basalt and Anorthosite. It is important to understand the role of composition on the thermophysical behavior. To this effect, the thermophysical parameters have been measured for Basalt and Anorthosite samples of 250 µm grain size. The temporal evolution of temperatures for basalt and anorthosite samples at four different depths are compared in figure 3. It is observed that the temperature rise is faster in the case of anorthosite than that of basalt. Similar trend of higher heat flow within anorthosite sample when compared to that of basalt was also observed. Although the thermal conductivity and specific heat capacities of Basalt and Anorthosites are comparable, the observed trend is puzzling and needs a detailed investigation. At this point, it may be assumed that this trend could be due to the arrangement of grains as a result of their shapes (effective contact area). However, this needs a further detailed study.

Summary: Thermophysical behavior of lunar soil using analogous samples under simulated lunar environment has been carried out. The role of interstitial pore fluids on thermophysical behavior has been found to be significant and needs to be properly taken care in such studies. The results obtained for composition dependence (between basalt and anorthosite) were puzzling, and a modelling study, incorporating grain shapes is underway.

References: [1] Urquhart and Jakosky, 1997 [2] Durga Prasad, (2016) PhD Thesis [3] Durga Prasad and Murty,(2013), Acta Astronautica, 89, 149-153 [4] Durga Prasad et al., (2015) 46^{th} LPSC #1768.pdf