Does The Emissivity of Basaltic Lava Surfaces Change With Temperature And Why Do We Care?

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Introduction

Infrared emissivity is an important physical property of a molten material because it directly affects the cooling efficiency, the determination of the bulk composition with cooling, and can therefore be significant in thermo-rheological models designed to study cooling and emplacement. Emitted energy from basaltic surfaces cooling from a molten to a solid state has been investigated in the past, yet remains enigmatic. This is largely due to complexities and errors that arise in measurements due to changes in the surface glass content and vesicularity, as well as mixing of multiple temperatures, as the lava cools. Thus is remains unclear whether emissivity of molten basaltic lava is truly different than that of the cooled surface. We see determination of correct surface emissivity and its change with time to be of great importance to anyone working with thermal infrared (TIR) data or modeling of lava flows. Novel techniques used to acquire both laboratory-based and field-based measurements of molten basaltic lava surfaces, and the results from these experiments, are presented here. These results validate the efficacy of the techniques as a means of characterizing emissivity of basalts.

Laboratory-Derived Emissivity

A series of laboratory thermal emission spectra were collected in the Image Visualization and Infrared Spectroscopy (IVIS) Laboratory at the University of Pittsburgh. The first set of experiments involved measuring the emissivity of basalt with change in physical state (molten to solid). A custom-built micro-furnace integrated with a Nicolet Nexus 670 FTIR spectrometer with a cooled XT-KBr detector was used to acquire TIR emitted energy from Hawaiian basalt samples at various stages in the melting and cooling process (Figure 1). Approximately 2 grams of basalt sample was crushed into mm-sized pieces, placed into a platinum crucible, and heated to ~200˚C above the liquidus (~1400°C) to ensure a complete melt. Thermal emission from the sample is reflected into the spectrometer by way of a collimating mirror, which is situated directly above the sample port of the furnace. Spectra were acquired of the basalt in 100°C increments from 1400°C to 500°C, with the sample held for ~5 minutes at each set point temperature. Significant differences can be seen in the position and depth of emissivity features in the basalt spectra, indicating that thermal emission spectral character changes between molten and solid states.

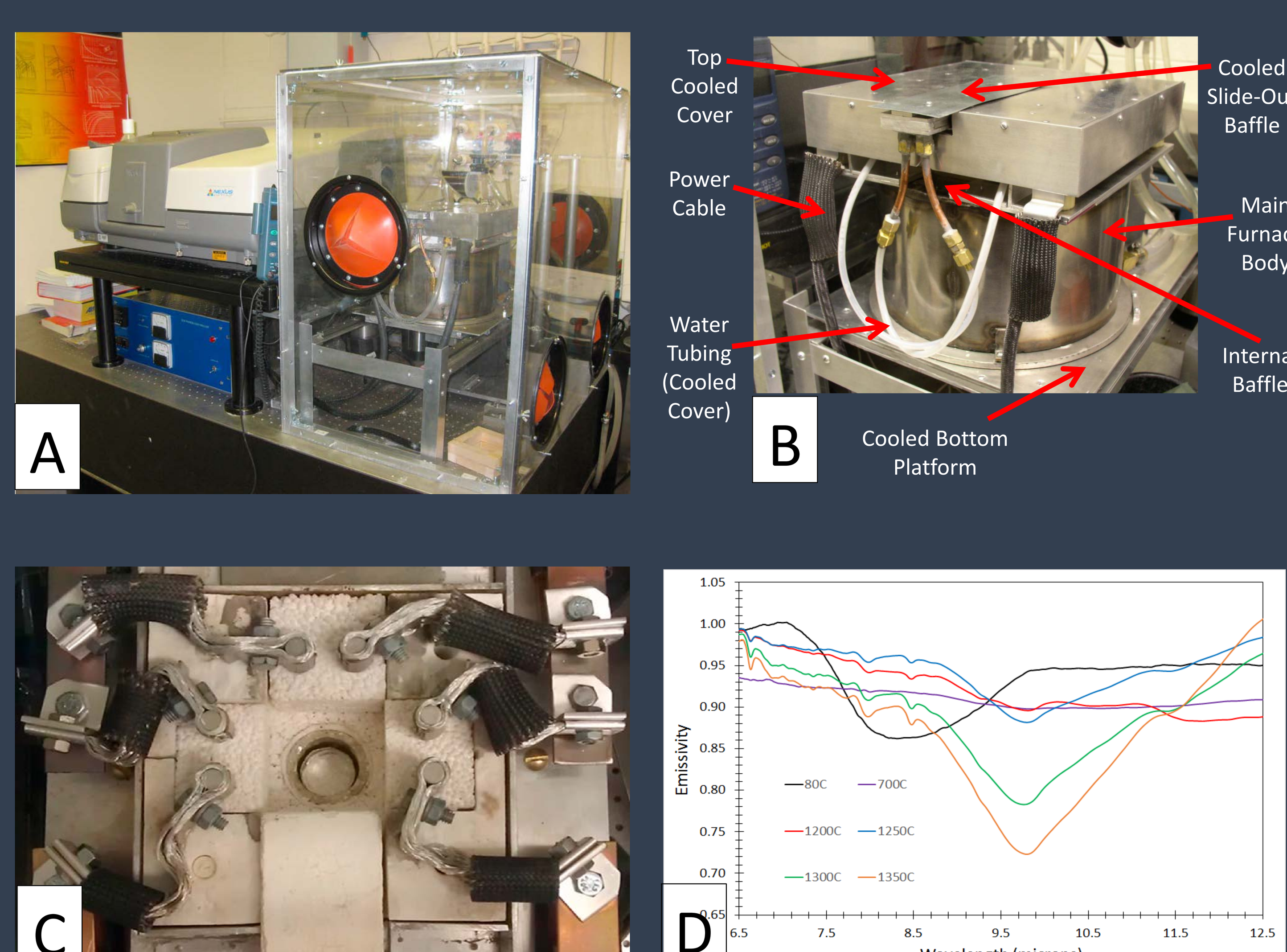

Figure 1: (A) The IVIS Laboratory spectrometer setup, with a Nicolet Nexus 670 FTIR spectrometer and Plexiglas glove box. The setup is continuously purged of CO_2 and H_2O. The glove box is open to the external port of the spectrometer via a hole, which allows for the sample's emitted signal to pass into the spectrometer during acquisition. **(B)** The micro-furnace is 21.6 cm in height and 28 cm in diameter at the base, and has an integrated water cooling system. The sliding portion of the top cover moves outward to expose the sample for analysis. **(C)** The crucible with sample is situated in the central portion of the furnace, and is surrounded by 3 heating elements. The sample is exposed to the spectrometer by sliding the insulated baffle out. **(D)** Emissivity spectra of a Hawaiian basalt sample at various temperatures. Spectral character is markedly different between solid (< 1200°C) and molten (>1200°C) states. Specifically, the emissivity minimum value and emissivity minimum position change with increasing temperature, which reflect the change in molecular structure of the sample as it transitions from a molten to a solid state (or vice versa).

Laboratory-Derived Reflectance

A newly-developed molybdenum micro-heater at the Australian National University was used to heat powdered glass samples of Galapagos MORB composition to amorphous solids (Figure 2A). A high-temperature furnace was subsequently used to heat the samples to 1200 °C in a platinum crucible, and then cool them at a known rate to 850 °C. At 850 °C, the sample was removed from the furnace and quenched. Reflectance (R- µFTIR) spectra were then collected of each sample using an IR spectrometer. (Figure 2B). Similarly to emissivity spectra, the major Si-O reflectance feature in each spectrum varies with composition and cooling rate. The cooling rate value is annotated to each spectrum.

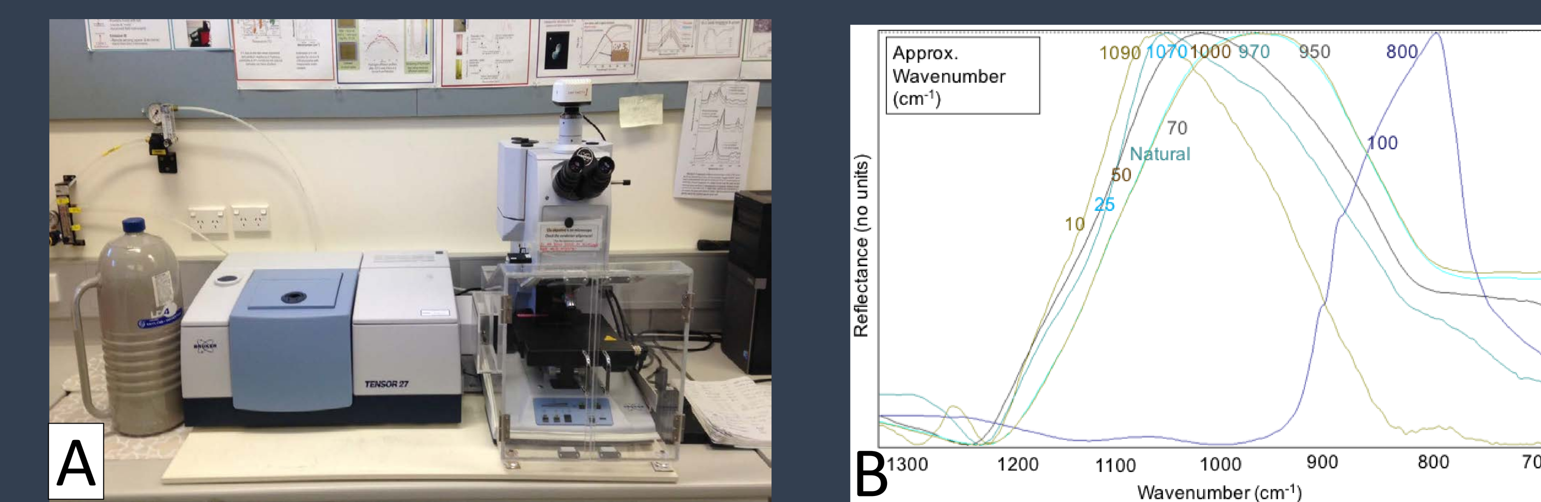

Figure 2: (A) the molybdenum micro-heater setup at Australian National University. Samples are heated to form amorphous solids using this setup. **(B)** After being melted and quenched to room temperature in a larger high-temperature furnace, reflectance spectra were collected of samples. A clear relationship exists between the wavenumber position of the Si-O band peak, and the cooling rate of the sample. Similarly to emissivity spectra, these spectra clearly show changes in spectral morphology with changing physical state of the glass.

Deriving Basalt Emissivity In The Field

FLIR cameras are hand-held infrared cameras capable of acquiring precise (0.08°C at 30°C) and accurate (± 2°C) TIR radiance data at a high spatial resolution in the 7.5 to 13 µm region. Because of their portability, and the advantages of TIR in studies of silicates, FLIR cameras have become increasingly utilized for the study of active and inactive volcanoes and their deposits [1, 2, 4]. The foreoptics of two FLIR cameras have been modified for use as multi-spectral TIR field imaging systems. The broadband wavelength range of each has been divided into individual wavelengths using external diffraction filters [3], making the camera capable of collecting both temperature and emissivity data. Wavelengths for filters were chosen because they match the wavelength ranges of other TIR sensors (ex: ASTER and Landsat). Due to lack of access to surface basalt flows in Hawaii, field-testing of the camera systems was conducted at at Halemaumau lava lake (Hawaii). The S-40 camera system was field-tested in August 2014 and continues to be used for both lava and ash studies. The newly-constructed MMT-cam system was tested in January 2017. The lava lake was an ideal target as it has dynamic variability and has a mixture of lava crust, molten lava, and SO_2 gas. All of these components were detected using both camera systems, and the emissivity changed with wavelength, as expected (Figure 3).

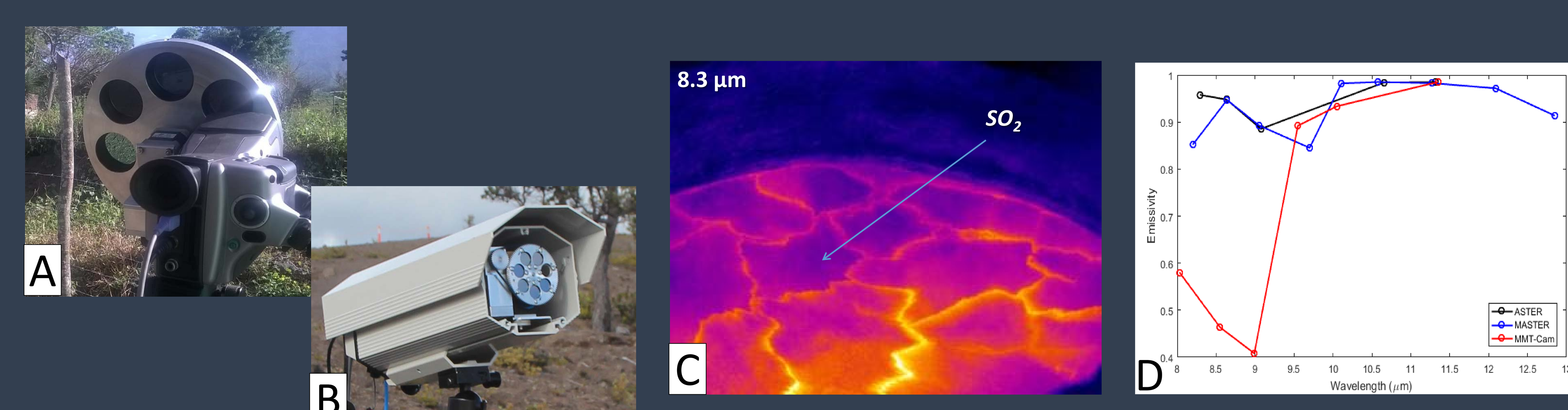

Figure 3: (A) The larger (prototype) field setup consists of a FLIR S-40 camera mounted onto a tripod with a 6-filter wheel in front of the camera lens. **(B)** The smaller MMT-Cam setup has a mini-FLIR camera and a mini 6-filter wheel, all housed in a portable field unit which can potentially be left in place long-term for remote studies. **(C)** Example FLIR image of Halemaumau lava lake at 8.3 µm. At this wavelength, SO_2 gas absorbs strongly. **(D)** six-point emissivity spectra of the lava lake surface from the MMT-Cam system, as compared with ASTER and MASTER – derived spectra. The characteristic drop in emissivity can be seen in each of the spectra, a phenomenon which is also observed in laboratory spectra of molten basalts.

Conclusions and Future Work

Initial results from both laboratory studies and of Halamaumau lava lake confirm that molten basalts experience significant changes in emissivity (and complementary reflectance) with change in physical state. Data collection at Halemaumau crater has helped calibrate the camera systems, and proven their efficacy for collecting reliable temperature and emissivity data. Future work includes utilizing the system to acquire emissivity spectra of active Hawaiian basalt flows at various phases of cooling and crust formation, and utilizing the laboratory setups to create and analyze additional basaltic melts of varying compositions. This research will ultimately provide a means to improve the accuracy of thermo-rheological models dependent on accurate cooling rates as well the ability of orbital TIR sensors to characterize future basaltic eruptions.

References: Carter, A. and Ramsey, M.S. (2009) *Rem. Sens. Environ.*, 113, 2412-2151; Patrick, M. et al. (2007) *Bull. Volc.*, 69, 769-784 DOI: 10.1007/s00445-006-0107-0; Ramsey, M.S. (2009) *Eos Trans. AGU, 90(52)*, Fall Meet. Suppl., Abst. V24B-01; Ramsey, M.S. and Harris, A., (2013) *J. Volcanol. Geotherm. Res.*, doi:10.1016.