A Combustion-Driven Power Plant For Venus Surface Exploration M. Paul[1], A. Rattner[1] and C. Greer[1]
[1]The Pennsylvania State University (Michael.V.Paul@psu.edu, Alex.Rattner@psu.edu, czg5155@psu.edu)

Introduction: The challenge of energy storage and power generation for a planetary lander is significantly magnified when considering a Venus mission. NASA has funded the Pennsylvnai State University Applied Research Laboratory to leverage decades of development of a TRL 9 U.S. Navy undersea power system to meet this challenge. Our solution may enable in situ exploration for hundreds of hours rather than hundreds of minutes, which is typical of past Venus landers as well as currently considered concepts, such as the 2013 Decadal Survey Venus concept Mission, VITAL [1, 2]. By increasing operational time on the surface of Venus by one or two orders of magnitude, missions are far more likely to return the expected science, will offer mission operators the opportunity to interact with the environment, choosing specific science readings (rather than simply see whatever a pre-programmed probe happens to first see), and deal with anomalies that would jeopardize a two-hour-long mission.

Through the Hot Operating Temperature Technology (HOTTech) program, the NASA Planetary Science Division has provided the most recent grant to advance the development of TRL 9 Stored Chemical Energy Power Systems (SCEPS). Instead of being hindered by the harsh conditions on Venus, SCEPS will take advantage of the environment for its operation. SCEPS systems have long provided both electrical and propulsive power for underwater systems [3] and are well suited to the rigors of planetary exploration. Conventional SCEPS engines make power by burning molten lithium with sulfur hexafluoride vapor, using the heat to drive a closed-loop Rankine cycle. The inherently high energy density of SCEPS is magnified for Venus applications, since the carbon dioxide atmosphere can be used as the oxidizer, significantly increasing the system-specific energy density. Other targets such as gas giants and Mercury's hot surface, would benefit from the use of SCEPS, as its high temperature combustion will allow it to work independent of its surroundings. Design specifics will change to suit each environment, but the basics of operation will stay the same.

The focus of the HOTTECH program is demonstration of a high-temperature Rankine cycle that would produce power on Venus and validation of a system-level concept for a long-duration mission. Through a 2011 Phase I grant from the NASA Space Technology Mission Directorate, we analyzed a complete mission concept [4] and begun characterization of lithium/CO_2 combustion. Through a 2015 NASA Innovative Advanced Concepts Phase II grant, we have demonstrated SCEPS reactor temperatures (>1000°C) when burning lithium with a gas mixture representative of the Venus atmosphere as the oxidizer (97% CO_2, 3% N_2). In the coming months, we will complete an additional experiment producing superheated steam from a SCEPS reactor, validating the heat generation and acquisition component of this power system. In addition, we have modeled the fundamental physics of lithium and CO_2 combustion, allowing us to estimate performance of this innovation on conventional SCEPS systems and make comparisons to the results of ongoing tests.

HOTTECH Focus: The work funded by the HOTTECH program, which we are calling the HOTLINE project (Hot Operating Temperature Lithium combustion for IN situ Energy and Power), complements our existing work by focusing on a thermodynamic cycle that will convert the heat into usable power for a lander. We have analyzed a Rankine cycle, using elemental iodine as the working fluid, which will reject its heat to the Venus atmosphere and condense into the liquid necessary for the pump-side of a Rankine cycle to work. We will build and test a physical system that demonstrates this capability. This system can also provide refrigeration for other components. We believe that these two features, active cooling and relatively long duration operations, will enable NASA to execute missions to the surface that address the Agency's goals for Venus exploration.

We believe that using SCEPS on the surface of Venus can enable NASA's plans to explore our sister planet and will work to ensure that the HOTLINE project is a significant step on the path to a future landed mission. We will discuss:

- Analysis and design of an end-to-end power system that meets a parameterized mission's requirements
- Design and of a test article that heats the selected working fluid to operational temperatures, drives a turbine to steady-state operation, measures work output by the turbine, and then condenses the working fluid by rejecting heat to a simulated Venus environment (hot, high-pressure air).
- Tests planned to show functionality at multiple operating conditions to characterize the thermodynamic state parameters at critical points in the Rankine cycle

References

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