A Deep Sea Hydrothermal Vent Bio-sampler for Large Volume In-situ Filtration of Hydrothermal Vent Fluids

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Abstract

The Hydrothermal Vent BioSampler (HVB) currently being developed at the Jet Propulsion Laboratory is designed to collect large-volume samples of hydrothermal vent fluid, operating with fluid temperatures reaching 400°C and vent at depths of up to 6,500 meters. The primary goal of the project is to collect ‘pristine’ samples untainted by the surrounding waters. Analysis of the collected samples can reveal the existence of thermophillic organisms within the vent fluid, extending the upper limits of life with respect to thermo-tolerance. Any biology found at such environments can contribute to research in astrobiology, while the technology developed for the system can contribute to bio-containment techniques useful for Arctic and planetary exploration.

The HVB performs in-situ filtering of hydrothermal vent fluids to concentrate a large volume of vent fluid to a smaller volume more suitable for transport. The HVB system is currently in the development phase. This paper provides a physical description of the current system, as well as a summary of the preliminary tests conducted in 2005: a pressure chamber test, a dive test in a 30 ft dive pool, and a dive operation at a hydrothermal vent off the northern coast of Iceland.

1 Introduction

Marine hydrothermal systems and the unique biota associated with them represent some of the most interesting ecosystems on the planet. These ‘hostile’ environments are often composed of vents spewing super-heated fluid containing a variety of reduced compounds, many of which can be used as substrates for growth by microorganisms. While evidence of microbial growth in hydrothermal associated habitats abounds, the evidence of microbial life within the hydrothermal plume has been elusive and difficult to validate. To prove life exists in these extreme environments, ‘pristine’ samples (i.e. fluids untainted by microbes entrained from the surrounding waters) must be collected.

To account for the presumed low biomass in the hydrothermal vent fluid, a sampler should be capable of collecting samples of significant volume. Most samplers being developed today has relatively small capacities ranging in the tens to hundreds of millimeters [1, 2, 3, 4].

A novel hydrothermal vent biosampler (HVB) sampler was recently developed by the JPL Robotic Vehicles Group with input from the Biotechnology and Planetary Protection Group and experts from the Monterey Bay Aquatic Research Institute (MBARI), Scripps Institute of Oceanography (SIO) and Woods Hole Oceanographic Institute (WHOI). The HVB has been designed to withstand extreme temperature (~400°C) and has been pressure tested to a simulated depth of 6,500 m. In-situ sensing devices have been positioned throughout the system to monitor real-time temperature and flow rates during sampling, ensuring that samples are collected from specific areas of interest (i.e. they are ‘pristine’). To account for low biomass samples, the HVB employs a series of pre-filters and a large surface area collection filter which effectively concentrates 10 L of fluid to a final volume of 200 mL.

2 Deployment

The hydrothermal vent biosampler is designed to be deployed by a manned submersible such as the Shinkai 6500. The submersible is deployed from a research vessel. It will descent and carry the sampler to a hydrothermal vent, where a robotic arm on the submersible will grasp the intake nozzle, which is attached to the HVB through a flexible hose, and
protrude it into the vent. A cable connecting the HVB to a control station inside the submersible provides the system with power and data signals. This allows an operator inside the submersible to command the HVB through the sample collection process.

3 Physical Components

The HVB has a main aluminum chassis onto which most of the components are mounted. On the front side of the chassis (Figure 1) is mounted the equipment box, protecting all of the electronics. The box is made of Delrin®, a high-strength polymer that can withstand moderately high temperatures. The equipment box is filled with Fluorinert™, a nonconductive and incompressible fluid used to withstand the high pressure environment in the deep ocean. A flexible membrane filled with additional Fluorinert™ acts as a pressure compensator to fill in any air gaps left in the equipment box.

The equipment box also houses a pump, a servomotor to actuate a four-way valve, and a flow meter. These mechanical components are placed inside the equipment box to provide easier connection with the electronics, while the other less delicate mechanical components are placed outside the equipment box.

On the back side of the chassis (Figure 2) are the remaining mechanical components: a series of pipes and filters constructed of stainless steel. Four commercial in-line filters with decreasing porosity (90, 60, 15, and 7 µm) are used to prefilter the incoming fluid, and a custom-made 0.2 µm filter with a large cross-sectional area is used to trap most of the biology in the hydrothermal vent fluid.

Currently the HVB in development has one set of such filters. In the final version (Figure 3), the system will have three identical sets of filter assemblies arranged in parallel, allowing for multiple sampling opportunities.

The hydrothermal vent fluid enters the system through an intake nozzle located at the system inlet. The intake nozzle is opened and closed by a servomotor (Figure 4). The nozzle is connected to the main HVB system through a flexible hose.
Figure 5 shows a schematic of the fluid flow through the HVB. A four-way valve actuated by a servomotor directs the incoming fluid from the nozzle to either the bypass pipe or one of three filter assemblies.

![Figure 5: Fluid flow schematic](image)

The bypass pipe is used to flush the system to eliminate cross-contamination between samplings. By first pumping fluid through the bypass pipe before actual sampling, fluid from the previous sampling left in the intake nozzle through the four-way valve will be flushed. The four-way valve is then rotated to one of the three filter assemblies to begin sample collection.

While the four-way valve acts to close off the front end of each filter assembly before and after sampling, a check-valve on the end of each filter assembly accomplishes the same on the back end. Each of the check valves is opened only when the four-way valve is aligned to its filter assembly and the pump is turned on. This completes the bio-containment mechanism.

A gear pump driven by a brushless DC motor is strategically located at the back of the system to pull the fluid through the HVB. This is done to protect its mechanisms from the high fluid temperature at the front end of the system, and to eliminate the need to sterilize it. All components from the intake nozzle through the filters need to be sterilized before deployment to ensure the authenticity of the collected samples.

While most of the fluid components (filters, pump, and flow meter) are connected together with stainless steel tubing, several of the connections are made using flexible hoses. These hoses, along with the long flexible hose connecting the intake nozzle to main HVB body, act as pressure compensators to the rest of the fluid-piping system. Under pressure, these hoses would compress, filling in air bubbles trapped inside the fluid system.

A suite of sensors is used to obtain environmental conditions during sample collection. Several high-temperature K-thermocouples are located at the front end of the system to withstand the higher temperature of the vent fluid. A digital thermometer is attached to each of the filters to monitor the condition that the fluid sample goes through. A flow meter at system outlet monitors the flow rate. A pressure sensor gives an indication of water depth.

4 Electronics

The electronics are placed inside the Delrin®-encased equipment box to protect them from the underwater environment. The system is powered with a single 24VDC supply. The power is fed in parallel to the DC motor of the pump and a power converter that provides the main circuit board (Figure 6) with a 12VDC supply. The system draws around 0.2 amps of current while idle. The pump draws approximately 2 amps, and each of the servomotors draws a maximum of 3 amps.

![Figure 6: HVB main circuit board](image)

The main component of the circuit board is the OWL2pe Data Logger from EME Systems, which is built around a BASIC Stamp microcontroller alongside a real-time clock and an analog-to-digital converter. 512K of onboard Flash memory allows measurement data from the sensors to be logged.

The microcontroller communicates with most of the sensors through a serial SPI interface. The DC motor driving the pump is throttled using PWM, while the two servomotors are actuated using a Futaba-compatible control pulse. In order for the servomotors to operate in the high pressure environment, their onboard electrolytic capacitors are replaced with solid capacitors.

5 Software System

The heart of the digital logic is the BASIC Stamp 2pe40. The software, written in PBASIC, has several well-defined tasks. After system initialization, the HVB polls its various sensors for measurement data. The data is logged onto the onboard memory and sent to the control station for display. It then awaits
commands from the operator and performs the appropriate controls such as operating the pump or actuating the servomotors. The program’s first iteration of the loop is now completed, and the system continually repeats the aforementioned tasks.

Figure 7: HVB software flow diagram

The total time needed to poll all the sensors is approximately 2 seconds, while the interval between measurement samples is configurable from 1 to 10 seconds.

Depending on the configured sampling interval, the onboard 512K of Flash memory allows for at least 2 hours of operations to be logged. The entire data log can be streamed to the control station after each sampling operation is completed.

6 Control Station

The control station, a graphical-user-interface (GUI) programmed in LabVIEW (Figure 8), can be run on a typical notebook computer. It communicates with the HVB system through a serial RS-232 interface. The control station displays measurement data from the HVB in virtually real-time. Controls are provided to allow the operator to actuate the pump, and to actuate the servomotors to position the four-way valve and open or close the intake nozzle. A timer function allows the operator to monitor the total amount of filtered fluid.

7 Testing

In order to test the HVB in the laboratory, a pressure tank is used to provide a 100 psi head on both ends of the system. Without the pressure tank, the pump is unable to pull fluid through the filters as the ambient atmospheric pressure is inadequate to overcome the 52 psi of resistance across the filters.

Figure 9: Setup for lab testing

Testing in the lab has shown a satisfactory flow rate of between 200 and 400 mL/min through the filtration system. At this rate, it would take the system 25 to 50 minutes to filter 10 L of fluid. The system was run successfully in the lab for more than 30 minutes with negligible reduction in flow rate.

A series of tests were conducted in the field to subject the system to the environment similar to the ones encountered during deployment in the deep ocean.

Figure 10: Pressure chamber testing

The HVB was tested twice in a pressure chamber (Figure 10) at the Scripps Institution of Oceanography at UCSD between June and August, 2005. The chamber was pressurized to 10,000 psi, analogous to a water depth of 6,500 meters. Most of
the components were verified to be operational. Although the servomotors broke down, their failure was well understood, and they are expected to be functional after minor modifications.

Testing was performed in July 2005 at a 30 ft dive pool at the Monterey Bay Aquarium Research Institute (MBARI). The dive pool testing provides a salt-water environment similar to hydrothermal vents found at shallow depths. It also provides a test bed for establishing the logistics of a dive operation. A flow rate of around 350/mL, comparable to the performance in the laboratory, was achieved. The system was run successfully for half an hour.

In September 2005, the HVB was deployed at a hydrothermal vent off the northern coast of Iceland, near the city of Akureyri. In conjunction with the University of Akureyri, the HVB was tested to a depth of approximately 60 ft, successfully filtering vent fluid reaching 70°C. The vent fluid was sampled for more than ten minutes before the HVB was brought to the surface and the filters recovered. The samples are currently being examined by our Icelandic colleagues and the results being compared to data from prior sampling at the same vent site.

The HVB and all of the tools needed for in-field servicing were brought to Iceland in the normal luggage allowance for two people on-board a commercial aircraft. Because the only required interfaces for the HVB are a 24V DC power line and a single serial link, it has proven to be easy to integrate and adapt to fit various means of deployment (boats, pressure chambers, ROVs, etc.) This was verified by easy setup and low impact that the HVB had on the University of Akureyri’s boat.

8 Future Work

The HVB system is still in the development phase. The current model has only one filter assembly, so work remains to be done to incorporate three filter assemblies in parallel to allow for multiple sampling opportunities. The tests conducted so far are only functional tests to verify the operation of the system. Procedures need to be established for sterilizing the unit and handling the filters to achieve proper bio-containment.

After the system is fully developed, the HVB system is envisioned to travel onboard a research vessel, where it can be deployed by a submersible at a hydrothermal vent in the deep ocean.

9 Summary

The HVB is designed to filter large volumes of hydrothermal vent fluid. The system is designed to operate under the high temperature and high pressure environment at deep ocean hydrothermal vents. Using an intake nozzle to be positioned directly into the hydrothermal plume, and a suite of sensors to monitor the sampling environment, the intake fluid is ensured to be pristine, free of contamination from the surrounding waters. The collected samples are biologically contained using a system of mechanical valves and proper sterilization and handling.
procedures. By performing in-situ filtration of the fluid, a relatively large volume of vent fluid can be sampled and concentrated into a smaller volume more suitable for transport.

Testing in the laboratory and preliminary testing in the field has demonstrated a functional system with a satisfactory flow rate through the filtration system. Further testing and development remains to be performed before the HVB is ultimately deployed at a deep ocean hydrothermal vent.

More information on the HVB project can be found online at:

http://robotics.jpl.nasa.gov/~behar/HydroVentSampler.html

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11 Biography

Alberto Behar has been a member of the Robotic Vehicles Group at the NASA Jet Propulsion Laboratory since 1991. His group designs the rovers and in-situ surface systems for several planetary missions. His previous studies earned him a PhD in EE (Astronautics Minor) from USC, an ME from Rensslelear and an MS with Specialization in Robotics from USC. His primary interests are developing, testing and deploying architectures for planetary surface spacecraft.

Jaret Matthews joined the Robotic Vehicles Group at the NASA Jet Propulsion Laboratory in 2003. He holds a BS in Aeronautics and Astronautics from Purdue University, a MS from the International Space University, and is currently working part-time on a MS in mechanical engineering at Stanford University. His primary interests are in the design, construction, and testing of planetary mobility system concepts.

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12 References

