Optical-proxies of Particulate Iron Formation Kinetics in Hydrothermal Plumes: a Proof-of-concept Study for Future In-Situ Measurements

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Iron flows to the ocean through hydrothermal vents may be similar in size to river inputs. The biogeochemical fate of this hydrothermal iron depends, in part, on how far currents transport it before particulate forms settle out of the water column. Very few measurements of particle size in hydrothermal vent plumes exist. Those that are available suggest that large, iron-containing particles may be present, but their numerical abundance is unknown. Particles also precipitate and dissolve as the hydrothermal plume evolves, such that high resolution observations are required to determine how quickly those processes occur.

Although water samples from within hydrothermal plumes can be analyzed in great detail to determine chemical composition, it is difficult to achieve the necessary spatial resolution, and samples can change during the hours it takes to bring them back to the surface. However, simple commercially-available underwater optical sensors can be used to measure the light-scattering properties of hydrothermal plume particles rapidly and directly at depth. Such optical properties are used routinely as proxies for particle concentration and composition in surface ocean environments but have rarely been rigorously applied in hydrothermal plume environments.

Figure 1: The ac-9 sensor (center), LISST (right edge offscreen) and sampling equipment on the lab bench aboard the ship.

With Ocean Ridge Initiative support, we have carried out a proof-of-concept test of the utility of these sensors in plume environments. We used two sensors, one already available at WHOI and the other on loan from a colleague at the University of Maine, to make measurements of particle light scattering properties at the Piccard Hydrothermal Field in the Mid-Cayman Rise, southwest of Jamaica. The first sensor, a Laser In-Situ Scattering and Transmissometry (LISST) meter, measures the beam attenuation and angle of light scattering which can be used to compute the approximate concentration and size distribution of particles in the water. The second sensor, an ac-9, measures the wavelength-dependent beam attenuation of the particles and can also be used to derive the concentration and particle size distribution (Figure 1). Both of the sensors we used did not carry pressure housings sufficient for use at the nearly-5,000 meter-deep Piccard hydrothermal field, so we used a custom-designed *in-situ* filtration system called the

SUspended Particulate Rosette (SUPR) sampler to bring hydrothermal plume water up to the surface for optical and chemical analysis aboard the ship (Figure 2).

The Piccard Hydrothermal Field is a high-temperature "black smoker" (Figure 3). While others have reported finding large sand-grain-sized particles at similar types of vents elsewhere in the ocean, our measurements suggested that such particles were rare in this plume, or at least not numerically abundant enough that we could detect them. Instead, we found particles mostly smaller than 30 microns in size, which implied that the extremely fine-grained, iron sulfide "black smoke" particles could be transported a great distance from the vent, perhaps dissolving in the oxygen-rich deep water along the way.

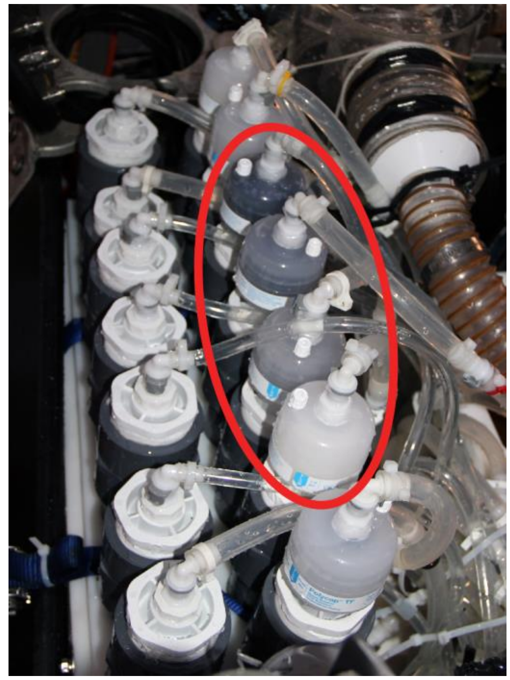

Figure 2: Sample filters on the SUPR sampler after returning from a dive to the vent site. The dark color of some of the filters is due to iron-containing particles filtered out of the plume.

This was also a fruitful study in that it forced us to identify the most important deployment design parameters to consider as we utilize optical sensors for broader applications near hydrothermal plumes. For instance, although it did not impact our measurements in this project, we realized that the "Schlieren effect" (the shimmer around hot fluids) at 350°C vent orifices might impact light scattering measurements! We now have identified several possible solutions to this problem. Future work will move toward *in situ* uses for these sensors, and especially validation of the optical proxies for particle size and concentration.

Figure 3: Beebe Vent #4 at the Piccard Hydrothermal Field, Mid-Cayman Rise, just before our samples were collected.

This study provided new insight into hydrothermal plume chemistry and demonstrated the feasibility of rapid, *in situ* proxy measurements of particles as they form in vent plumes. We are preparing a manuscript for publication in the peer-reviewed literature, with the goal of better-acquainting the hydrothermal vent plume community with the capabilities of these sensors, as well as presenting our measurements from the mid-Cayman Rise.

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