SWAM: A Submersible Water Activity Meter for Use in Hypersaline Bodies

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Introduction: Water activity (a_w), a metric which describes the availability of water molecules, is often used to characterize habitability. In the exploration of Deep Hypersaline Anoxic Basins, analogs for extraterrestrial saline water bodies, a_w is a key indicator of habitability (Fisher et al. 2021). Assessing the a_w of a sample in situ will be a useful capability for remotely operated undersea vehicles on Earth or on Ocean Worlds such as Europa.

Basic Principles: To directly measure water activity one can measure the relative humidity (RH) of an air cavity in equilibrium with the water body in question (Desai et al. 2021). For example: an RH of 78% would correspond to an a_w of 0.78 at equilibrium. This requires a vapor chamber housing a RH meter and a route for vapor exchange between the chamber and the liquid water. However, contact between water and the RH meter (through splashes and inversion of the device) could be problematic. Therefore, a simple "submerged bubble" with an opening to water at the bottom is not feasible.

Model: To address this challenge, a Submersible Water Activity Meter (SWAM) was created (Figure 1). The cylindrical electronics box is mounted atop the syringe and vapor chamber assembly. The red square represents the RH meter and temperature/pressure sensors while the small hole at the bottom of the vapor chamber holds a water-vapor permeable membrane. The upper end of the syringe body is exposed to ambient water through an opening underneath the electronics box (not visible) for pressure accommodation.

Membrane: To prevent flooding the vapor chamber is enclosed and interfaces with the water indirectly via a semipermeable (Nafion™) membrane. This 2-way tetrafluoroethylene film allows the water vapor to equilibrate between the vapor chamber and the water (Mauritz & Moore 2004). The equilibration across this membrane was tested and indicates that the Nafion™ does not inhibit vapor flow or prevent accurate equilibration, however it may slow equilibration time. Further testing is needed to quantify this effect.

Syringe Design: An earlier design for a non-submersible instrument by Desai et al. (2021) was advanced to include an enclosed vapor chamber that adapts to external pressure via a mobile syringe wall. This syringe is plunged and drawn passively as the instrument moves through differing pressure regimes. The upper side of the syringe is open for water to compress the plunger while the lower side is the mobile upper wall of the vapor chamber. This prevents overpressure at the membrane and reduces strain. Internal and external pressure sensors verify proper syringe movement.

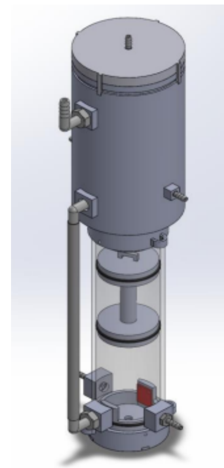

Figure 1: A CAD model of the SWAM instrument prototype.

Fabrication and Testing: The first fabrication and testing of a submersible water activity meter was achieved after less than a month of development. Though not yet rigorously tested, it shows qualitative signs of success. Known failure modes such as leaks will continue to be addressed. Based on the work of Desai et al. 2021, the idea of a submersible water activity meter was conceived and planned (TRL 1). This was then CAD prototyped and built through 3D printing and the use of prefabricated plastics (TRL 2). The RH sensor was then separately validated, similarly to the Desai et al. 2021 work. Meanwhile, the syringe and membrane critical functions were tested (TRL 3). Finally, all components were integrated and subjected to qualitative and semi-quantitative testing in a lab and in a deep artificial pool to verify the pressure-accommodation mechanism. The device was shown to accurately measure a_w through the Nafion membrane and to adapt to pressure while submerged at increasing depth up to 17 feet (pool depth limit).

Future Work: Design changes may be able to reduce the equilibration time significantly. It is expected that the equilibration time decreases as the volume of the vapor chamber is reduced and the size of the Nafion membrane interface with water is increased. A design with a shorter, wider vapor chamber and a larger Nafion/water interface may achieve these goals. Fabrication with more robust materials and better sealing is also needed as depth increases.

References: [1] Desai, P. P. et al. (2021) PSS, 195,105132. [2] Dunbar, B., "Technology Readiness Level," NASA (2021). [3] Fisher, L. A. et al. (2021) Environ. Microbiol., 23,3360-3369. [4] Mauritz, K. A. & Moore, R. B. (2004) Chem. Rev., 104, 10, 4535–4586

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