Development of an Underwater Mass Spectrometer for Dissolved Gases, Solutes, and Large Organic Compounds

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Mass spectrometers generally have extremely high sensitivity, isotopic resolution, and wide dynamic mass range. Field-portable units in particular are considered by many as the ultimate goal of chemical oceanography. However, useful low power and compact instruments capable of field applications, especially autonomous units capable of operating in the deep ocean, have been difficult to develop. This difficulty is due to three basic problems of in situ mass spectrometer use: sample introduction, vacuum maintenance and power consumption. With support from JPL and CEROS (National Defense Center for Excellence in Research in Ocean Sciences) we have largely overcome these problems. We currently have a shallow and deep-water device consisting of an aquatic-based sensor head, vacuum system pressure case and associated electronics (called Mass SURFER). The entire unit fits within a 6.5 inch ID pressure vessel, 68 inches long, and incorporates the Rotating Field Mass Spectrometer (RFMS) developed at JPL. Seawater samples are admitted through on of three different introduction systems. The first is an osmotic membrane boundary and gas-based ionizer. The gas-sampler incorporates a hydrophobic membrane that has been successfully used in the lab to 200 bars hydrostatic pressure and in field deployments on Loihi Seamont off Hawaii Island to 1300-m water depth. The second interface is an on-line capillary nano-electrospray interface (ESI) nozzle capable of high-sensitivity mass spectrometry at nanoliter-per-minute flow rates. The seawater liquid with its load of dissolved gases is directly injected into submersible vacuum chamber. The challenge for this type of interface is clogging by fine suspended particles (course particles can be screened) and salts build-up. Direct seawater injections have produced no significant deleterious effects, but we can incorporate a small dialysis-like tip which for very low flow rates is capable of salt removal approaching 100%. The remaining water plus heavy organics are efficiently injected into the nanospray, which provides a direct liquid/vacuum interface. The third interface system includes a miniature capillary electrophoresis column that can presort large organic materials. Vacuum levels need only be at the millitorr level for a quality measurement, and the complete system nominally draws <10 watts. The RFMS mass resolution of 1 part in 500 is comparable with the best of other small mass spectrometers and it has extremely large analytical mass range (from 1 to >100,000 amu) making it capable of analyzing proteins and DNA fragments. We present recent spectra of seawater and large organic compounds as well as the current development and field deployment status.