EQUILIBAR
PRECISION PRESSURE CONTROL

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Prototype electrolyzer for generating oxygen in space

Background

Flow cell electrolysis is a common way to facilitate a continuous electrochemical reaction while separating products and providing adequate fluid mixing and reactant distribution. In the electrolyzer, a reaction can proceed continuously, while maintaining constant conditions, allowing for analysis of long-term performance.

For spaceflight applications, precedent for using a flow cell electrolyzer has been set by the Oxygen Generator Assembly on board the International Space Station. The assembly uses a flowing water electrolyzer to generate enough oxygen from water to keep up with the crew's metabolic requirements.

Many of the current electrolyzer designs require a downstream gas-liquid separation process, which presents multiple challenges in a microgravity environment. One complication is two-phase flow caused by bubble generation in the electrolyzer: bubbles can cavitate pumps and reduce efficiency of the electrolyzer.

Jordan Holquist, a recent PhD graduate from the University of Colorado at Boulder, proposed an alternative electrolyzer configuration with the objective of high per-pass CO2 utilization efficiency, high-purity gaseous product output, and little to no need for downstream gas-liquid separation of products from the electrolyte. Holquist's design is similar to the fuel cell-type configuration in that a catalyst-coated gas diffusion electrode is used for the cathode, but instead of introducing gas on the backside of the cathode, a coarse vacuum is pulled through an outlet of the gas headspace. The intent of this vacuum is to separate gaseous products through the electrode as they are generated in a process Holquist calls vacuum-assisted product removal (VAPR). VAPR is similar to what is done in differential mass spectrometry, but at a larger scale.

Challenge

Since pressure was one of the two main parameters tested in the evaluation of Holquist's VAPR prototype system, the ability to accurately and reliably control the pressure at the backside of the gas diffusion electrode was critical. The purpose of pressure testing was to observe the pressure at which liquid infiltration of the gas collection headspace would occur in order to determine Pdiff,max, or maximum operating differential pressures. Pdiff,max is a key performance parameter and dictates maximum product gas flow rate through the gas diffusion electrode.

Solution

Holquist was able to use an Equilibar regulator to provide uncomplicated and instantaneous control of the vacuum pressure, making the parametric testing simple and reliable even when dialing in to pressure resolutions down to 0.01 psia. This was possible in part because Equilibar's patented regulator design results in superior precision as well as frictionless control.

After consulting engineers at Equilibar, Holquist chose the EVR-LF2 model vacuum regulator with PTFE diaphragm and Viton O-rings to regulate the vacuum pressure of the gas collection headspace. The Equilibar® EVR-LF2 with ¼" inlet and outlet ports is one of the smallest vacuum models and is useful for low flow upstream vacuum pressure control in research laboratories. An Equilibar QPV electronic vacuum pressure regulator was chosen to pilot the EVR-LF2 in order to easily vary and record the vacuum setpoint for experimental testing.

Also useful was the fact that an inert gas could be introduced to the pilot port of the EVR-LF2 to prevent hazardous concentrations of gaseous products being introduced to the downstream vacuum pump.

> *"With research prototypes and new experimental set ups, it is always difficult to find the exact components you need. Sometimes it is even difficult to figure out the specifications those components should have. The Equilibar application engineers easily interpreted the requirements from my designs to provide a solution that fit perfectly in my application." - J. Holquist*

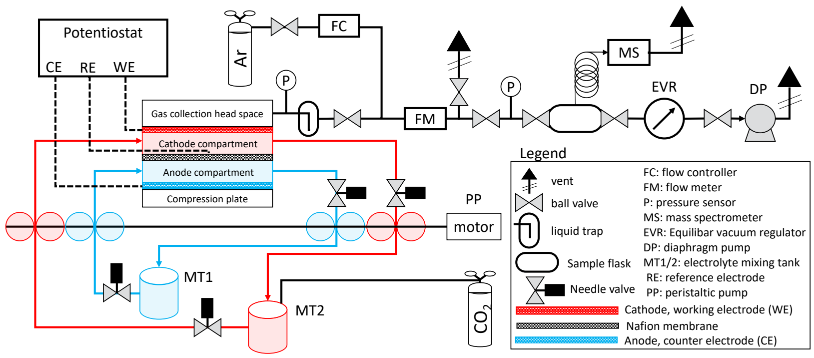

Figure 1. Schematic of electrolyzer prototype

Figure 1 shows a schematic of the electrolyzer support system with the Equilibar® vacuum regulator (EVR) downstream of the gas collection head space, providing precise vacuum pressure control for the VAPR system.

Figure 2 is a photograph of the electrolyzer prototype in the lab. The Equilibar QPV pilot regulator mounted on top of the EVR is visible behind the glass sample flask used by the mass spectrometer as a sample port. The EVR-LF is not visible from this view but is mounted just below the Equilibar QPV.

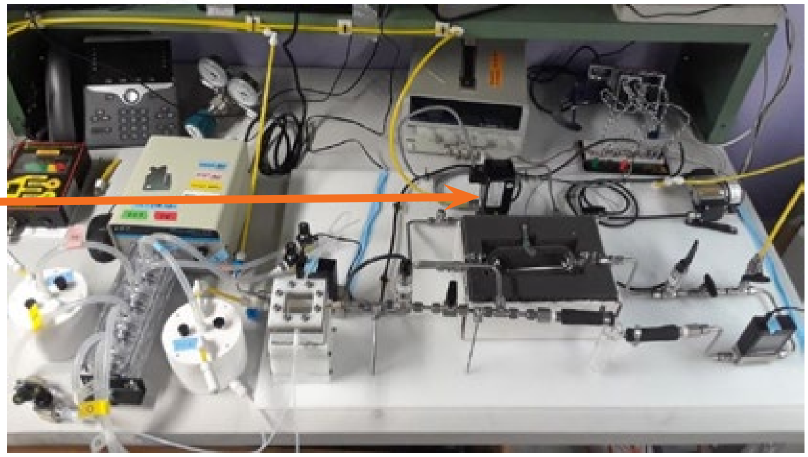

Figure 2. Photo of electrolyzer prototype setup

The plot in **Figure 3** shows an example of the pressure testing of the flow cell electrolyzer. The Equilibar vacuum regulator with the QPV pilot controlled the headspace pressure very closely through a variety of process changes to help determine the performance characteristics of the electrolyzer.

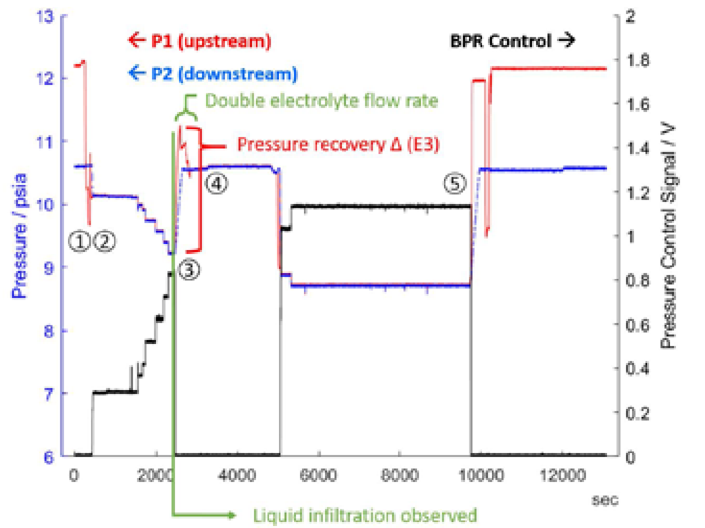

Figure 3. Plot of electrolyzer pressure testing

Application details:

The pressure difference across the gas diffusion electrode (GDE) and the gas permeable membrane was affected by the pressure of the gas in the headspace, the flow rate of the electrolyte (increased flow rate of the electrolyte reduces the pressure on the electrolyte side of the GDE), and the hydrostatic pressure of the fluid on the membrane (based on orientation with respect to gravity). The highest resolution and accuracy of control of that pressure difference was obtained with the Equilibar EVR/QPV, as the peristaltic pump control resolution was fairly coarse and inaccurate, and the orientation could only be changed to allow electrolyte flow perpendicular to gravity or against gravity.

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The EVR/QPV enabled the high-resolution parametric variation of the pressure difference by regulating the vacuum pressure while holding the electrolyte flow and orientation of the electrolyzer constant. That made it possible to dial in to which pressure differences caused breakthrough of the electrolyte, and then quickly back off from those pressures to prevent liquid accumulation downstream where the measurement equipment was. The EVR also damped out oscillations in the pressure due to the downstream diaphragm vacuum pump operation that could have had negative effects on the experiments.

Safety considerations

Working with potentially explosive gases, which are products of the electrolysis process, also brings safety concerns. The equipment for this study needed to be designed to work safely with CO and H2, which could also affect working lifetimes of wetted materials in the flow regulator. The PTFE and Viton wetted parts in the EVR alleviated those concerns. The ability to introduce an inert gas at the EVR pilot port, instead of allowing oxygen from the air in, kept the mixture from possibly becoming flammable/explosive before reaching the diaphragm vacuum pump, which mitigated a big safety concern.

Equilibar advantages for vacuum control

Equilibar vacuum regulators feature a synergistic design that offers multiple advantages, including instantaneous control, high resolution and simple operation. They are dome-loaded and pilot operated for superior computer automation. They are available in materials to meet the needs of the most challenging vacuum environments including aggressive chemicals.

About CU Boulder Bioastronautics Research Group

The Bioastronautics Research Group at the University of Colorado Boulder conducts multidisciplinary research involving the biological, behavioral, and medical factors that govern humans and other living organisms in space flight environment. Research areas include design of payloads, spacesuits, spacecraft habitats, and life support systems. In short, this focus area spans the study and support of life in space. https://www.colorado.edu/bioastronautics/

Contact Equilibar

Equilibar is a provider of unique and innovative pressure control solutions based in Fletcher, North Carolina. Equilibar's patented pressure regulator technology is used in a wide array of processes including catalyst, petrochemical, sanitary, supercritical and other industrial applications. For more information please contact an Equilibar applications engineer at inquiry@equilibar.com or 828-650-6590.

Jordan Holquist is a recent PhD recipient from University of Colorado Boulder Bioastronautics. His Ph.D. research focused on the "Direct Generation of Oxygen via Electrocatalytic Reduction of Carbon Dioxide in an Ionic Liquid," with an emphasis on spaceflight applications. Holquist's previous research at CU Boulder has been in the areas of thermal management and air revitalization technologies. He has been involved in NASA's X-Hab projects, focusing on robotic gardening, space-based greenhouses, and carbon dioxide capture technologies. Holquist is currently studying at the Technical University of Munich, Germany on a Fulbright Scholarship.

Diane Jacober is a Technical Marketing Specialist at Equilibar, LLC, provider of high precision pressure control solutions. She has B.S and M.S degrees in engineering and has worked as a process engineer, project engineer and technical marketing specialist in several industries. Diane can be reached at info@equilibar.com or 828-650-6590.