EQUILIBAR® PRECISION FLUID CONTROL

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Using supercritical water oxidation to destroy toxic waste:

Equilibar's H6P high pressure back pressure regulator provides steady control in extreme conditions to enable important research

Background

Common methods of destroying dangerous chemical waste include incineration to destroy toxic organic constituents and/or disposal in a landfill. Both methods can be problematic. Incineration, for example, reduces the volume and toxicity of waste but still emits flue gas to the atmosphere, which can contain heavy particulates, and produces contaminated ash that must then go into a landfill. Aqueous wastes such as certain chemical warfare agents and the "forever chemical" perfluorooctane sulfonate (PFO) are particularly difficult to destroy because the majority of the waste is water, which the incinerator must heat to destruction temperatures, thereby wasting energy.

Researchers in the Mechanical Engineering Department at the University of Washington are exploring supercritical water oxidation (SCWO) as a safer, less polluting and more energy efficient alternative to incineration of aqueous toxic wastes. The SCWO reactor uses the water within the solution to destroy itself, without producing harmful emissions or ash.

Maintaining reliable pressure control of the SCWO reactor is one of the challenges the researchers face. Because the reactor must operate at supercritical water conditions, a pressure greater than 25 MPa is required. Moreover, pressure must be tightly controlled to provide best data results and operate smoothly and safely. Traditional back pressure regulators (BPRs) often struggle to perform well under these extreme conditions; however, the unique direct-sealing diaphragm valve technology of Equilibar's high pressure research series BPR has proven to be capable of providing steady, reliable pressure control with minimal maintenance or downtime.

The Challenge

Stuart Moore is a Ph.D. graduate student in the Mechanical Engineering Department at the University of Washington – Seattle, where he is a research assistant in the Novosselov Research Group. The group is exploring a vast array of topics associated with SCWO. Not surprisingly, researchers in the group frequently face complex technical problems.

"As this is a developing technology, there are different ideas about how to best design the reactor itself, from materials to geometry and all the minute things in-between," Moore said. "Due to the nature of the system and the substances being destroyed, the reactor is very susceptible to corrosion and clogging. The kinetics, combustion, and fluid dynamics occurring within the reactor during operation are also not well understood. Experimentally, different pilot fuels, oxidants, concentrations, and air-fuel ratios were tested to find the ideal operating conditions."

Due to the system's many complexities and the need to consistently gather comprehensive and accurate data from experiments, reliable pressure control of the reactor is crucial for the researchers' success.

Initially, Moore used a traditional manual twisting, needle, and orifice-style BPR to control reactor pressure. "In some ways, this worked well because it was a standalone unit and did not require the use of an external N2 tank," Moore said. "The device was too sensitive to particulates, however, and would fail regularly. We needed a more robust, high-pressure BPR to handle some particulate flow."

The Solution

To replace the original BPR, Moore worked with engineers from Equilibar to select the research series H6P BPR, which is designed for high pressure applications. They chose a body made of stainless steel with Viton O-rings and PEEK diaphragm. Configured this way, the device is rated for 4500 psi and up to 100° C.

The H6P proved capable of competently handling the small-particulate flow of a mixture of gases and liquid. Moore reports that he has had zero problems and no downtime since switching. By contrast, the previous traditional BPR required occasional maintenance to replace gaskets and clean the orifice and needle.

Below is a schematic of the complex reactor setup.

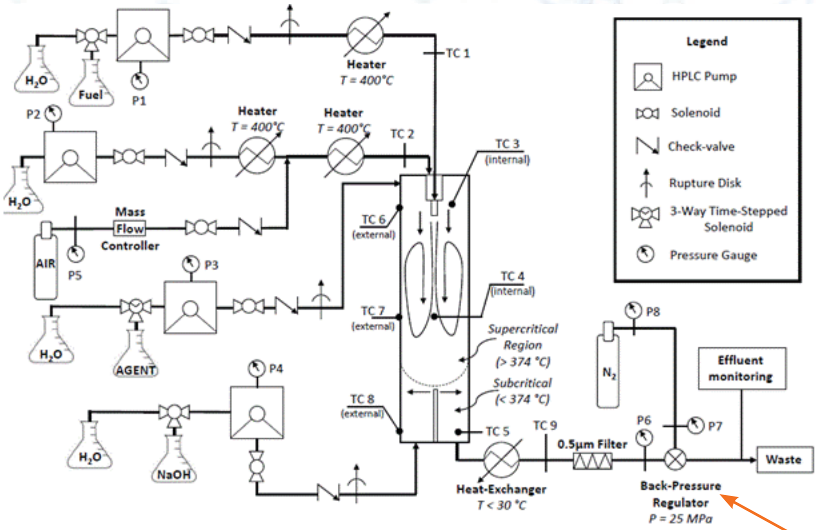

Figure 1. Schematic of Moore's laboratory Supercritical Water Oxidation equipment with Equilibar H6P as the pressure control element for the reactor.

How the H6P Works

Like Equilibar's other patented fluid control devices, the H6P uses a direct-sealing diaphragm technology in which a thin diaphragm covers a field of parallel orifices. Inside the BPR, the diaphragm is positioned between the main body and the reference cap. The main body contains orifices that are covered and sealed by the diaphragm when they are not engaged. The device is controlled with pneumatic pilot operation at a 1:1 ratio, which means that gas or air is fed into the top (dome) area of the BPR to provide the pressure setpoint for the process. The pressure of the gas in the dome is set by a secondary standard regulator called a pilot regulator.

As fluids flow through the BPR, the thin and supple diaphragm lifts off the orifices to release pressure once the setpoint is reached. When flow is minimal, only a portion of one orifice will open. When flow is high, the diaphragm is pushed up to engage more orifices. The responsiveness and flexibility of the diaphragm engaging with the multiple orifices result in an extremely versatile flow rate range. The body, O-ring, and diaphragm materials can be custom selected to handle harsh process conditions such as corrosive chemicals and extreme temperatures.

For process fluids with particulates, the H6P's multiple orifices are especially helpful as they allow multiple flow paths. If one orifice begins to restrict, the remaining orifices compensate for the change in flow to allow for continuously smooth and accurate pressure control.

Figure 2. Equilibar H6P

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The Solution continued

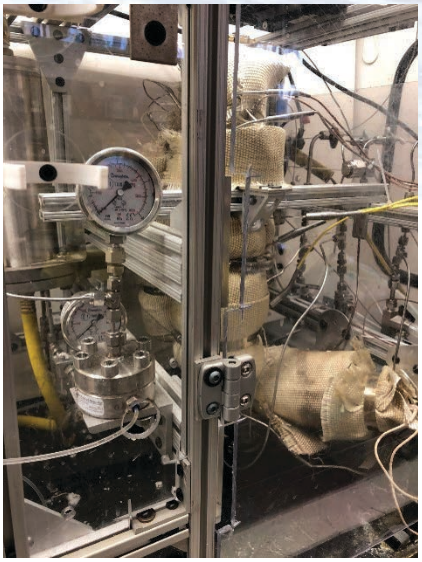


Figure 3. Equilibar H6P back pressure regulator in the SCWO reactor at Novosselov Lab

According to Moore, the HP6 has been in constant use for a year with excellent and reliable performance. "It has been operated with various chemicals and pH levels from very basic to very acidic and has not had any problems," he said. "Once we set the pressure it remains extremely consistent. No change is observed during operation, even when switching between 0 SLPM to 6+ SLPM of airflow and back to zero (the system is constantly running approximately 35mL/min of fluid, mostly water). It also remains consistent during periods when pressure change is expected, like when transitioning to supercritical, and during ignition when a spike in pressure should occur."

This is the second H6P BPR Moore's group has used. The first was used on the same system and worked with no issues but was unrecoverable and incinerated due to possible lethal contamination after testing Sarin (GB) and mustard (HD) through the reactor.

> "*It has operated* with various chemicals and pH levels from very basic to very acidic and has not had any problems."
>
> ***- S. Moore***

Impact

The H6P BPR's success has enabled the Novosselov Group's research, which was originally funded by the Department of Defense (DTRA), and the Army Research Office to show the feasibility of creating a mobile (small-scale) reactor that could successfully destroy mustard (HD) and sarin (GB) gases.

SCWO shows potential to offer multiple benefits over existing technology of destroying toxic waste:

- The process is efficient because the SCWO reactors use the water within the solution to destroy itself. Most of the organic wet wastes involved in the research have a heating value. With the injection of oxygen into the system, the oxidation process of the substances can help sustain the required temperature of the reactor. The added oxidation, coupled with the hydrolysis occurring, speeds up the process, allowing for faster residence times within the reactor to be achieved.
- The gaseous by-product of the SCWO process is CO2 rather than toxic gases.
- No heavy metal-containing ash is produced. Moreover, the system is capable of breaking substances down to basic substances that are not hazardous and require no post-process treatment.
- As with some incinerators, SCWO plants may include energy reclamation—the heat produced can be used to generate electricity and can do so with fewer emissions than coal plants, allowing for an even smaller environmental footprint.

Moore found it helpful to work with Equilibar fluid control specialists to fine tune the pressure control for the reactor. "In a niche market where high-pressure, research-grade equipment is extremely hard to come by, Equilibar had exactly what we needed and, comparably, at a fantastic price," he said. "The experts were extremely knowledgeable in their systems and helpful in ordering exactly what we needed with the parts that would work for the fluids/gases in our system.

"Additionally, during a period when I was attempting to ascertain the reason why the reactor was operating at abnormal pressures, the engineers at Equilibar were again extremely helpful. I thought that perhaps the problem was with the BPR and was advised that I should install a pressure gauge just upstream from the inlet and on the N2 line for troubleshooting, as these should always match if the BPR is functioning correctly. Twenty minutes later, I knew the issue was not the BPR and didn't have to waste time and money disassembling the BPR to clean and troubleshoot. Every reactor with a BPR I have made since has included these troubleshooting pressure gauges."

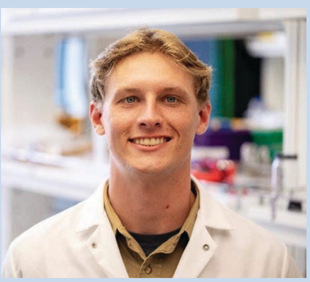
About Novosselov Research Group

The Novosselov Research Group at the University of Washington conducts multidisciplinary research in the areas of combustion, aerosol science, supercritical fluids, and fluid dynamics. https://depts.washington.edu/nrglab/

For more information about the globally important work of the Novosselov Research Group, visit *Researchers Destroy "Forever Chemicals" Using Supercritical Water*, a white paper from ASME

Contact Equilibar

Equilibar is a provider of unique and innovative fluid control solutions based near Asheville North Carolina. Our dome-loaded, multiple-orifice technology is used in a wide array of processes including catalysis, fuel cells, biopharmaceutical, petrochemical, supercritical and other industrial applications. For more information please contact an Equilibar applications engineer at inquiry@equilibar.com or 828-650-6590.



Stuart Moore is a Ph.D. graduate student in the Mechanical Engineering Department at the University of Washington – Seattle. He is a research assistant in the Novosselov Research Group (NRG), led by Professor Igor Novosselov. Moore's research interests revolve around the design, fabrication, and optimization of complex thermal fluid systems, specifically development, improvement, and implementation of a mobile SCWO reactor for the destruction of aqueous wet wastes such as chemical warfare agents and per- and polyfluoroalkyl substances (PFAS).

Simply put, he enjoys working with his hands, tinkering, and solving complex solutions to real-world problems that make the world a better place.