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PRECISION PRESSURE CONTROL

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# Equilibar Plays Key Role in Research of Enhanced Oil Recovery Using Carbonated Water Flooding

### Dome loaded regulator holds pressure under extreme testing conditions at the Technical University of Delft

## Background

Researchers at the Technical University of Delft in The Netherlands are exploring a novel method of using Carbonated Water Flooding to increase the amount of oil that can be recovered from sandstone reservoirs and to improve the environmental impact and safety of the oil extraction process. As part of this endeavor, they used an Equilibar® back pressure regulator that is able to withstand harsh process fluids and operate in the high pressure range while also holding pressure at low flow to practically zero flow rates.

## Enhanced Oil Recovery Research

Studies have shown that as much as 60 percent of oil remains in oil fields after primary and even secondary extraction methods have been used. Finding efficient and environmentally responsible ways to recover this valuable energy source is the focus of Enhanced Oil Recovery (EOR) research. One of the most promising EOR techniques is $CO_2$ flooding, which involves using $CO_2$ to push the remaining oil into an accessible position. $CO_2$ flooding is economically feasible but presents challenges due to the high mobility, low density and viscosity of $CO_2$ compared to reservoir oil, resulting in flow instabilities such as viscous fingering and gravity tonguing.

Anna Peksa, a PhD researcher in Delft's Department of Petroleum Engineering, is studying Carbonated Water Flooding (CWF) as an alternative method of $CO_2$ flooding. CWF has the potential to eliminate many challenges while also improving the total recovery of oil from waterflooded sandstone reservoirs. An additional benefit of CWF is the ability to combine oil recovery with underground storage of carbon dioxide, reducing harmful $CO_2$ concentrations in the atmosphere.

To date, CWF has been under-investigated, highlighting the importance of Peksa's efforts. Research goals include developing a more efficient use of carbon dioxide, slower $CO_2$ breakthrough, and an acceptable sweep efficiency due to viscosity differences. Peksa's research also offers a new method for mitigating the harmful effect of greenhouse gases through the permanent and safe disposal of $CO_2$.

## The Problem

As detailed below, an important element of Peksa's research requires using a back pressure regulator that is compatible with a range of process fluids and is also able to operate in the high pressure range. In this complex application, the Flow Coefficient (Cv) required from the back pressure regulator changes depending on the variation of process fluid that occurs during testing. An additional challenge is that the unit must hold pressure at very low to practically zero process flow rates.

Since traditional regulators need at least some flow to keep the unit in an active precision control state, Peksa and fellow researchers determined that they would need to find a completely different technology to provide stable pressure control.

## Research Details

An important aspect of the Carbonated Water (CW) and $CO_2$ research focuses on the role of molecular diffusion of $CO_2$ into oil. Researchers are investigating oil swelling as a result of $CO_2$ diffusion by monitoring the process in a high-pressure glass dead-end pore tube, which mimics recovery of residual oil after water flooding. In addition, the study compares the diffusion process in pure $CO_2$ flooding and in CWF for better understanding of both processes.

a)

b)

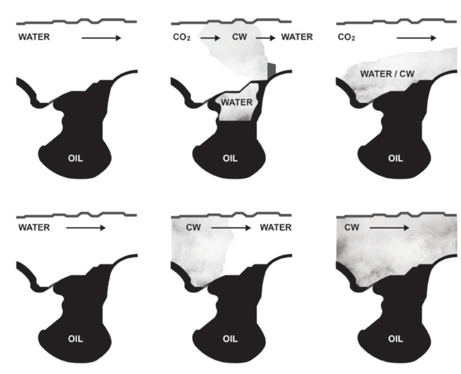


Figure 1: Example of an oil trapped in a dead-end pore introduced to a) flowing carbonated water after water flooding b) $CO_2$ that diffuses through the water barrier creating "unstable" carbonated water (Peksa et al. 2013)


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To study the diffusion of $CO_2$ into oil, researchers conducted a series of displacement experiments using a high-pressure dead end pore glass tube, a Quzix™ injection pump for water injection and peripheral P, V equipment to acquire the mass balance data (Figure 2). For flooding experiments, the flow system was additionally equipped with a double acting cylinder connected to the pump while $CO_2$ injection experiments used a double ISCO pump connected to a booster and $CO_2$cylinder. Additionally, a back pressure regulator was installed that maintained stable PT conditions for the equilibrated Carbonated Water solution and $CO_2$ flow.

The procedure for each experiment is a delicate series of actions:

1. A vacuum is created in the system.
2. Oil is injected until the glass bubble is filled.
3. Remaining oil in the tube is replaced by water until all oil outside the bubble has been removed and no air bubbles are present.
4. The system is pressurized with water to operational conditions.
5. The injection is switched to CW coming from the double acting cylinder (for CW experiments) or $CO_2$ coming from the ISCO pump (for $CO_2$ experiments).

To create flow, the pressure in the $CO_2$/ $H_2O$ cylinder (or ISCO pump) is kept slightly higher than in the glass tube so that the flow starts in the tube with rates of 0.25, 0.5, 1 ml/min, depending on the experiment. To make the interface of the fluids more visible, oil is dyed red. The Carbonated Water solution is prepared by filling a cylinder with 80 vol. % of water and then introducing pure $CO_2$ into the pressurized system. It is mixed by a magnetic stirrer until reaching equilibrium at the specified operational conditions. The displacement experiments are conducted at operational pressure between 30 and 105 bars, with temperatures between 20 and 55°C.

As Figure 2 shows, the multiple demands of the experiment present significant pressure control challenges.

## The Solution

To address the application's complex set of pressure control demands, researchers tried using standard nitrogen back pressure regulators with Viton membranes. These regulators caused obstructions to flow, which resulted in disturbances in the regulated upstream pressure during the low pressure CW and $CO_2$ tests. Additional problems arose when high pressure $CO_2$ and CW were injected and the unit failed to maintain

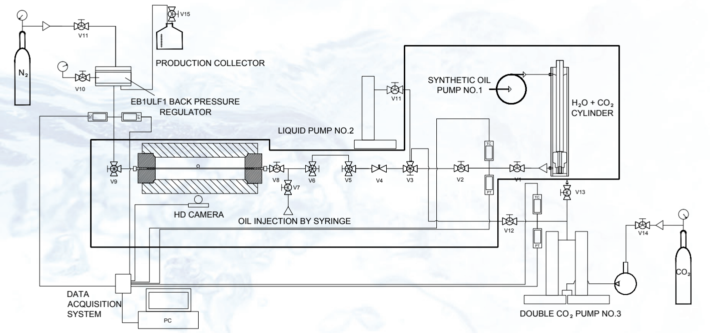



Figure 2: Schematic description of the experimental set up for study on molecular diffusion of $CO_2$ from $CO_2$ source into the oil

pressure. This required researchers to exchange membranes every time a new test was run. In some cases the test required several back pressure regulators in series to reduce the pressure drop across the units.

Peksa and her colleagues contacted Equilibar engineers about using a dome-loaded back pressure regulator. Unlike traditional back pressure regulators, Equilibar's dome loaded back pressure regulators are designed to use a flexible and frictionless diaphragm as the only moving part. This design allows the Equilibar to accurately maintain stable pressure over a wide range of flow rates.

For Peksa's two- phase oil recovery application, Equilibar engineers recommended the Research Series model number EB1ULF1 unit . The unit was provided with four diaphragms in varying materials, to determine which was best suited for this application's unique challenges.

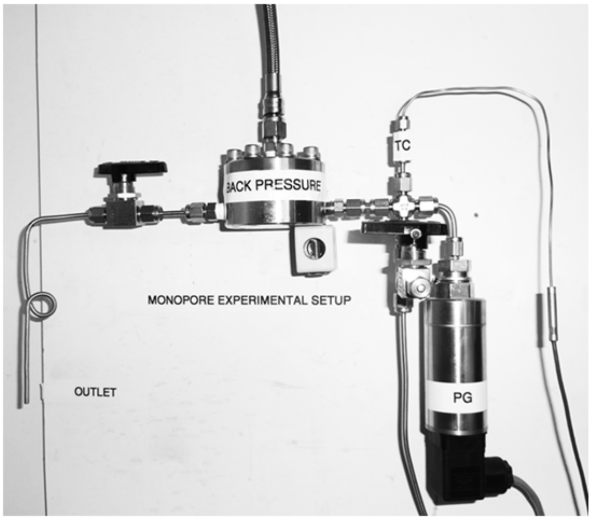



Figure 3: Back Pressure Regulator EB1ULF1


Figure 4: Diaphragms used in in the flooding research. 1) Buna 60 2) SS316 3) Polyimide 4) PTFE/Glass Laminate Composite or PGL

## Diaphragm Selection

The application at Delft uses three types of fluids: (1) water/brine, (2) carbonated water, and (3) carbon dioxide (in gaseous, liquid and supercritical state). Of the four diaphragms provided by Equilibar, the polyimide offered the best overall performance, operating at a range from 30 to 100 bars with all three operational fluids. This diaphragm performed well for six months of experiments (conducted for 50 to 90 percent of the week) before showing signs of wear. This was noticed during start up when the flow stabilization started to be inconsistent. The membrane held pressure at 90-95 bar with a pilot signal of 100 bar (see figure 5-7). With the flow at a constant rate, the pressure would be stable over the length of the test.)

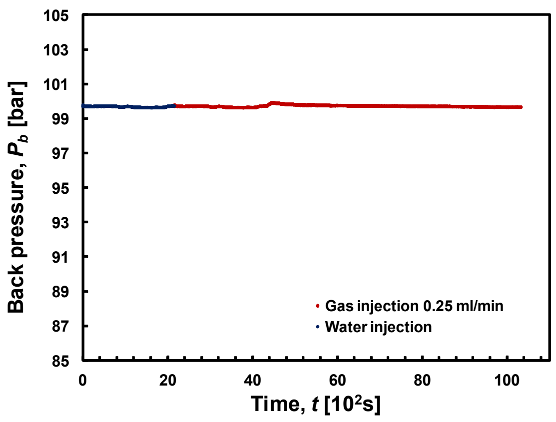
Membrane no. 2, SS316, was used during trial tests with carbon dioxide and carbonated water. Problems with the injecting cylinder caused particulates in the system and required the researchers to dismantle the test stand and clean each component. Performance of membrane no. 1, Buna, performed well during injection of water , carbonated water, and $CO_2$ in gas and liquid states at lower pressure range (up to 75 bar); however with liquid and supercritical $CO_2$, it developed leaks and was not able to precisely control upstream pressure. One hypothesis is that the higher pressure could have caused permeability through the rubber and reinforcing nylon. Diaphragm no. 4, PTFE/Glass (PGL), worked well during water injection and pressurization but failed when injection was switched to $CO_2$.

## Summary

Because of its novel design using a diaphragm as the only moving part, the Equilibar® back pressure regulator with a polyimide diaphragm was best able to meet both the low flow rate, high pressure, and phase change conditions encountered in this Carbonated Water Flooding testing. Researchers are also able to choose from different types of diaphragms to best meet the needs of this complex application.

Equilibar's Research Series of regulators is tailored for scientists with demanding pressure control challenges. Equilibar application engineers have extensive experience with reservoir core analysis, core flooding, slim-tube testing and other related fields of research. For more information visit. http://www.equilibar.com/application/reservoir-core-analysis/ or call 828.650.6590.

## Additional Data



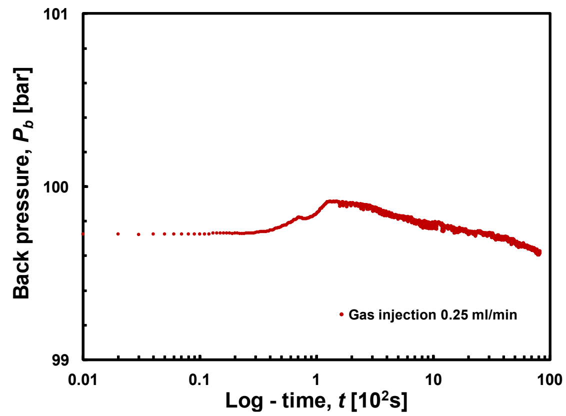




Figure 5a and 5b: Experimental conditions: back pressure at pressure 100 bar, temperature 35° C. (a) Back pressure over whole process - first degas water injection 1ml/min, then $CO_2$ injection; (b) Back pressure fluctuations during $CO_2$ injection with flow rate 0.25 ml/min. (Membrane no. 3)



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## Additional Data Continued

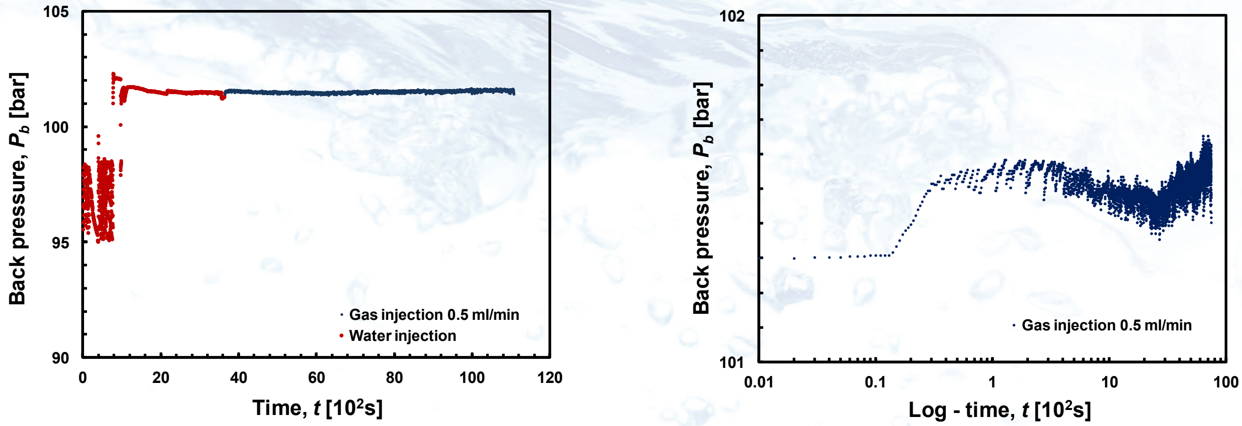


Figure 6a and 6b: Experimental conditions: back pressure at pressure 100 bar, temperature 35° C. (a) Back pressure over whole process - first degas water injection, then $CO_2$ injection; (b) Back pressure fluctuations during $CO_2$ injection with flow rate 0.5 ml/min. (Membrane no. 3)

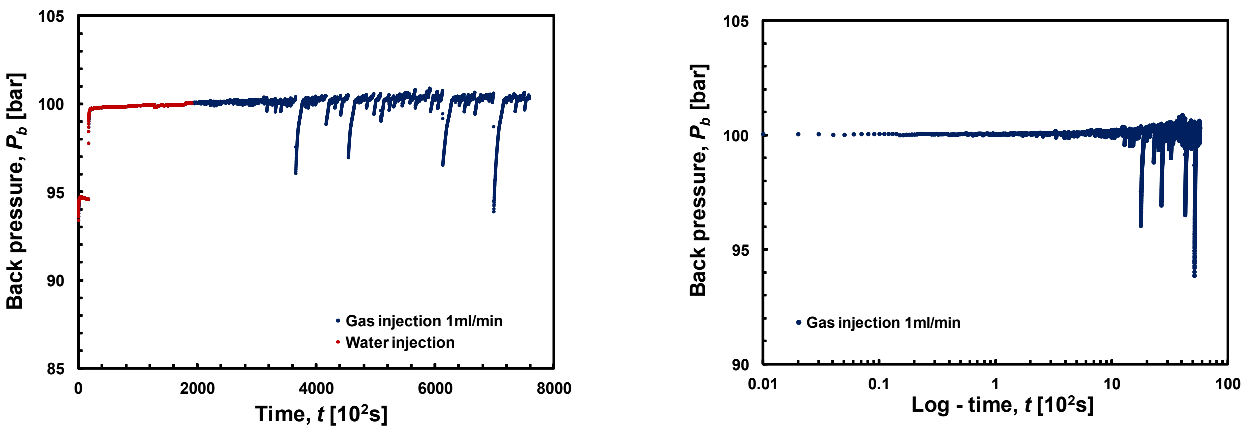


Figure 7a and 7b: Experimental conditions: flow rate 1 ml/min, back pressure at 100 bar, 35° C. (a) Backpressure over whole process - first degas water injection, then $CO_2$ injection; (b) Backpressure fluctuations during $CO_2$ injection with flow rate 1 ml/min. (Membrane no. 3)

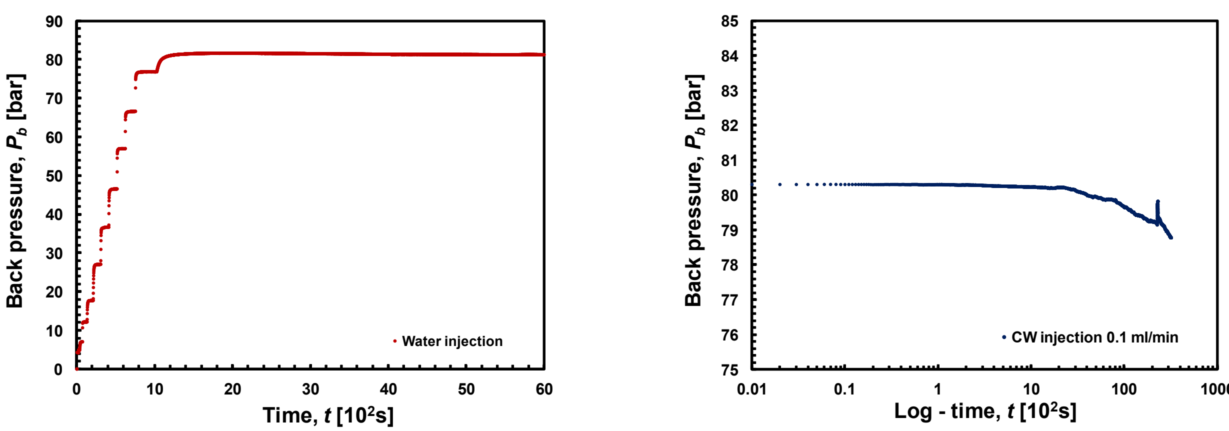


Figure 8a and 8b: Experimental conditions: back pressure at 80 bar, 35° C. Carbonated water injection experiment (a) pressure build up and back pressure stabilization. (Membrane no. 3)



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## Contact Equilibar

Based in North Carolina, Equilibar provides unique and innovative pressure control solutions for applications around the world. Their back pressure technology is used in a wide array of processes including catalyst, petrochemical, supercritical and other industrial applications. For more information please contact an Equilibar applications specialist at www.equilibar.com, 828.650.6590 or inquiry@equilibar.com.

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