Application Note

Measuring the Liquid Volume in a Flexible Bioprocess Container with PendoTECH® Single Use Pressure Sensors™

Abstract

PendoTECH has recently developed a novel Single Use Pressure Sensor with a new form factor for use in flexible bioprocess containers. In order to validate this sensor for measuring the liquid volume in a flexible bioprocess container, PendoTECH performed an experiment that simulates actual end-user usage. The sensor was installed on the bottom of a 200L 2D bag, supported by a custom tote, and connected to a PendoTECH High Resolution PressureMAT® Sensor Monitor. The sensor at the bottom of the bag measured the pressure exerted by the water in the bag as it was filled. The pressure reading at specific fill points was then converted to a theoretical liquid level, which was compared to the actual liquid level in the bag as measured with a caliper. The theoretical liquid level was within 2% of the actual liquid level at all points and the average error was less than 1%. This experiment demonstrates that PendoTECH's single use pressure sensor can be a valuable, low cost, convenient tool for measuring the volume in flexible bioprocess containers.

Introduction

PendoTECH's novel Single Use Pressure Sensor was specifically designed for monitoring pressure in flexible bioprocess containers in both gas and liquid applications. The actual pressure sensing technology is the same as PendoTECH's existing inline pressure sensors. The most significant difference with this product is its form factor, which makes it easy to integrate with almost any flexible bioprocess container. The sensor connects to a bioprocess container via a custom PendoTECH port plate welded into the container, and uses a special locking ring to secure it in place.

Figure 1: Image of a PendoTECH's Single Use Pressure Sensor connected to a PendoTECH custom port plate

The novel design of PendoTECH's pressure sensor makes it valuable for several applications, including monitoring pressure in a disposable bioreactor and integrity testing of single use systems. Most notably, this sensor can be used to accurately measure the liquid height or level of a fluid in a bioprocess container, which can then be used to calculate the volume in the container. This application is especially useful for buffer and media storage bags, where volume measurements otherwise require a scale/load-cell that can expensive and difficult to integrate. The ability to determine the liquid level from the pressure in the bag is based on Pascal's Principle. Pascal's Principle states that in a static environment, the depth of a liquid generates a force that is directly proportional to the height of the liquid. This principle can be represented by Equation 1 below, where ΔP is the hydrostatic pressure, ρ is the fluid density, g is the acceleration due to gravity, and Δh is the height of the liquid.

Equation 1: $$\Delta P = \rho g(\Delta h)$$

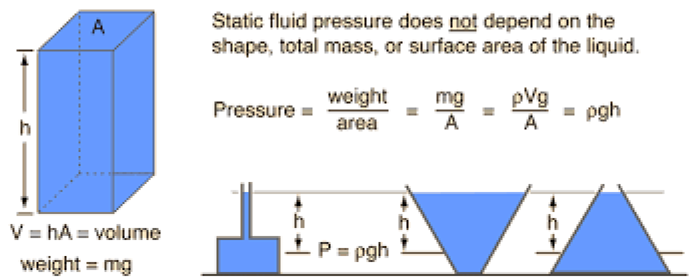

Figure 2: Sample diagram explaining Pascal's Principle

Since gravity and fluid density of a specific liquid will always be constant in this application, the pressure in the bag will be solely dependent on the liquid height or level. Using the geometry of the container, once the height is known, a simple calculation involving the cross-sectional area can be used to determine the volume of liquid present.

In order to accurately determine the liquid level in a bag via a pressure measurement, there are two important requirements: locational accuracy (the physical location of the sensor), and the accuracy and resolution of the pressure reading in low pressure ranges. A water column of 1 inch correlates to only 0.036 psi (0.0025 bar), therefore, even minimal error can significantly impact the reading. The sensor port must be installed directly on the bottom of the bag, otherwise the measured pressure will not correspond to the actual liquid level in the bag. Additionally, the application's stringent accuracy and precision requirements is the reason that PendoTECH recommends pairing its single use pressure sensors with a High Resolution PressureMAT Sensor Monitor (models PMAT2HR or PMAT-SHR). These monitors excel in low pressure applications because of their optimized zero offset stability, or level of variation of the lowest measured reading when compared to a perfect reading. High resolution monitors have a zero offset stability of only ± 0.003 psi, which is 10x better than other models for higher pressure applications. This feature greatly enhances the monitors performance and resolution at low pressures, which makes it excellent for use with flexible bioprocess containers. PendoTECH has previously validated and published on its sensor performance at low pressures when used with a High Resolution PMAT:

http://www.pendotech.com/wp-content/uploads/2019/10/BPI_Low_Pressure_Measurement.pdf

A Lot 1131340 — Irradiation Level 27.5–33.0 kGy (low)

Gauge Pressure (psi)	Sensor # 1	2	3	4	5	Group Average	Standard Deviation	Relative Std. Dev.
−0.500	−0.502	−0.501	−0.500	−0.498	−0.501	−0.500	0.0015	0.30%
−0.250	−0.253	−0.250	−0.251	−0.250	−0.251	−0.251	0.0013	0.52%
−0.100	−0.101	−0.101	−0.100	−0.100	−0.100	−0.100	0.0005	0.55%
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.00%
0.050	0.050	0.049	0.050	0.050	0.051	0.050	0.0004	0.90%
0.100	0.100	0.099	0.100	0.100	0.101	0.100	0.0004	0.45%
0.150	0.149	0.150	0.149	0.150	0.151	0.150	0.0005	0.37%
0.200	0.200	0.200	0.199	0.200	0.201	0.200	0.0004	0.22%
0.250	0.250	0.249	0.249	0.249	0.251	0.249	0.0005	0.22%
0.500	0.500	0.500	0.500	0.498	0.502	0.500	0.0009	0.18%
1.000	1.000	1.004	0.999	0.997	1.005	1.000	0.0025	0.25%
2.000	2.007	2.006	2.003	1.999	2.012	2.003	0.0035	0.18%

Table 1: Sample data table depicting low pressure performance of PendoTECH pressure sensors with a high resolution monitor from *BPI* article

Experimental Procedure

The experiment was conducted using a custom 200L 2D bioprocess container with a PendoTECH Port Plate (PN: PORT-PRESS-T) welded to the bottom (courtesy of Saint-Gobain S.A.). The bag was supported by a 200L tote, which was modified to have cascading slits cut along the height of the container so that the liquid level in the bag could be easily measured and a 2" diameter whole cut out at the bottom to accommodate a PendoTECH sensor and cable (Figure 3). A PendoTECH single use pressure sensor (PN: PTPL-PREPS), designed for use in flexible bioprocess containers, was installed in the port at the bottom of the bag with a locking ring (PN: PORT-RING) to secure it in place. The sensor was properly placed so that it was flush with the bottom of the bag (Figure 3), which is crucial because the accuracy of the liquid level measurement is dependent on the location of the pressure sensor. The sensor was connected to a PendoTECH High Resolution PressureMAT Sensor Monitor (PN: PMAT2HR) to measure the pressure in the bag, and tared at atmospheric pressure prior to filling up the bag with water.

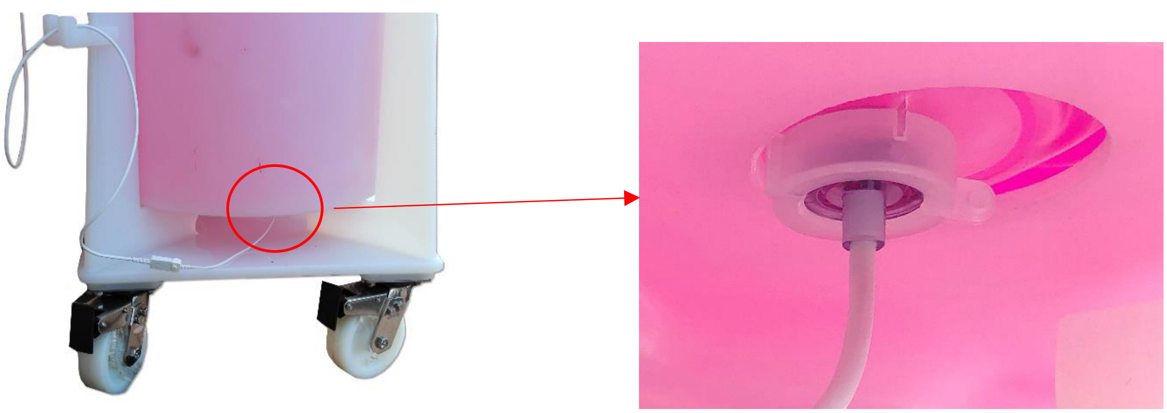

Figure 3: Location of the PendoTECH Single Use Pressure Sensor on bioprocess container

Once the bag and tote were completely setup, the fill-up process began. The water used to fill up the bioprocess container was dyed with a colorant to further facilitate the physical measurement of the liquid level. With the dyed water, it was possible to identify the meniscus of the liquid level through the slits on the side of the tote. Liquid level measurements were taken approximately every 0.15 to 0.20 psi (4 to 6 inches of water). These measurements were made with a large caliper through the slits cut into the side as seen in Figure 4 on the right. The theoretical liquid level was calculated using the actual pressure reading recorded on the PMAT2HR (1 psi = 27.7076 inches of water). The approximate volume in the bag was then calculated using the equation for the volume of a cylinder, $V = \pi r^2 h$, where h was the measured liquid level. Although, there was no reference volume measurement made for comparison, the calculations were made to demonstrate the application. This was repeated until the bag was nearly filled with water.

Figure 4: Image of the filled bioprocess container (left) and a measurement being made (right)

Results

Shown in Table 2 are the pressures exerted on the sensor at the bottom of the bag recorded on the PMAT2HR, the corresponding theoretical liquid level, the actual liquid level measured with a caliper, the calculated percent error between the liquid levels, and the calculated volume. The theoretical and actual liquid level measurements were nearly identical, differing by an average of less than 1% across all points. The largest recorded error occurred at a pressure of 0.920 psi, where the actual measurement was 0.39 inches greater, resulting in a percent error of 1.53%, which is within PendoTECH's pressure sensor accuracy specification of ± 2% of reading. Conversely, the most accurate data was collected at a pressure of 0.620 psi, where the actual liquid level was only greater than the theoretical by a hundredth of an inch, or 0.06%. As demonstrated in Figure 5, the results were also almost perfectly linear, which is expected per Pascal's Principle.

Bag Pressure Measured (psi)	Theoretical Liquid Level (in Aq)*	Measured Liquid Level (in Aq)*	Percent Error	Calculated Volume (L)
0.305	8.45	8.54	1.07%	53.2
0.451	12.50	12.56	0.48%	78.2
0.620	17.18	17.19	0.06%	107.1
0.769	21.31	21.27	0.19%	132.5
0.920	25.49	25.88	1.53%	161.2
1.13	31.31	31.54	0.73%	196.5

**in AQ refers to inches of water*

Table 2: Theoretical vs Actual Liquid Level Measurements

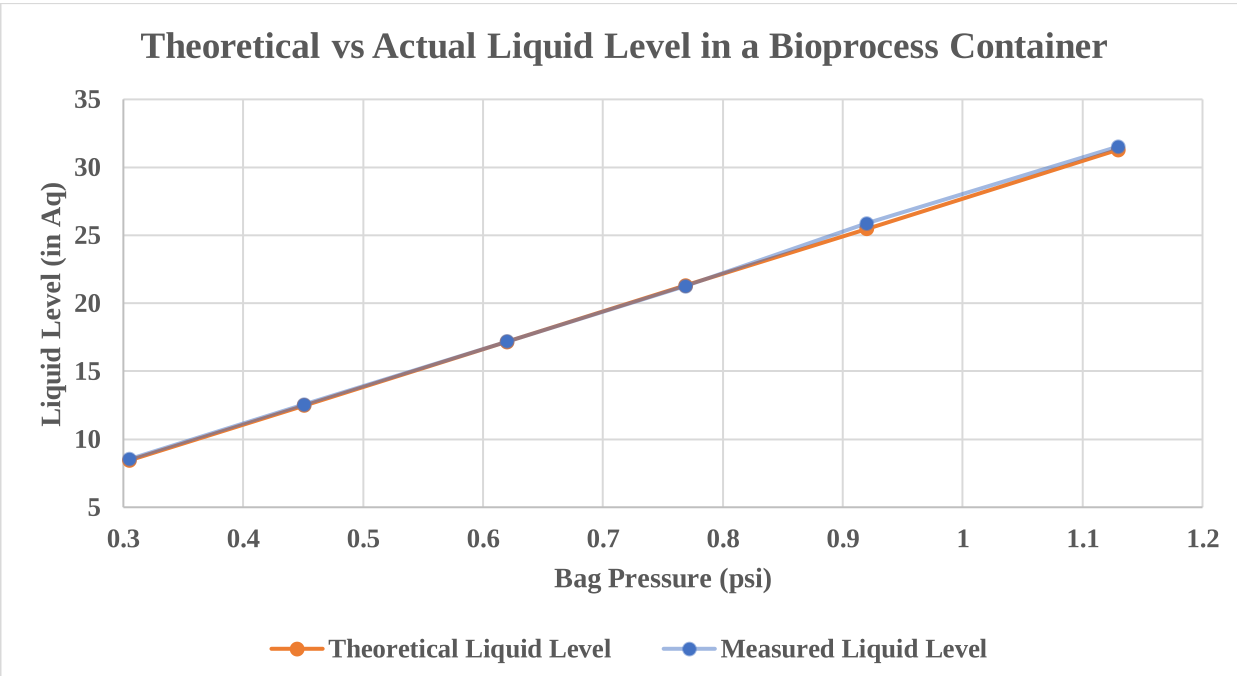

Figure 5: Theoretical vs Actual Liquid Level Measurements

Additionally, an experiment was carried out to preliminarily assess the accuracy of the volume measurement calculated from the pressure reading. During the experiment, the bag was filled to the 160L graduation mark on the tote. While this is not a calibrated measurement, the reference mark allowed for a qualitative comparison. The measured liquid level at this point was approximately 26 inches, which corresponded to a volume of approximately 166L. The less than 4% difference between the volume calculated from the pressure reading and the tote's reference point is readily explained by the qualitative nature of this experiment. Although preliminary, these results suggest that the calculated volume is within a reasonable range of the actual volume. These results will also serve as a precursor to future volume accuracy validation.

Conclusion

All of the data collected was well within PendoTECH's sensor accuracy specification of ± 2%. This indicates that pressure measurements made by PendoTECH's sensor with a High Resolution PressureMAT Sensor Monitor can determine the actual liquid level, and therefore the volume, in a bioprocess container with extreme accuracy. Future experiments will involve measuring the actual volume of water used to fill the bag (as opposed to just the height) as this will reduce any measurement error in the experiment and better simulate actual customer usage.