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Effects of Pump Pulsation on Membrane Filter Retention

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Abstract

Hydraulic shocks caused by flow stoppages through microporous membrane filters have been shown to dramatically increase particle release from the filters. The magnitude of the release can be mitigated by techniques like Stabilized Distribution™ [1]. In Stabilized Distribution™, a minimum flow rate is always maintained through system filters to minimize particle release. Changes in the flow rate through a filter have also been shown to affect filtrate particle concentrations [2].

This experiment was undertaken to determine if pump induced flow pulsations also affect filter performance. Three types of pumps (diaphragm, bellows, and centrifugal) with varying degrees of pulsation were tested at similar average flow rates and backpressures. The magnitudes of the flow pulsations from each pump were measured at all test conditions. Particle retention by two different types of 0.1 μm membrane filters was also characterized as a function of pump pulsation intensity. Particle retention decreased with increasing pulsation intensity.

Introduction

Various types of pumps have been used in bulk chemical delivery systems, recirculating etch baths (REBs), and other high purity process applications. Many of these pumps (i.e. bellows, diaphragm, etc.) create flow pulsations that may impact the performance of the filters used in the process loop. This experiment was undertaken to quantify the magnitude of pump-induced flow pulsations in three pump systems and to correlate those pulsations with filter retention. It was assumed that flow pulsations were directly related to pressure variations. Hence, a fast response pressure transducer was used to quantify the magnitude of the flow pulsations. Although a flowmeter could have been used for these measurements, flowmeters generally have much slower response times than pressure transducers and likely would be too slow to adequately monitor the flow variations.

Filter performance was determined by measuring the retention of monodisperse polystyrene latex (PSL) spheres with two types of 0.1 μm membrane filters. Filter retention was characterized at three flow rates for each type of pump.

A bellows pump, a diaphragm pump, and a centrifugal pump were tested. In some applications, pulsation dampeners are used to minimize the effect of the pulsations on the system. In this test, pulsation dampeners were not utilized to determine the impact of flow pulsations on filter performance under worse case conditions.

Experimental Procedure

Retention Measurements:
A schematic of the test system is presented in Figure 1. A Levitronix BPS-3 pump was used to circulate water through dual 10” 0.1 μm Mykrolis filters. These filters provide a continuous feed of low particle (<0.2/ml ≥ 0.12 μm) deionized water to the pumps being evaluated.

Filter retention measurements were made by injecting monodisperse PSL spheres into the flow stream upstream of the pump being evaluated. The PSL challenge solutions consisted of particle sizes ranging from 0.1 to 0.5 μm in diameter. Particle retention measurements were conducted at flow rates of 5, 7.5, and 10 gpm with a backpressure of 20±2 psig. Particle concentrations were monitored upstream and downstream of the test filter during each particle injection. In addition, upstream and downstream background measurements were made prior to and after each particle injection test to ensure that particle concentrations were adequately low to perform the particle challenge. Two different 10" filters were tested during this evaluation (see Table I): a Mykrolis 0.1 µm Etchgard HPX and a Pall 0.1 µm Ulti-Etch filter. The filter face velocities ranged from 1-4 cm/min. The particle concentrations were monitored with a Particle Measuring Systems HSLIS S-100. This spectrometer is capable of measuring particles from ≥ 0.1 - ≥ 1.0 µm over 16 size channels. The retention efficiency of each filter was calculated for each pump at each particle challenge size.

Figure 1. Test system schematic

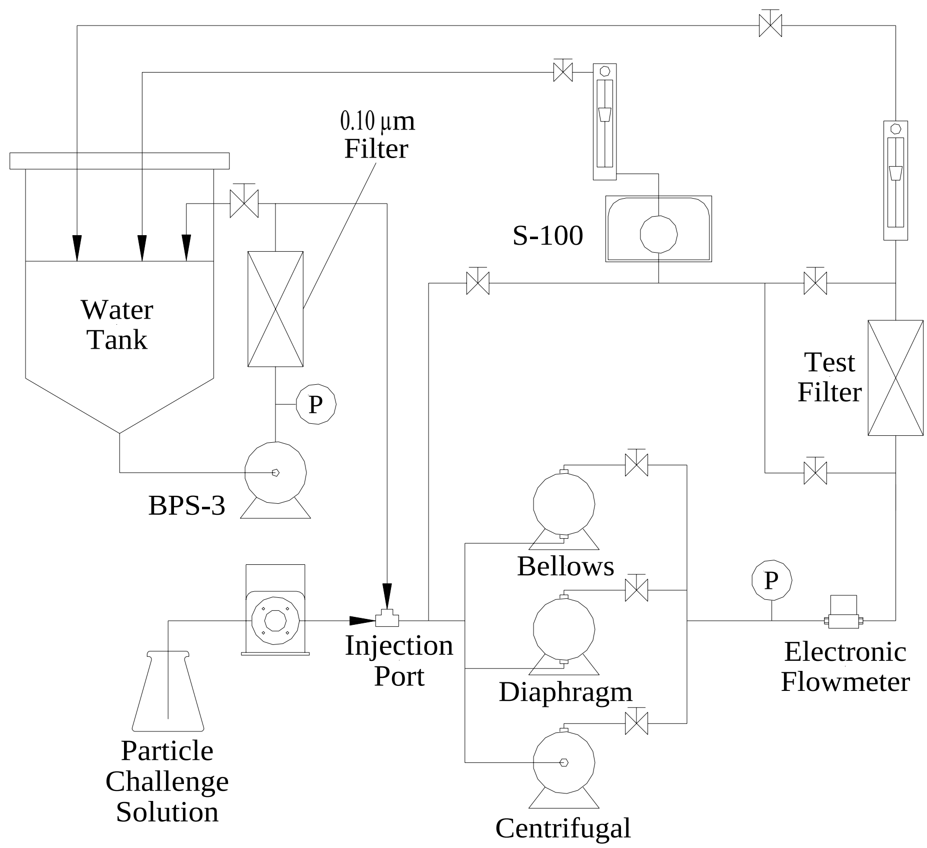


Table I. Specifications of the two filters

Manufacturer	Filter	Pore Size	Membrane Material
Mykrolis	Etchgard HPX	0.1 µm	ultra high molecular weight polyethylene
Pall	Ulti-Etch	0.1 µm in recirculation mode	PVDF

In this report, filter retention data are expressed as the filter log reduction value (LRV). The LRV is defined as:

$$LRV = \log_{10}((C_I - C_{BI}) / (C_O - C_{BO}))$$

where:

C_I = particle concentration at the filter inlet during particle injection
C_{BI} = background particle concentration at the filter inlet after particle injection
C_O = particle concentration at the filter outlet during particle injection
C_{BO}= background particle concentration at the filter outlet prior to particle injection

The relationship between LRV and filter retention efficiency is shown in Table II.

Table II. Relationship between filter retention efficiency and LRV

LRV	Filter Retention Efficiency (%)
1	90
2	99
3	99.9
4	99.99

Pulsation Intensity:
A fast response NT® International pressure transducer was installed downstream of the pump being evaluated. This transducer, which has a response time of about 1 millisecond or better, was used to quantify the magnitude of the pressure pulsations. Tests were performed under nearly identical test conditions (flow rate and back pressure) for each pump system. Pressure measurements were collected at 1000 Hz. Data were collected and analyzed over one-minute time intervals at each test condition.

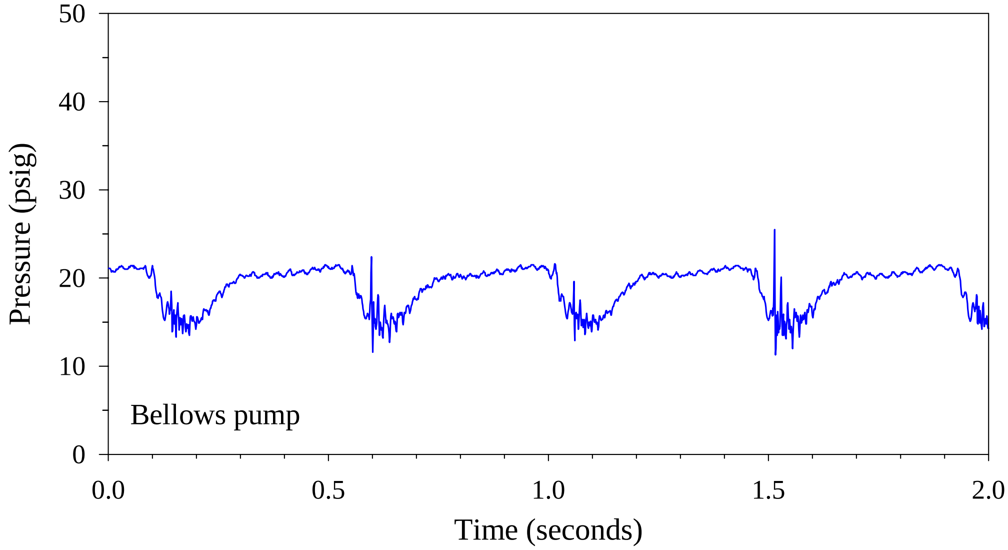
Results and Discussion

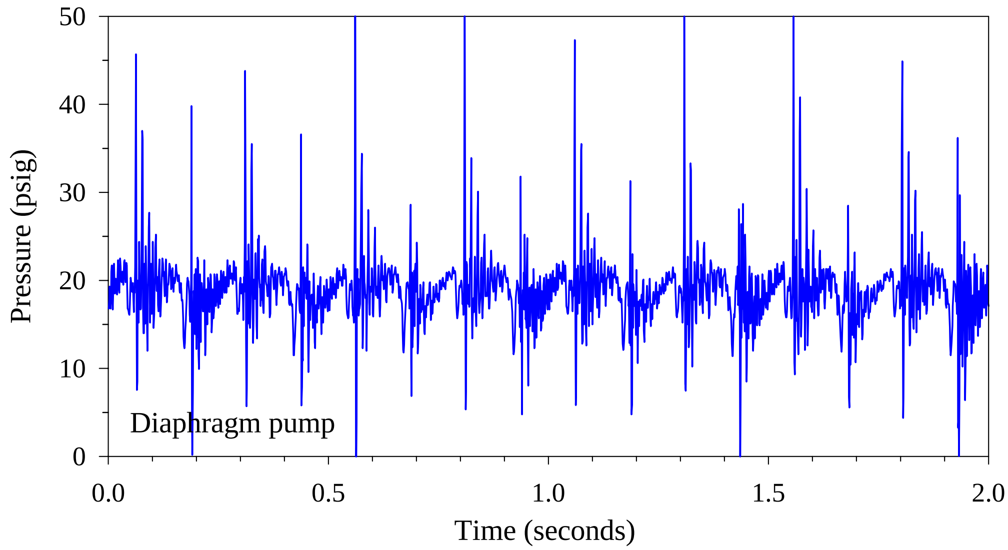
Pulsation Results:
Figures 2 and 3 show the magnitude of the pressure pulsations for each type of pump at 5 and 10 gpm, respectively. (Measurements were also performed at 7.5 gpm, but are not included here.) As expected, the pulsations from the bellows and diaphragm pumps were substantially higher than the centrifugal pump. Furthermore, the pulsations increased with increasing flow rate for both the bellows and diaphragm pumps.

An analysis of the pulsation data is presented in Table III. The pulsation intensity, defined in this paper as the relative standard deviations (RSDs) of the pressure measurements, was calculated over one-minute test intervals for each pump at each test condition. RSD is defined as the standard deviation divided by the mean. Figure 4 shows the pulsation intensity as a function of flow rate for each pump type. The pulsation intensity measurements indicate that the pressure pulsations from the bellows and diaphragm pumps were about 4-7 and 10-20 times higher than the centrifugal pump, respectively. There is some variability in the pressure signal that may be due to electrical noise. The pulsation intensities measured with the centrifugal pump may have been significantly lower than presented if this noise were eliminated. Thus, the pulsation results presented for the centrifugal pump represent a worse case scenario.

The magnitude of the pulsations increased substantially with increasing flow rate for the bellows and diaphragm pumps. The magnitude of the pulsations increased roughly 30% and 100% as the flow rate was increased from 5 to 10 gpm for the bellows and diaphragm pumps, respectively. The pulsations were essentially unchanged for the centrifugal pump.

Figure 2. Magnitude of pressure pulsations for each pump at 5 gpm





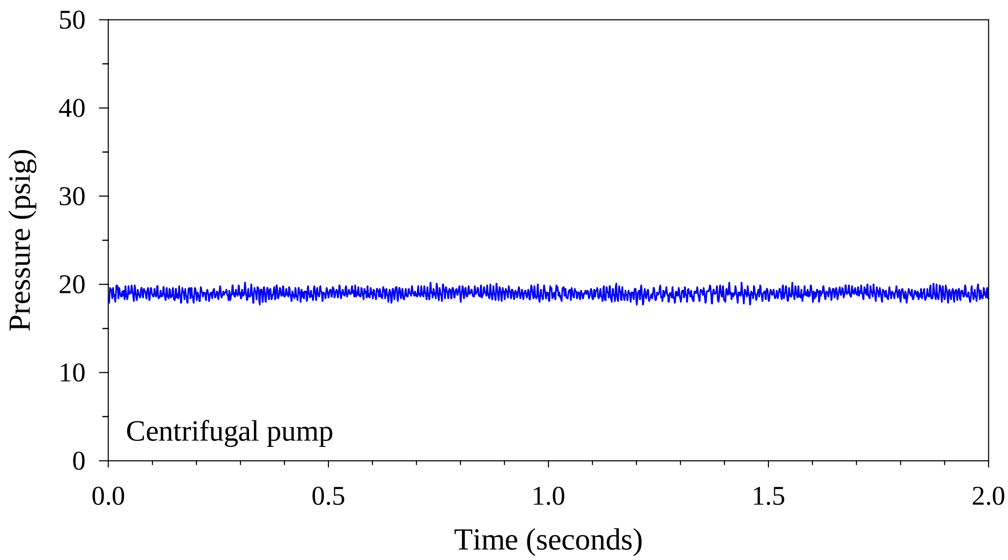


Figure 3. Magnitude of pressure pulsations for each pump at 10 gpm

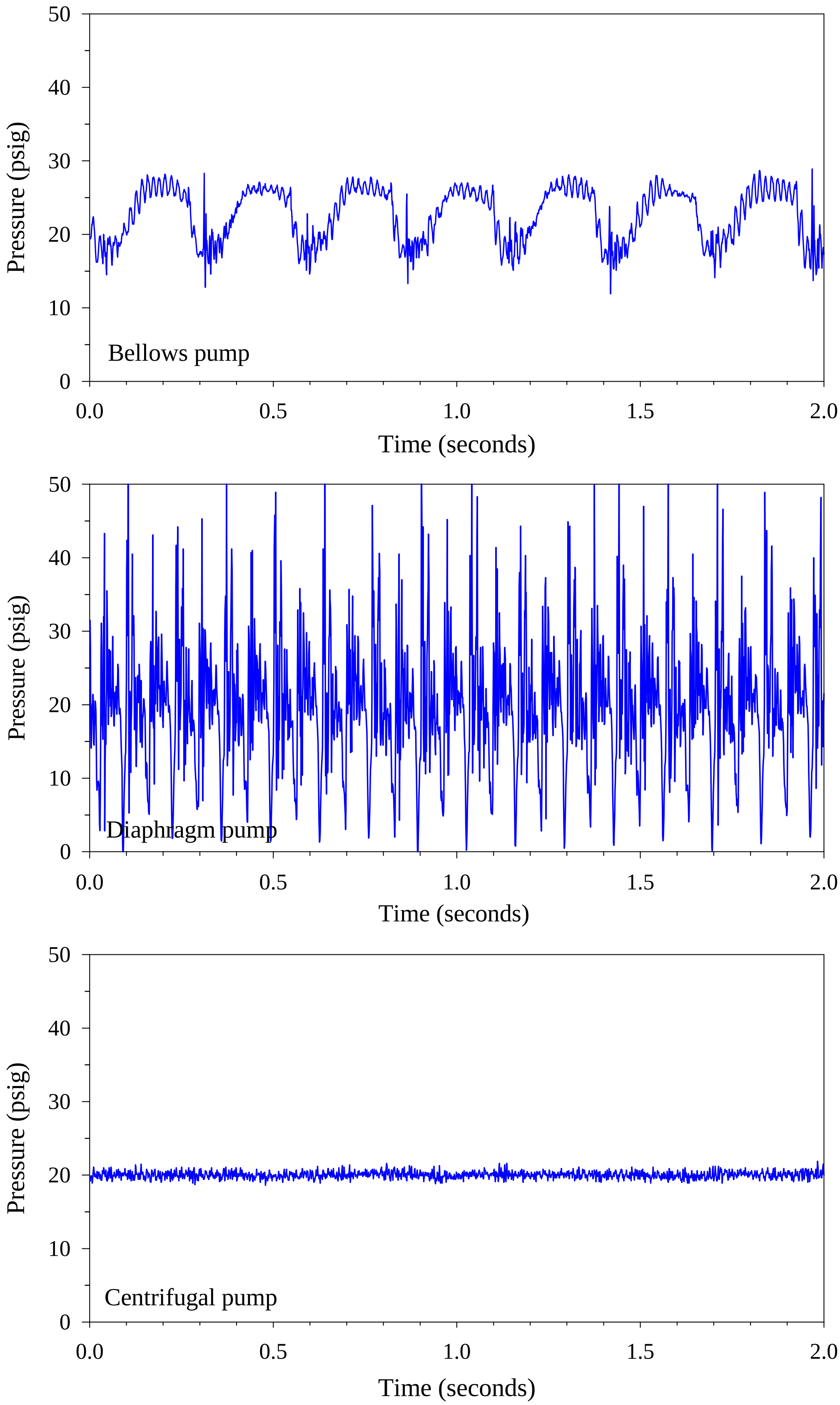
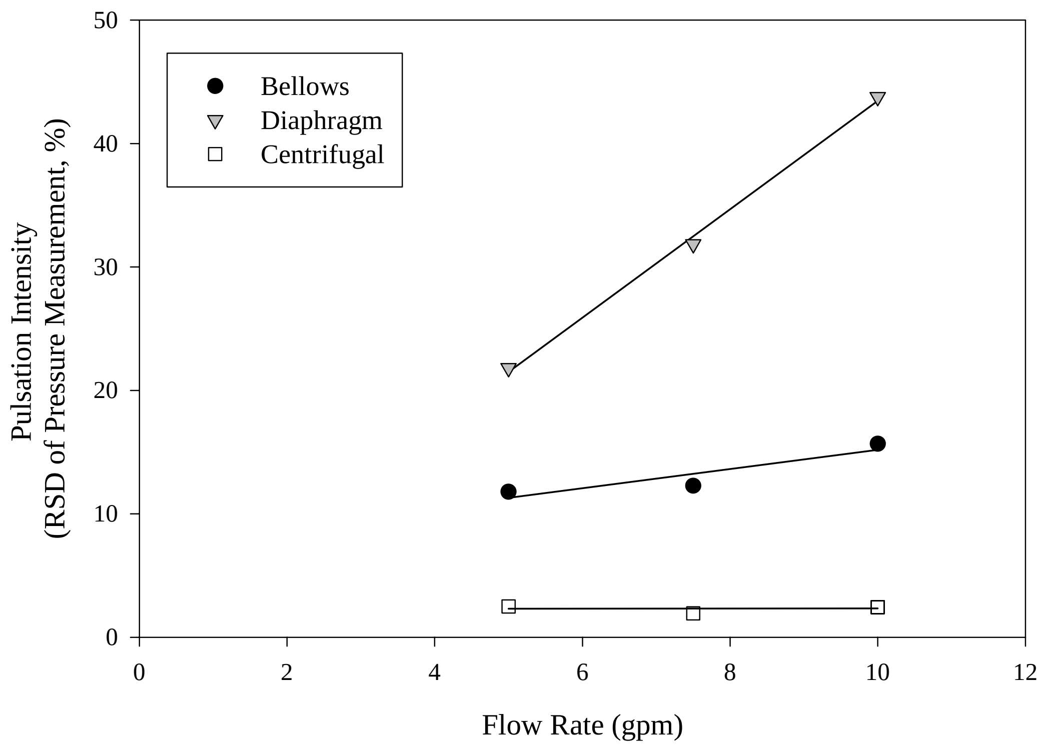


Table III. Summary of pulsation intensity measurements

Flow Rate	Pulsation Intensity (RSD of Pressure Measurements, %)		
	Centrifugal	Bellows	Diaphragm
5 gpm	2.5	11.8	21.8
7.5 gpm	1.9	12.3	31.8
10 gpm	2.4	15.7	43.8

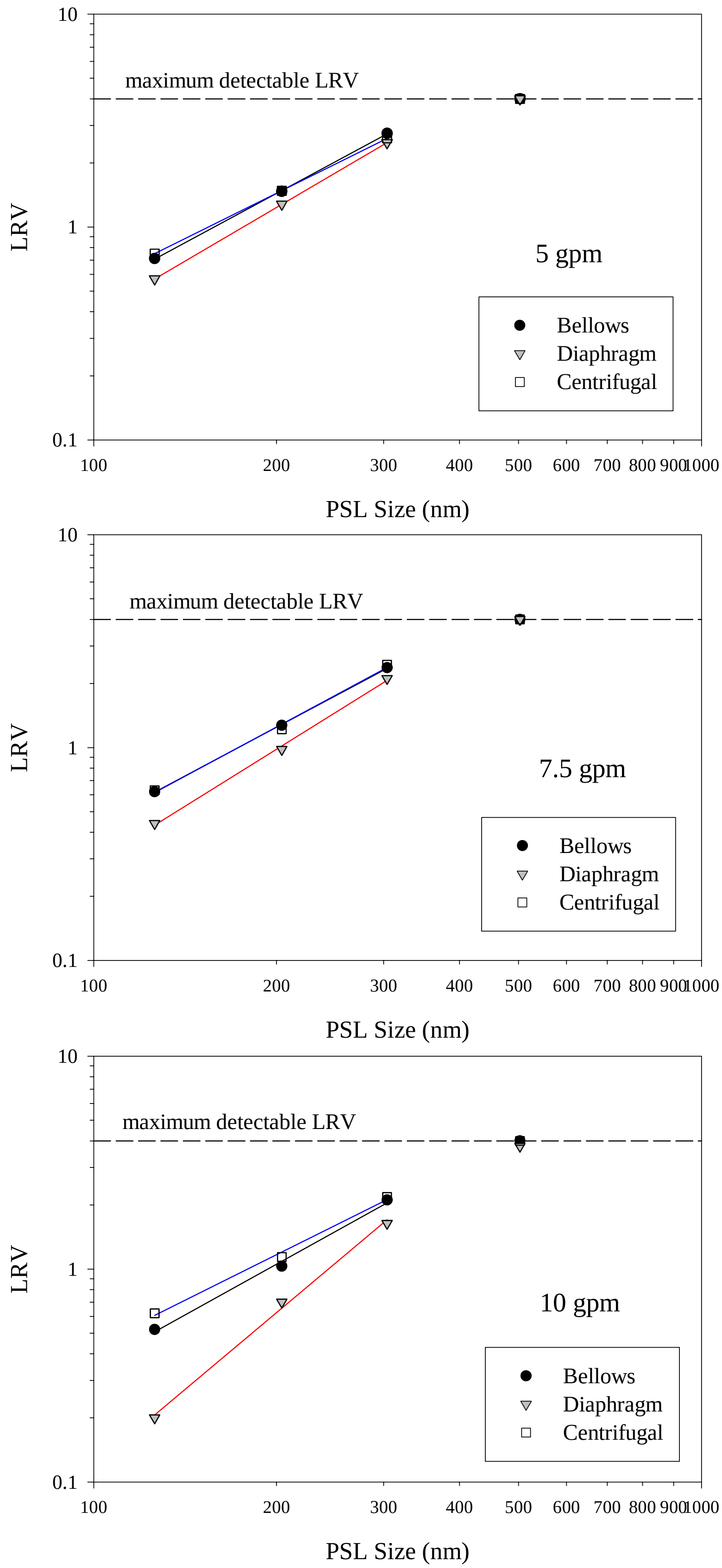
Figure 4. Pulsation intensity as a function of flow rate



Filter Retention:
Figure 5 shows the retention efficiency of the Mykrolis 0.1μm Etchgard HPX filter as a function of particle size for each of the pumps at flow rates of 5, 7.5, and 10 gpm. (The maximum detectable LRV with this test method was 4, thus LRV values greater than this were plotted at a value of 4.) As expected, LRV increased with increasing particle size in each test and was linear when plotted as a function of particle size on a log-log scale.

The centrifugal pump, which provides the most stable flow of the pumps tested, exhibited the highest retention values at each flow rate tested. For low flow rates, the retention values with the bellows pump were indistinguishable from the centrifugal pump, even though it delivers flow that has significant pulsation as shown above. At 10 gpm, the retention values measured using the bellows pump were slightly lower than those measured using the centrifugal pump. However, the retention values obtained with the diaphragm pump, which exhibited the largest pulsation of the pumps tested, were significantly less than the other pumps, particularly at higher flow rates.

Figure 5. Retention efficiency of 0.1 μm Etchgard HPX at 5, 7.5, and 10 gpm



In general, the higher the flow rate used, the greater the difference in filter retention between the pumps that deliver flow with and without pulsation. Although it is not easily distinguishable in these figures, the retention values measured using each pump decreased slightly as the flow rate increased.

The trends observed with the Etchgard filter were similar to those with the Ulti-Etch filter (not shown). The Ulti-Etch filter was slightly more retentive than the Etchgard filter at all test conditions.

Although both the Etchgard and Ulti-Etch filters are rated at 0.1 μm, both filters exhibited low retention (LRV ~0.5 or 70% retention) for particles of this size. This is because these filters are typically used in recirculating etch bath (REB) applications. Filters used in REB applications are often rated differently than filters used in other filtration applications. In a REB application, the cleanup time of the bath is not only a function of the retention characteristics of the filter, but also the bath turnover rate. Thus, the most retentive filter may not cleanup a REB the fastest [3]. More open, less retentive filters with lower pressure drop are often more effective at reducing bath particle concentrations.

These tests were performed at low particle loadings on each filter. Filter efficiency typically decreases quickly as a filter is loaded with particles, followed by a slow decrease and eventually leveling off at higher filter loadings [4]. The effect of pulsation on loaded filters was not investigated.

Correlation between pulsation intensity and retention efficiency:
Figure 6 presents the retention efficiency of both membrane filters plotted as a function of pulsation intensity. Data from all three pumps are included. The retention efficiency is presented as the LRV of 125 nm particles for each filter. Linear regressions are plotted for each type of filter regardless of the pump used. As anticipated, these data indicate that the LRV decreased as the pulsation intensity increased for both filters. The LRV decreased from 0.7 (80% retention) to 0.3 (50% retention) when the pulsation intensity increased from 3% to 45%.

Figure 6. Overall retention efficiency as a function of pulsation intensity

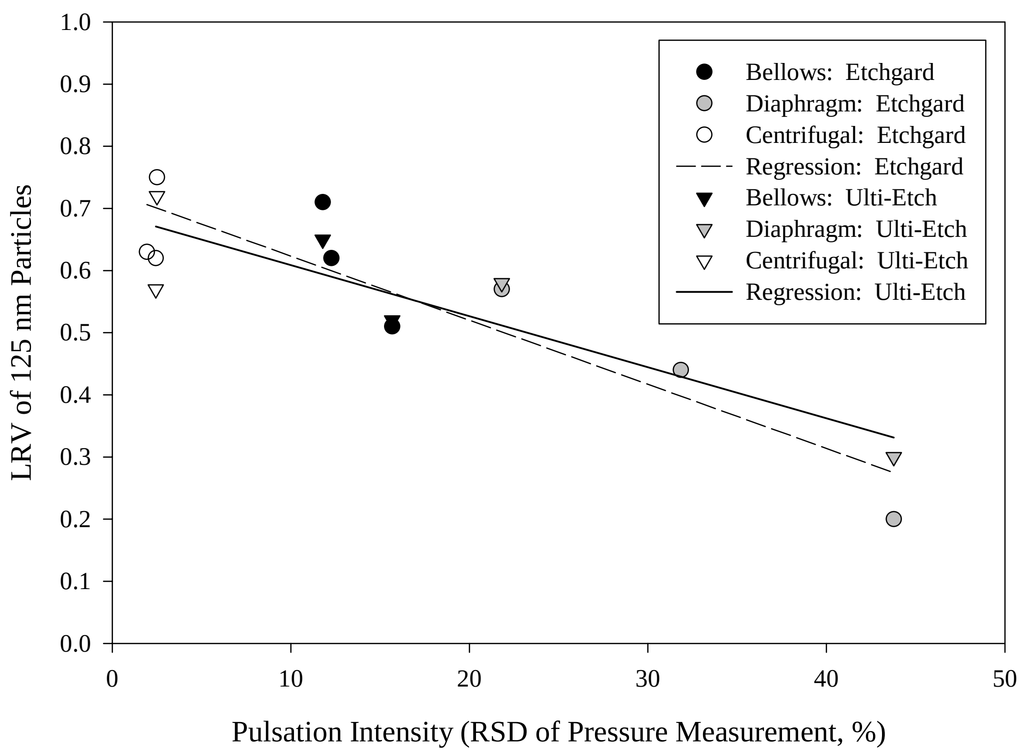
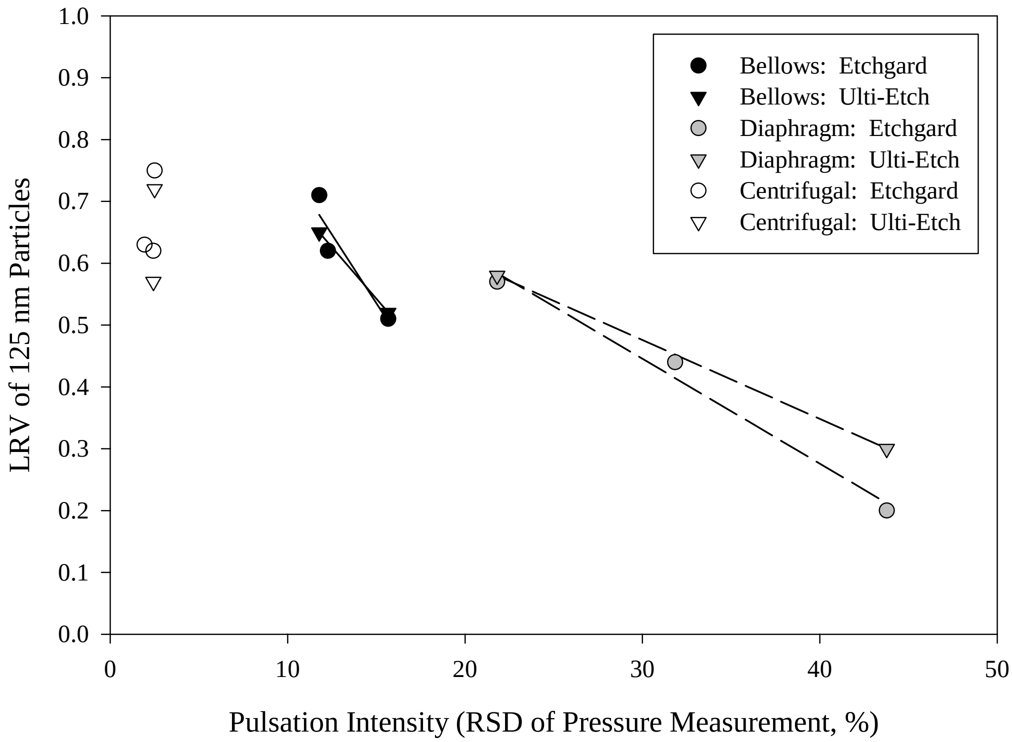


Figure 7 presents the same data as Figure 6, except the regressions are plotted for each pump/filter combination separately. (Regressions for the centrifugal pump data are not included.) These data indicate a good correlation between LRV and pulsation intensity for each pump-filter combination.

Figure 7. Retention efficiency of each filter type as a function of pulsation intensity



Summary

The effect of flow pulsations on filter particle retention was measured for two types of filters used in recirculating etch bath applications. Flow pulsation intensity was measured using a fast acting pressure transducer and assuming that flow pulsations are directly related to pressure pulsations. Filter retention decreased with increasing pulsation intensity.

The centrifugal pump provided the lowest pulsation intensity. Pulsation intensities from the bellows and diaphragm pumps were approximately 6 and 15 fold higher, respectively. The pulsation results presented represent a worse case scenario since no attempt was made to eliminate the measurement variability due to electrical noise. Pulsation intensity increased as flow rate delivered by the bellows and diaphragm pumps increased. The retention of 125 nm particles decreased from 80% to 50% as pulsation intensity increased.

References

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