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Effect of Pressure and Flow Pulsations on Filter Retention

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Introduction

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 quantify the magnitude of pump-induced flow and pressure pulsations in three pump systems and to correlate those pulsations with filter retention. In a previous study (CTA document #: LTX 815 1123 "The Effect of Pump Pulsation on Filter Retention"), the filter retention of three different types of 0.1 μm membrane filters were characterized as a function of particle size and flow rate for each type of pump. The filter retention study indicated that filter retention was highest with the Levitronix pump and lowest with the Trebor pump, particularly at high flow rates. In general, the higher the flow rate, the greater the difference in filter retention between the three types of pumps. For low flow applications, the filter retention results were nearly indistinguishable.

In this experiment, a fast response pressure transducer and flowmeter were used to quantify the magnitude of the pressure and flow pulsations under the same test conditions as the previous filter retention study.

Experimental Procedure

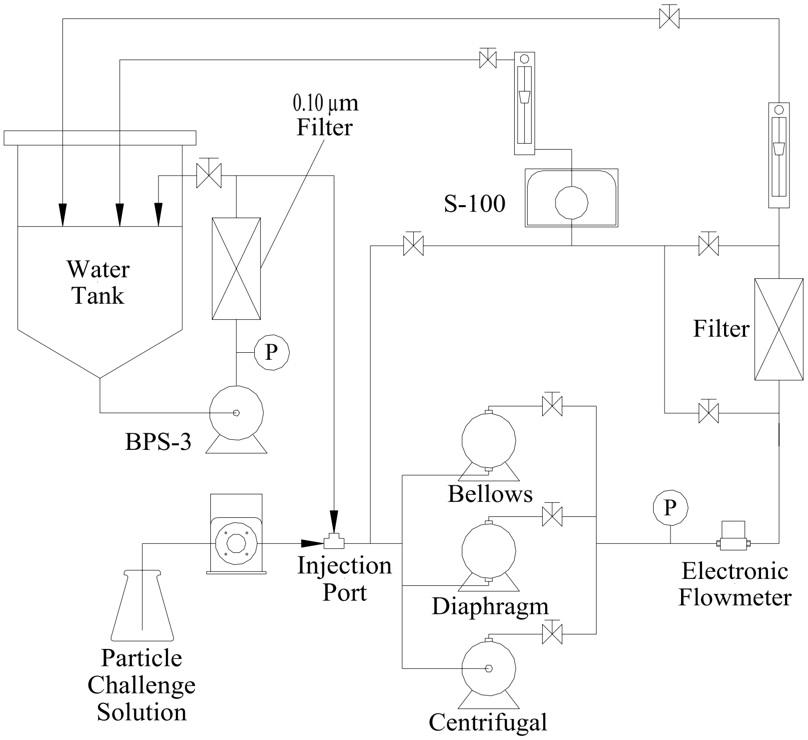
The pumps evaluated were a White Knight AP200 bellows pump, a Trebor Magnum 620R diaphragm pump, and a Levitronix BPS-4 centrifugal pump (Table I). Pulse dampeners were not used.

Table I. Specifications of the three pump systems

Pump Manufacturer	Type of Pump	Model # of Pump
White Knight	Bellows	AP200
Trebor	Diaphragm	Magnum 620R
Levitronix	Centrifugal	BPS-4

A schematic of the test system is presented in Figure 1. A fast response pressure transducer and flow meter were installed downstream of the pump being evaluated. A Gems Sensors 2600 series pressure transducer, which has a response time of 0.5 milliseconds and an NT® International single-port pressure transducer Model 4150, which appears to have a response time similar to the Gems Sensor (manufacturer did not provide response time specifications) were used to quantify the magnitude of the pressure pulsations. Data from the NT pressure transducer are presented in this report. An NT® International electronic flowmeter Model 4400, which has an update rate of 50 milliseconds, was used to quantify the magnitude of the flow pulsations. This flowmeter was chosen for its relatively fast response compared to other types of flowmeters, although it is not nearly as fast as the pressure transducer. The flowmeter has an integration time of approximately 50 ms. The integration time is a compromise between speed and accuracy of the flow measurements. Furthermore, there may be an offset of about 100 ms between the pressure and flow rate measurements due to the response of the flowmeter.

Figure 1: Test system schematic



Tests were performed under nearly identical test conditions (flow rate and back pressure) as the previous filter retention study. The pressure and flow measurements were collected at 1000 Hz. Data were collected and analyzed over one-minute time intervals at each test condition.

Results and Discussion

Figures 2-4 show the magnitude of the pressure and flow pulsations for each type of pump at approximately 5, 7.5, and 10 gpm, respectively. As expected, the pressure pulsations from the bellows and diaphragm pumps were substantially higher than the centrifugal pump. Furthermore, the pressure pulsations increased with increasing flow rate for the bellows and diaphragm pumps. Likewise, the flow pulsations from the bellows and diaphragm pumps were also significantly higher than the centrifugal pump; however, the response of the flowmeter may have been too slow to adequately characterize the magnitude of the flow pulsations. Unlike the pressure pulsation results, the magnitude of the flow pulsations decreased with increasing flow rate, but this unexpected observation may have been influenced by the integration time of the flowmeter.

An analysis of the pressure and flow data is presented in Table II. The relative standard deviations (RSDs) were calculated over a one-minute test interval for each pump under each test condition. Figure 5 shows the relative standard deviation of the pressure measurements as a function of flow rate for each pump type. The RSDs of the pressure data indicate that the pressure pulsations were about a factor of 5 times higher for the bellows pump compared to the centrifugal pump. Furthermore, the RSDs of the pressure data for the diaphragm pump were about 2-3 fold higher than the bellows pump.

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

Table II. Relative standard deviations of pressure and flow data

Flow Rate	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
Flow Rate	RSD of Flow Measurements (%)		
	Centrifugal	Bellows	Diaphragm
5 gpm	0.59	4.8	2.7
7.5 gpm	0.48	2.8	1.3
10 gpm	0.40	2.8	0.86

Meanwhile, the RSDs of the flow data indicate that the flow pulsations induced by the bellows and diaphragm pumps were significantly higher than the centrifugal pump. The magnitude of the flow pulsations were 2-4.5 fold higher for the diaphragm pump relative to the centrifugal pump, while the flow pulsations of the bellows pump were 7-8 fold higher than the centrifugal pump. The response of the flowmeter appears to be too slow to adequately characterize the magnitude of the flow pulsations,

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

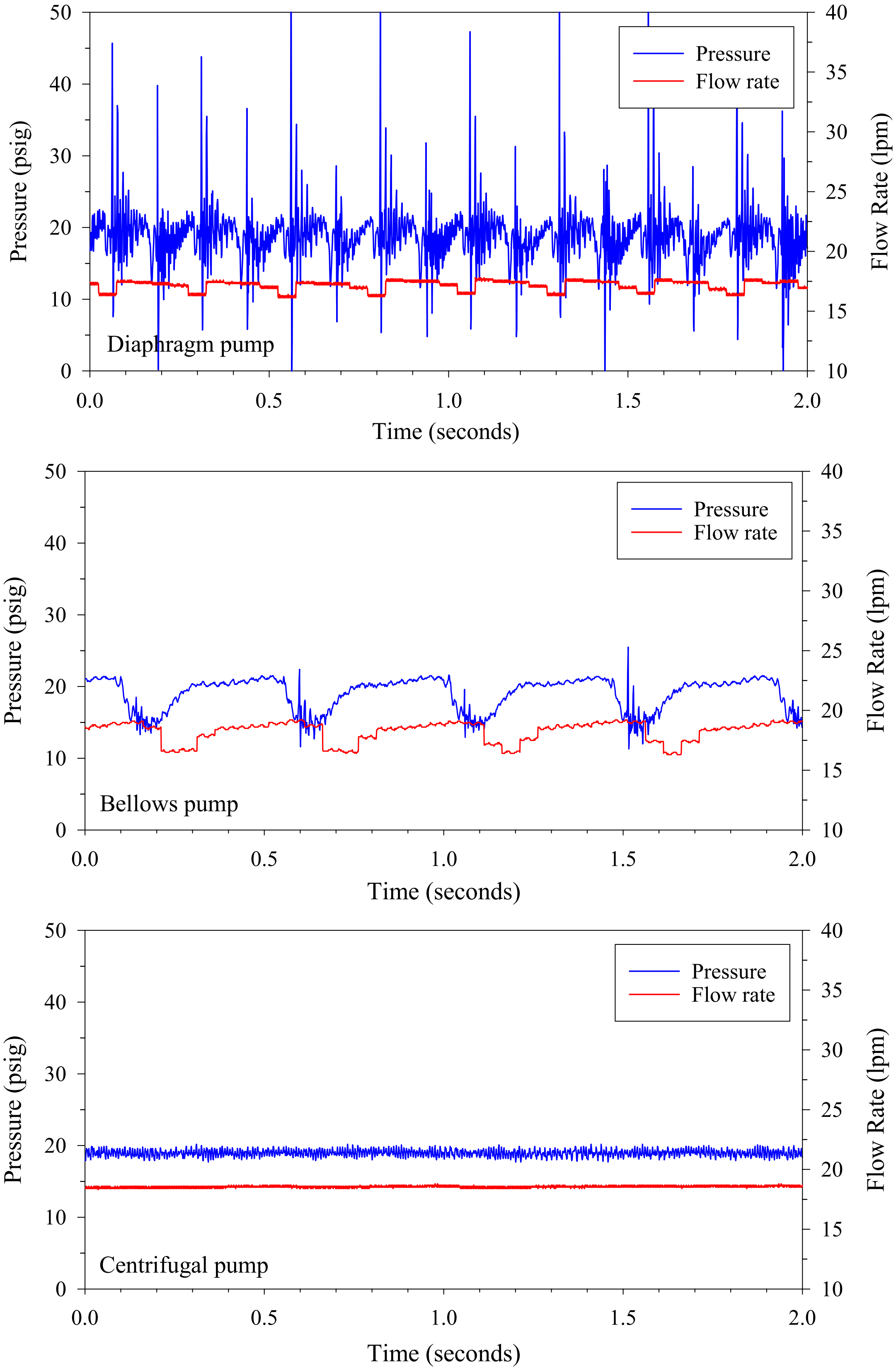


Figure 3. Magnitude of pressure and flow pulsations for each pump at 7.5 gpm

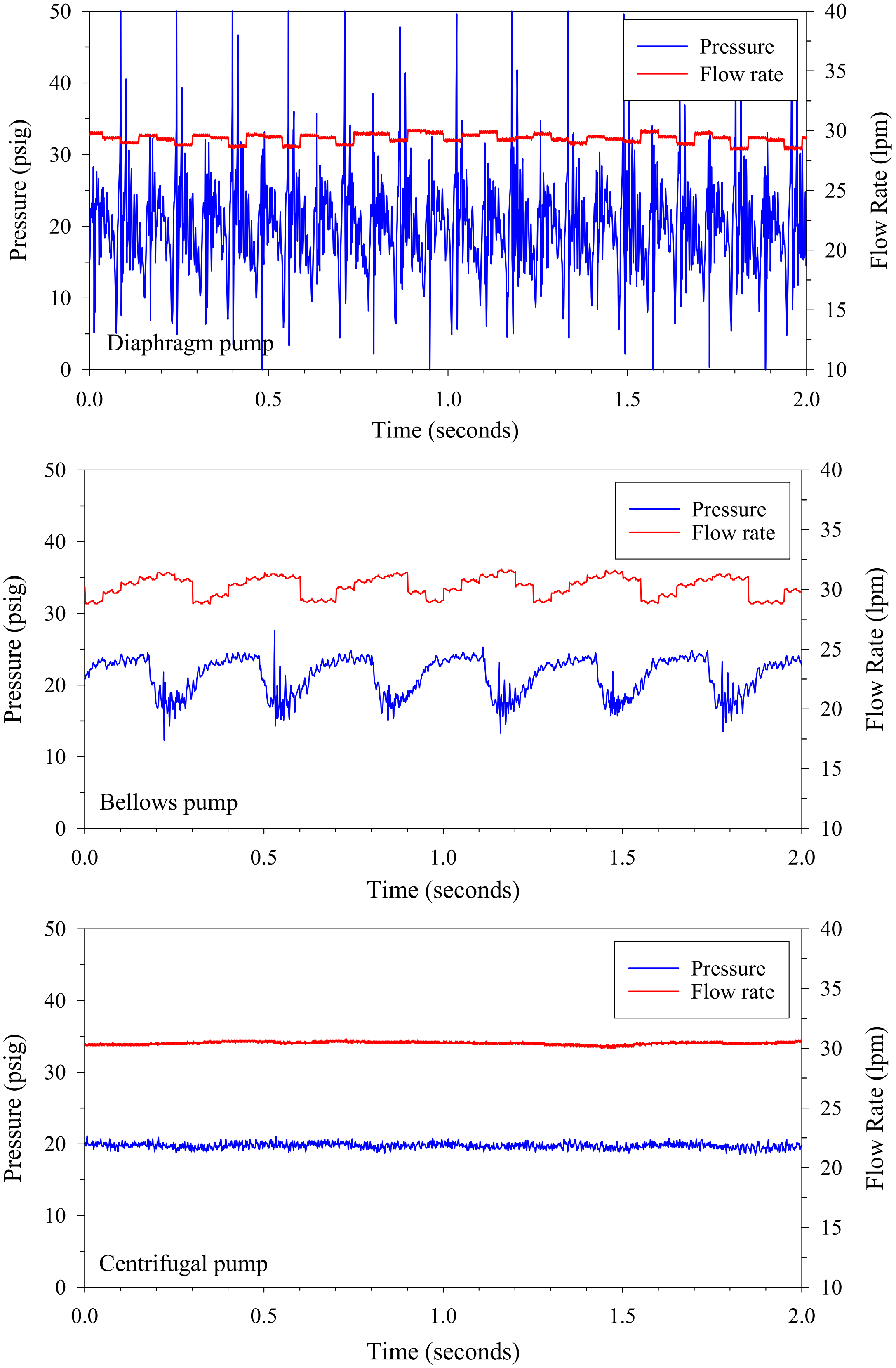
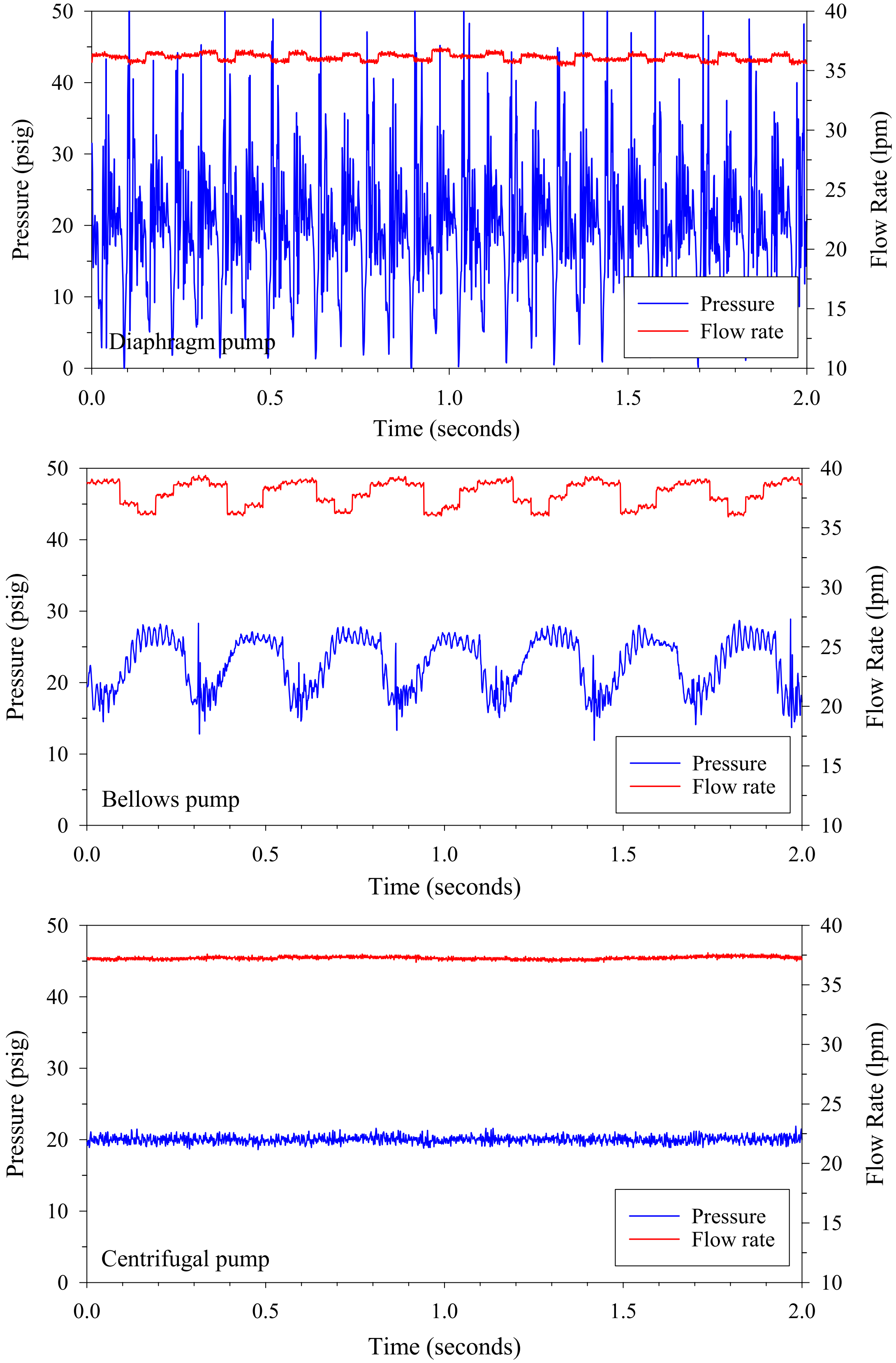


Figure 4. Magnitude of pressure and flow pulsations for each pump at 10 gpm



particularly for the diaphragm pump since it cycles at a much higher rate (about 4 fold) than the bellows pump. This is due to the fact that the integration time of the flowmeter is about 50 ms while the time to perform a stroke with the diaphragm pump is about 60-120 ms depending on the flow rate. The RSDs of the flow pulsations tend to decrease with increasing flow rate for each of the pumps, but this is observation is mostly likely influenced by the integration time of flowmeter.

Figure 5. Relative standard deviations of pressure measurements as a function of flow rate

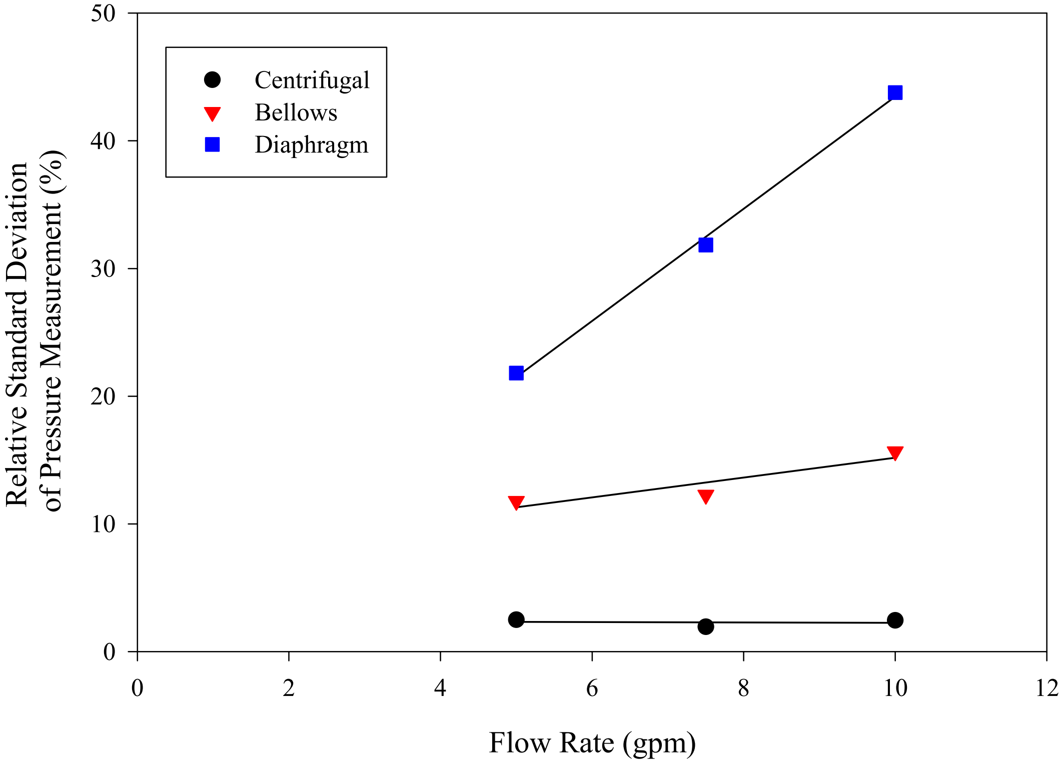


Figure 6 presents the retention efficiency of two membrane filters for each type of pump plotted as a function of the RSD of the pressure measurements quantified in this study. The retention efficiency is presented as the Log Reduction Value (LRV) at a particle size of 125 nm for each filter. Linear regressions are plotted for each type of filter regardless of the pump used. As anticipated, these data indicate that the LRV decreased as the magnitude of the pressure pulsations increase for both filters.

Figure 7 presents the same data as Figure 6, except the regressions are plotted for each pump and filter combination separately. (No regressions are included for the centrifugal pump data.) These data indicate that there is a good correlation between LRV and pressure pulsations for each pump-filter combination.

Figure 6. Retention efficiency as a function of pressure pulsation

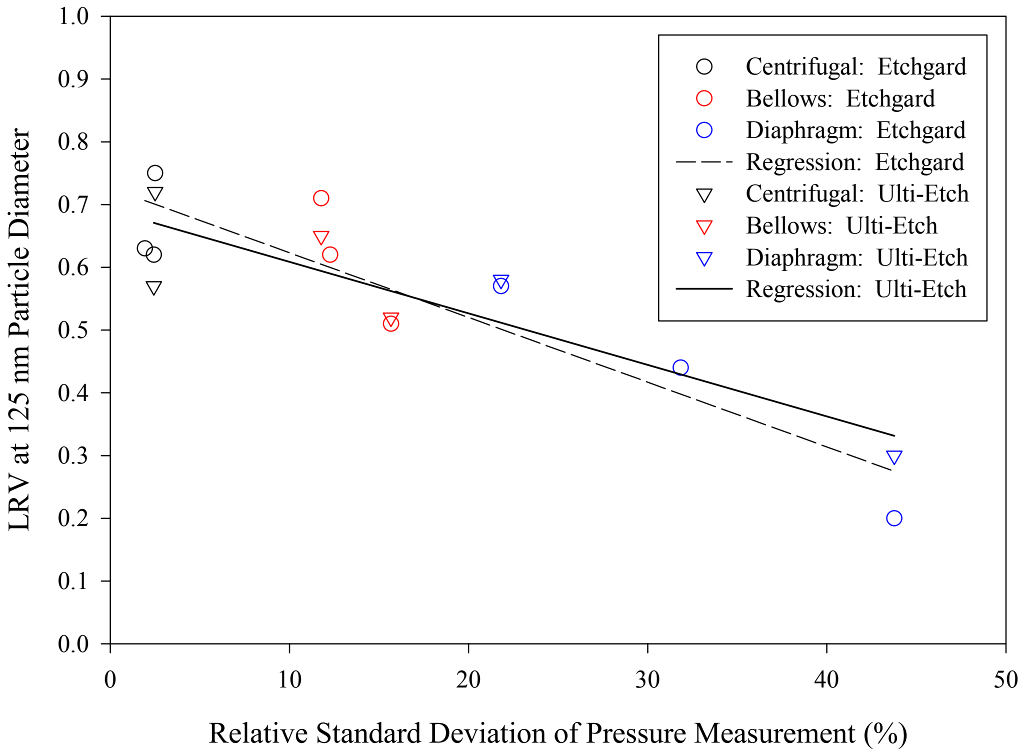
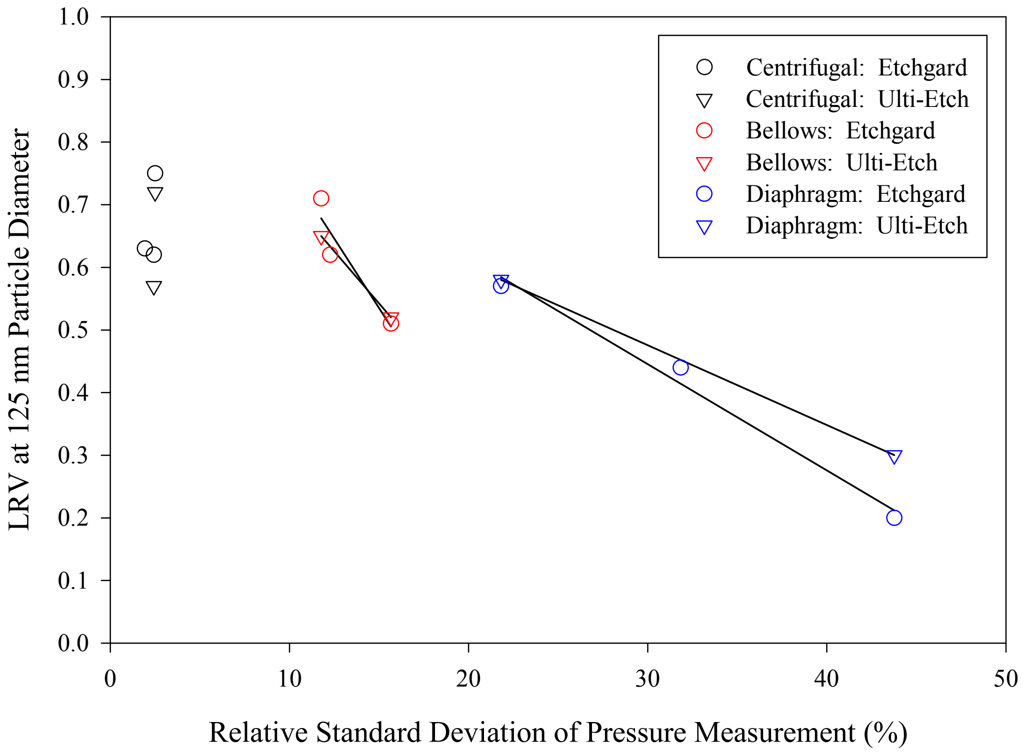


Figure 7. Retention efficiency as a function of pressure pulsation



Conclusions

- As expected, the pressure pulsations from the bellows and diaphragm pumps were substantially higher than the centrifugal pump. The variability of the pressures downstream of the bellows and diaphragm pumps were about 5 and 15 fold higher than the centrifugal pump, respectively.
- The pressure pulsations increased with increasing flow rate for both the bellows and diaphragm pumps.
- Filter retention decreased as the magnitude of the pressure pulsations increased for both types of filters.
- The flow pulsations from the bellows and diaphragm pumps were also significantly higher than the centrifugal pump. The magnitude of the flow pulsations decreased with increasing flow rate; however, this unexpected result was most likely influenced by the response time of the flowmeter.

References

1. Deal DB and DC Grant (1994). "Chemical Delivery Systems: Past, Present and Future, "Contamination Control and Defect Reduction in Semiconductor Manufacturing III, DN Schmidt, Ed., Proceedings Volume 94-9, The Electrochemical Society, Pennington, NJ, pp. 167-179.
2. Grant DC and WR Schmidt, “Particle Performance of a Central Chemical Delivery System,” presented at the 7th Annual Millipore Microelectronics Technical Symposium, May 22, 1989.