CT Associates, Inc.
7121 Shady Oak Road, Eden Prairie, MN 55344-3516
Telephone: (952) 470-0166 Fax: (952) 942-0293
Website: http://www.ctassociatesinc.com

Comparison of Particle Shedding from Ten Different Pumps in Water

Submitted to:

Reto Schoeb
Levitronix GmbH

Submitted by:

Mark Litchy
CT Associates, Inc.

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Introduction

Ten pumps from four different manufacturers (Levitronix, Yamada, Trebor, and Almatec) were evaluated for particle shedding in ultra pure water during operation at multiple test conditions. Three pump sizes from Levitronix, Yamada, and Trebor were tested and one pump size from Almatec was tested. The pump sizes chosen were selected based on similarity to Levitronix BPS-1, BPS-3, and BPS-4 magnetically levitated centrifugal pump systems. However, because the Yamada, Trebor, and Almatec pumps are positive displacement pumps, the operating curves are significantly different than the Levitronix pumps. The three smallest pumps (one from each manufacturer except Almatec) were tested at the same operating conditions (flow rates and pressures). Likewise, the three intermediate and four largest pumps were also tested at similar test conditions. The operating conditions were chosen for each group of pumps such that all pumps in the group could achieve the test conditions. Some of the pumps were also tested at additional test conditions that were not common to the pumps in their size category (e.g. higher flow rate for the Levitronix pumps or higher pressure for the positive displacement pumps).

Experimental Procedure

Table I shows the pumps that were evaluated in this test program. A schematic of the pump particle shedding test system is shown in Figure 1. A centrifugal pump was used to deliver filtered water to the pump under test. This pump was operated continuously to circulate water through the main loop at a flow rate of approximately 11-12 gpm. The water was filtered using dual 10” Mykrolis Durapore Z cartridge filters arranged in parallel. The pump being evaluated drew filtered water from this supply. There was no restriction on the main loop return to the tank downstream of the filters. As a result, the pressure at the inlet of the test pump was on the order of 1 psig, which resulted from the head pressure of the water above the pump. A pulse dampener was located immediately downstream of the test pump. The same pulse dampener was used in all tests. Nearly all of the flow out of the test pump was returned to the tank through a large flow meter and valve that controlled the flow rate and outlet pressure on the pump. The remainder of the water was delivered to the liquid particle counters.

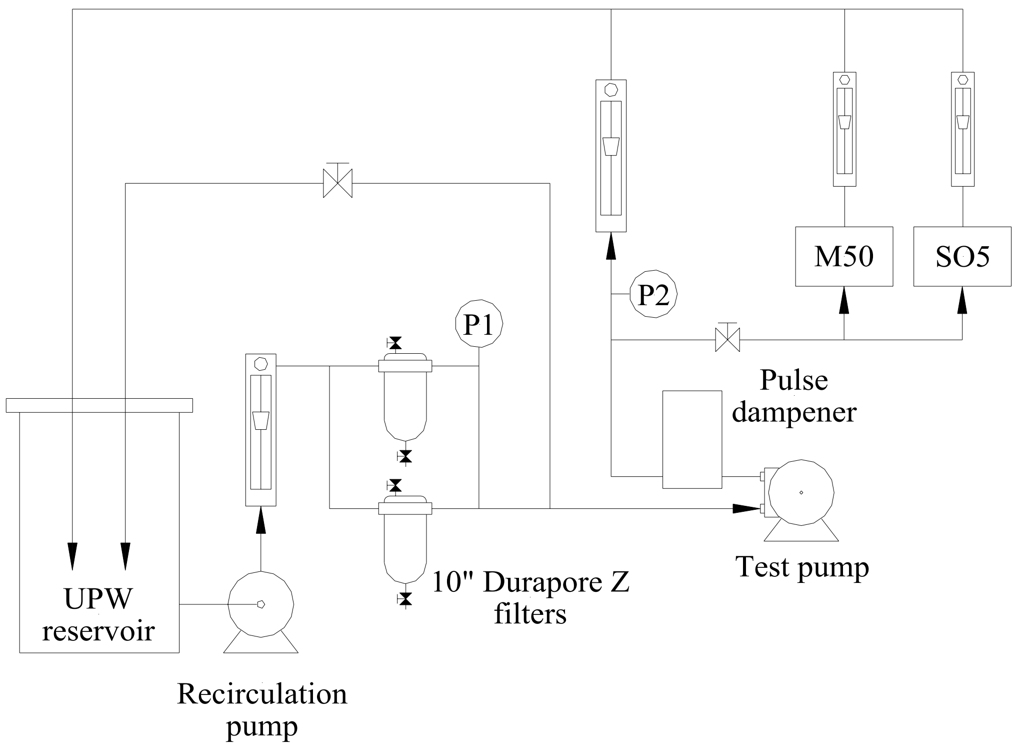
Table I. Comparison of pumps evaluated

Manufacturer	Pump Type	Maximum Flow Rate (gpm)	Maximum Discharge Pressure (psig)
Small Pumps			
Levitronix	BPS-1.5	5.5	23
Trebor	110R	5.3	60
Yamada	DP-5F	2.9	70
Intermediate Pumps			
Levitronix	BPS-3.7	20	36
Trebor	Magnum 620R	11.4	80
Yamada	DP-20F	14.3	45
Large Pumps			
Levitronix	BPS-4.2	37	65
Trebor	Mega 960D	22	80
Yamada	DP-25F	16.9	70
Almatec	Futur 50 H	13	85

Two optical particle counters were used in this evaluation: a Particle Measuring Systems HSLIS M50 particle monitor and a Particle Measuring Systems LiQuilaz S05 liquid particle counter. The M50 has four size channels and measures the following particle sizes: ≥ 0.05, ≥ 0.10, ≥ 0.15, and ≥ 0.20 µm. The LiQuilaz

S05 has 15 size channels ranging from ≥ 0.5 to ≥ 20 µm. Particle concentrations were recorded continuously downstream of the test pumps.

Figure 1. Schematic of test system



The residence time from the pump to the liquid particle counters was approximately 180 seconds. This was achieved by placing a long length of PFA tubing between the pump and the liquid particle counters. The purpose of the long residence time was to eliminate any bubbles that might be present downstream of the pump. The S05 liquid particle counter was included in the tests to aid in determining whether bubbles were present at the particle counters.

A chiller (not shown) was used to maintain the temperature of the water in the system at 24±1°C, except during the BPS-4 pump tests in which the chiller was not able to remove all of the heat generated by the two pumps in the system. During these tests, the temperature of the water increased to 30°C at the highest BPS-4 speeds.

Spool pieces were installed in place of the test pumps to determine the background particle level of the test system. A valve located in the bypass loop was throttled to provide sufficient backpressure in the system to measure particle concentrations without a test pump in the system. Thus, the conditions in which the background tests were performed were similar, but not identical to the conditions in which the pumps were tested.

Each pump was run under typical operating conditions for a minimum of three days prior to the start of this test program. This was done to ensure that any particles being shed were not simply a result of the pump being brand new. Following this break-in period, the quasi steady-state particle shedding from each pump was monitored at multiple operating conditions over the range of conditions shown in Table II. Each condition was monitored for a minimum of two hours. A minimum of 1-2 hours of data was averaged once the particle concentrations had stabilized following each change in operating conditions. If the concentration appeared to be changing, particle concentrations were monitored for a longer period of time.

Table II. Operating conditions common to each group of pumps

Pump Size	Flow rate (gpm)	Outlet Pressure (psig)
Large pumps	10	40
	7.5	40
	5	40
	10	20
	7.5	20
	5	20
Intermediate pumps	5	30
	3.75	30
	2.5	30
	5	15
	3.75	15
	2.5	15
Small pumps	2.5	15
	2	15
	1	15
	2.5	10
	2	10
	1	10

The desired operating conditions were achieved by either adjusting the pump speed or air pressure to the pump and the pump outlet pressure with a control valve located downstream of the test pump. Some of the pumps were evaluated at additional test conditions that may not have been common to the other pumps in their size category. For example, the Levitronix pumps, which are typically capable of higher flow rates than the other pumps, may have been tested at additional higher flow rates. Meanwhile, the diaphragm pumps are typically capable of higher pressures, and thus may have been tested at a few higher pressures. The maximum flow rate attainable in the test system was 10 gpm, thus no results are presented at higher flow rates even though many of these pumps are capable of delivering liquid at significantly higher flow rates.

Results and Discussion

System background particle levels are presented in Table III. The results shown represent the mean concentrations measured over a period of five days.

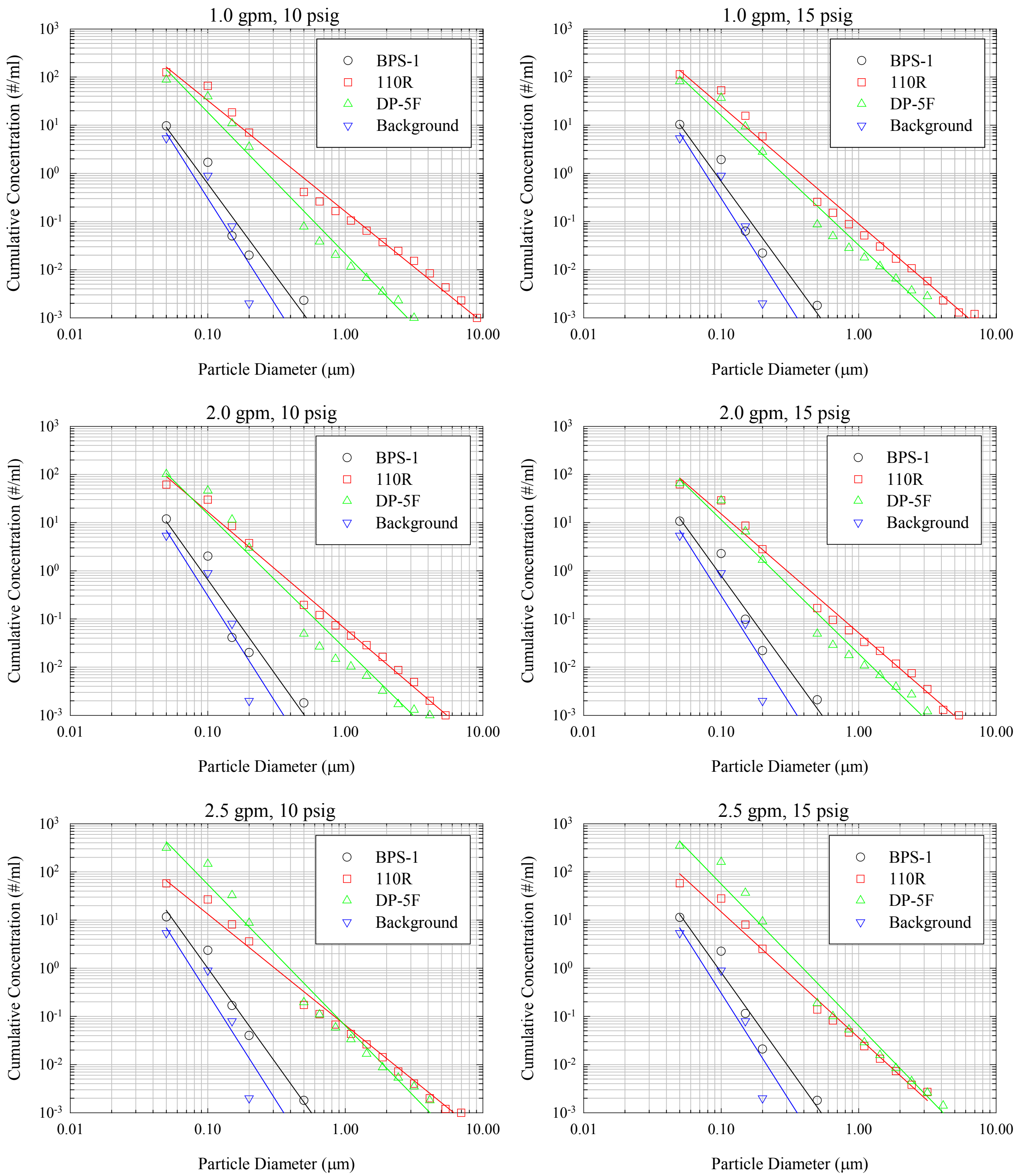
Table III. Background particle concentrations

Location	Cumulative Particle Concentrations (#/ml)				
	≥ 0.05 µm	≥ 0.10 µm	≥ 0.15 µm	≥ 0.20 µm	≥ 0.50 µm
Test loop	5.4	0.9	0.08	0.002	0.0004

The quasi steady-state particle concentrations measured downstream of each pump are presented in Figures 2-4. The system background particle concentrations are also presented in each figure. These figures present the results for the smallest, intermediate, and largest group of pumps, respectively. Six graphs are presented in each figure, one for each test condition common to the group of pumps. (The DP-25F pump was not capable of operating at the highest flow rate and pressure setting, and thus there are no results presented at 10 gpm and 40 psig for this pump.) Each graph presents the cumulative particle size distribution (PSD) at the operating conditions (flow rate and pump outlet pressure) denoted above each graph. The results from the M50 and S05 liquid particle counters were combined and presented in each graph.

The Levitronix pumps consistently shed the fewest particles of the pumps tested regardless of the operating conditions. Furthermore, in many cases, the particle concentrations measured downstream of the Levitronix pumps were very close to (within a factor of 5) the background particle levels measured in the system. (Background particle concentrations were not subtracted from the concentrations measured downstream of the pumps.) As a result, particle shedding from some of the pumps may be even lower than presented.

Figure 2. PSDs measured downstream of small pumps



The PSDs presented were linear when plotted on a log-log scale, which is typical of many types of components measured in liquids. A linear regression through each set of data is also included in each graph. The PSDs tend to flatten out at the ≥ 0.05 µm size channel. This is due to the fact that the detection limit of the M50 is actually ~0.07-0.08 µm, rather than 0.05 µm. This is not because the M50 is not calibrated, but rather due how the manufacturer defines the sensitivity at 0.05 µm.

Figure 3. PSDs measured downstream of intermediate pumps

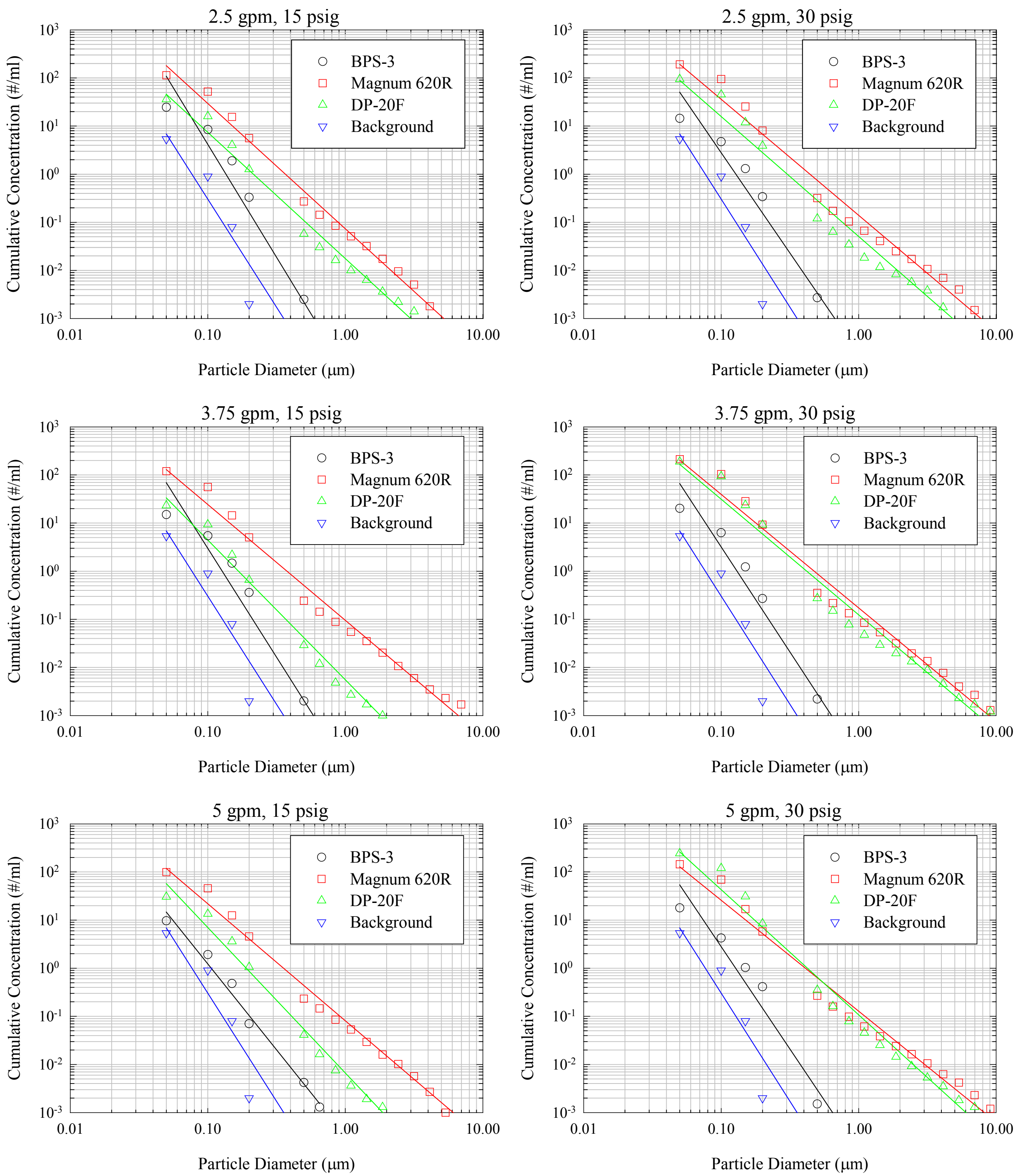
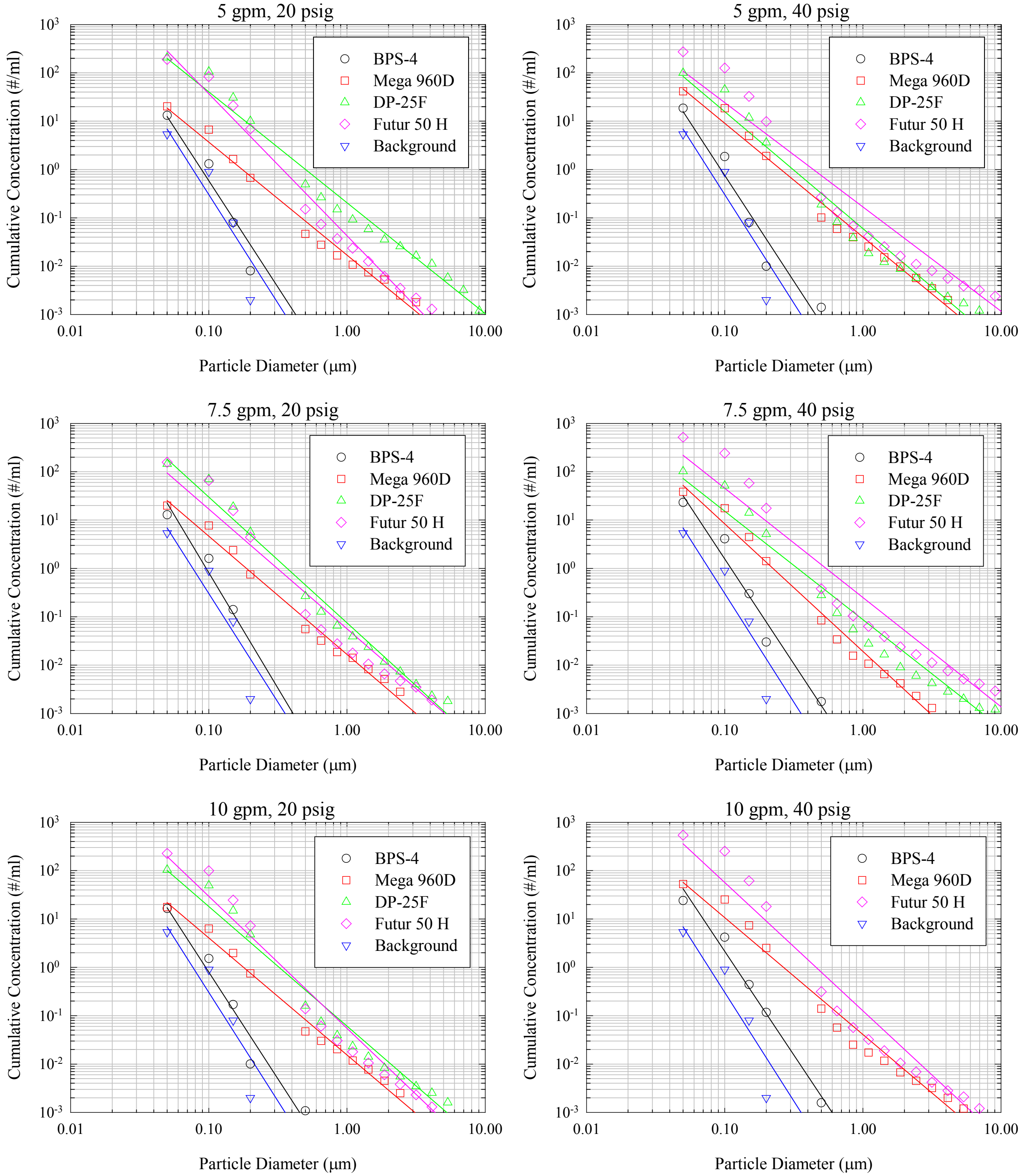


Figure 4. PSDs measured downstream of large pumps



Typically, the slopes of the PSDs measured downstream of the Levitronix pumps (-4.0 to -4.5) were steeper than the other pumps and were similar to the slope measured downstream of the filters (-4.5). Table IV presents the mean and standard deviation of the slopes of the PSDs from each pump at common operating conditions. The steeper slopes measured during the Levitronix pump tests resulted in much larger differences in particle concentrations between the Levitronix pumps and the other pumps at larger particles sizes and smaller differences at smaller particle sizes.

Table IV. Average slopes of the PSDs from each pump at common operating conditions

Slopes of PSDs (Mean ± Standard Deviation)								
Levitronix		Trebor		Yamada		Almatec		Background
BPS-1	-3.98 ± 0.07	110R	-2.43 ± 0.12	DP-5F	-2.85 ± 0.11			-4.50
BPS-3	-4.26 ± 0.39	Magnum 620R	-2.42 ± 0.10	DP-20F	-2.67 ± 0.24			
BPS-4	-4.43 ± 0.17	Mega 960D	-2.44 ± 0.11	DP-25F	-2.41 ± 0.14	Futur 50 H	-2.54 ± 0.30	

In general, particle shedding from the Trebor, Yamada, and Almatec pumps were similar. For the small and intermediate size pumps, the Yamada pumps shed fewer particles than the Trebor pumps, but for the largest size pumps, the Trebor pumps shed fewer particles than the other positive displacement pumps. Typically, if a pump shed fewer particles than a similarly sized pump at one test condition, it shed fewer particles than the other pump at all operating conditions.

Figures 5-7 present the effect of flow rate and outlet pressure on particle shedding from each pump over a wider range of operating conditions than presented in Figures 2-4. The figures include results from operating conditions that were not common to each pump within its size category. Figures 5-7 present the results for the smallest, intermediate, and largest group of pumps, respectively. Six graphs are presented in each figure. The three graphs on the left present particle concentrations ≥ 0.1 μm for each of the pumps tested in this size category, while the graphs on the right present particle concentrations ≥ 0.5 μm for the same three pumps. The ≥ 0.1 μm size channel was chosen instead of the ≥ 0.05 μm size channel due to the sensitivity issues regarding the ≥ 0.05 μm size channel that were discussed earlier. In addition, the background particle concentrations are presented in each figure. In most cases, particle concentrations measured downstream of the Levitronix pumps were very close to the concentrations measured without a test pump in the system.

Table V presents a semi-quantitative summary of the effects of outlet pressure and flow rate on particle concentrations downstream of the pumps. Outlet pressure appeared to have a significant effect on particle concentrations, while flow rate appeared to have less of an effect than outlet pressure, at least over the limited range of flow rates evaluated in this study.

Outlet pressure did not have a significant effect on particle concentrations downstream of the BPS-1 or BPS-3 pumps. However, during the BPS-4 pump tests, particle concentrations increased 5-20%/psig as outlet pressure was increased.

As the outlet pressure was increased, particle concentrations for particle sizes ≥ 0.1 μm increased for each Trebor pump evaluated. For particles ≥ 0.10 μm, a 5-15%/psig increase in particle concentrations was typically observed as the pump outlet pressure was increased during the Trebor pump tests. Little increase in particle concentrations due to varying pressure was observed at larger particle sizes.

Pressure did not appear to have a significant effect on particle concentrations downstream of the smaller and larger size Yamada pumps. However, particle concentrations measured downstream of the intermediate size Yamada pump increased substantially with increasing outlet pressure, particularly at higher flow rates. Up to a 60% increase in particle concentrations was observed per 1 psig increase in outlet pressure at small and large particle sizes.

Table V. Effect of pump outlet pressure and flow rate on particle concentrations

Manufacturer	Pump Type	Increasing Pressure		Increasing Flow Rate	
		Small Particles	Large Particles	Small Particles	Large Particles
Small Pumps					
Levitronix	BPS-1	0	0	0	0
Trebor	110R	+	0	-	-
Yamada	DP-5F	0	0	+	+
Intermediate Pumps					
Levitronix	BPS-3	0	0	0	0
Trebor	Magnum 620R	+	0	+	+
Yamada	DP-20F	++	++	0	0
Large Pumps					
Levitronix	BPS-4	+	+	+	0
Trebor	Mega 960D	+	+	0	0
Yamada	DP-25F	0	0	0	0
Almatec	Futur 50 H	+	+	0	0

key:

Concentration Change	Concentration Change due to Increasing Pressure (%/psig)	Symbol	Concentration Change due to Increasing Flow Rate
Small Decrease	<0	-	< a factor of 2 decrease
None	0-5	0	< a factor of 2 increase
Small Increase	5-20	+	> a factor of 2 increase
Large Increase	>20	++	NA

In most cases, the particle concentrations remained unchanged or slightly increased with increasing flow rate. However, during the Trebor 110R tests, the particle concentrations decreased slightly with increasing flow rate. The largest increase in particle shedding was observed with the Yamada DP-5 in which an increase of approximately a factor of 2-3 was observed at the highest flow rate tested. Most other changes in particle concentrations due to flow rate were less significant. Thus, in most cases particle shedding, that is, the number of particles shed by the pump, increased linearly with increasing flow rate. (Since particle concentrations did not increase with increasing flow rate, when the flow rate was increased by a factor of two, the number of particles shed by the pump must also increase by a factor of two.)

Figures 8-10 present the ratios of particle concentrations downstream of the Trebor, Yamada, and Almatec pumps to the Levitronix pump in the same size category as a function of particle diameter. These figures present the results for the smallest, intermediate, and largest group of pumps, respectively. Four graphs are presented in Figures 8 and 9; two comparing the Trebor pump to the comparable Levitronix pump at two different outlet pressures and two comparing the Yamada pump to the comparable Levitronix pump at two different outlet pressures. Figure 10 includes two additional graphs comparing the Almatec pump to the BPS-4 pump at two different outlet pressures. Each graph contains the results at multiple flow rates that were common in the tests. Results were not presented for particles sizes larger than 0.8 μm since the concentrations of particles above this size were very low during the Levitronix pump tests.

As stated earlier, the Levitronix pumps consistently shed the fewest particles of the pumps tested regardless of the operating conditions. Furthermore, the difference in particle shedding between all of the positive displacement pumps and the Levitronix pumps increased substantially as particle size increased.

Figure 5. Effect of operating conditions on particle shedding for small pumps

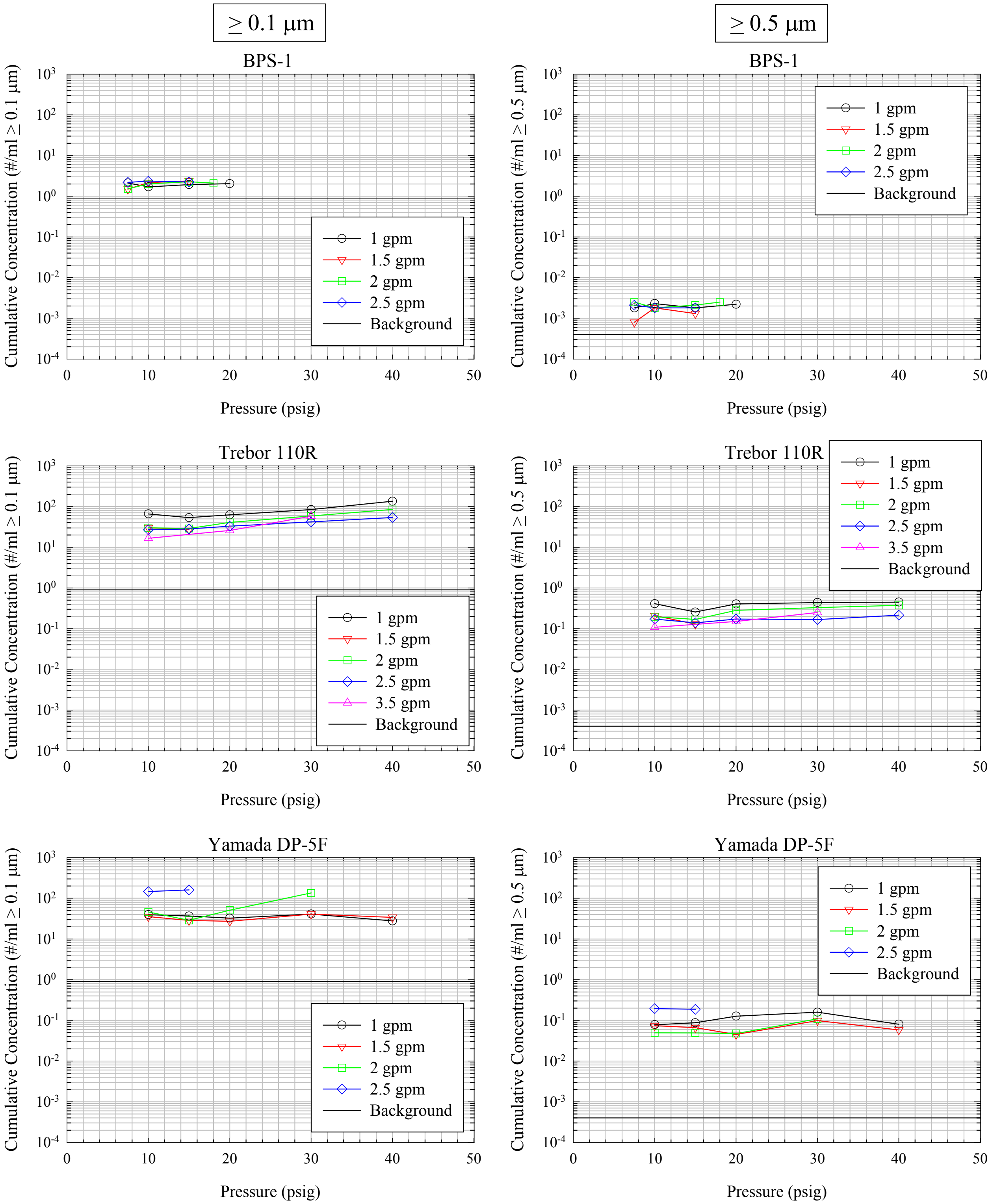


Figure 6. Effect of operating conditions on particle shedding for intermediate pumps

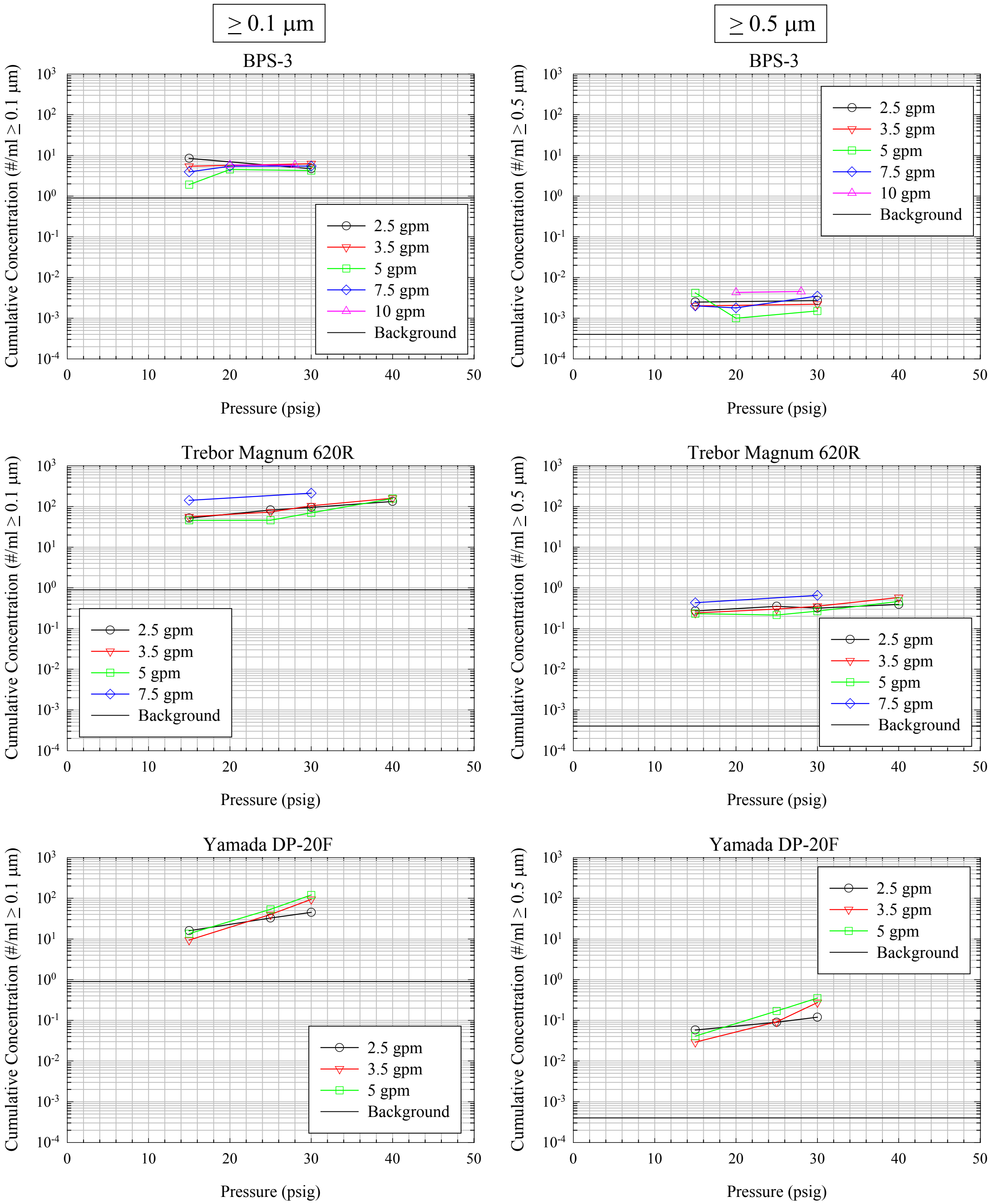


Figure 7. Effect of operating conditions on particle shedding for large pumps

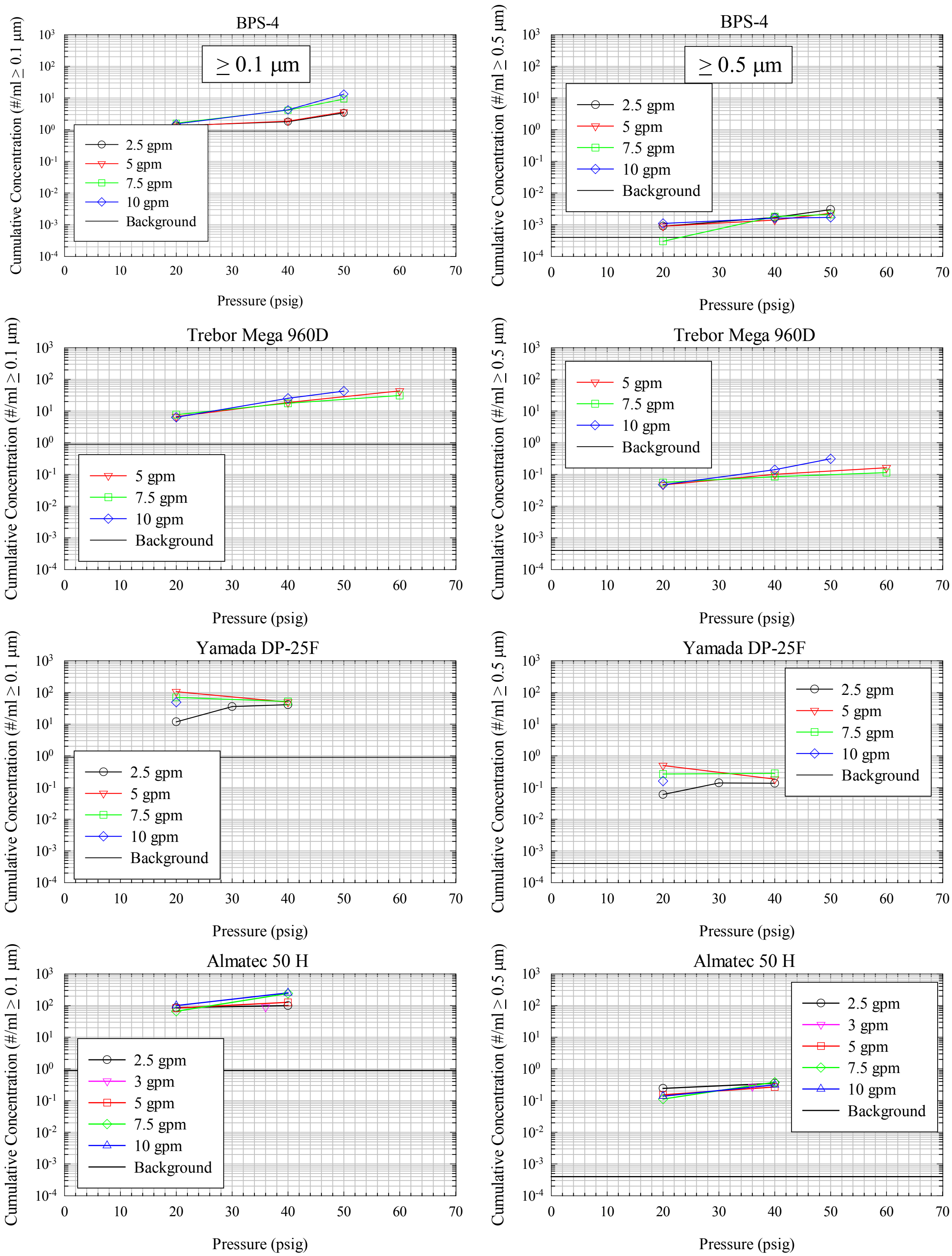


Figure 8. Small pump particle concentrations relative to the Levitronix BPS-1 pump

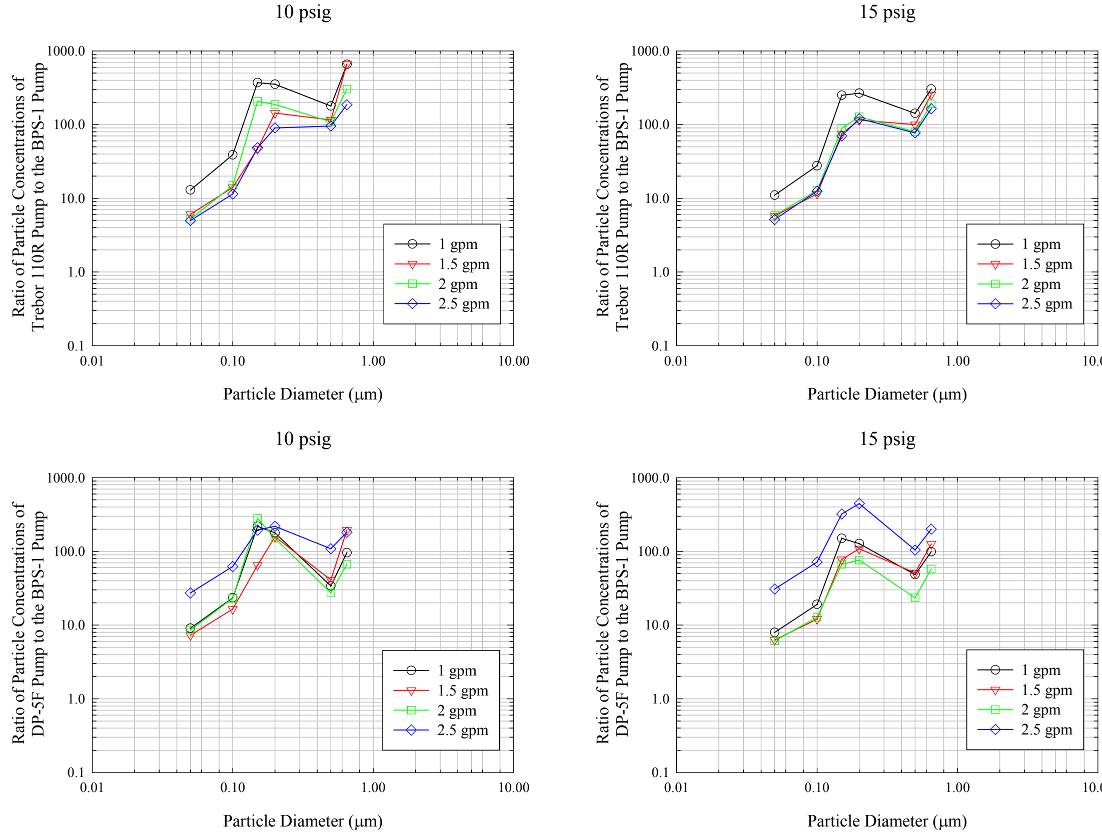


Figure 9. Intermediate pump particle concentrations relative to the Levitronix BPS-3 pump

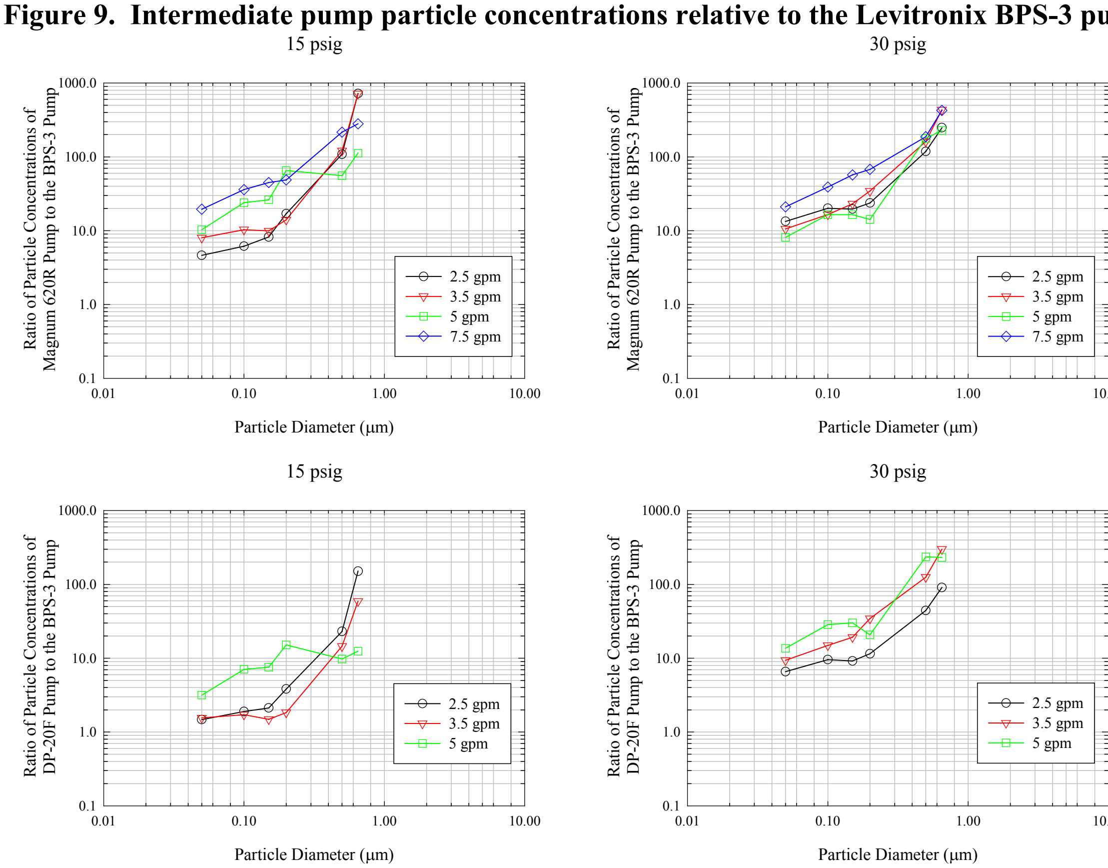


Figure 10. Large pump particle concentrations relative to the Levitronix BPS-4 pump

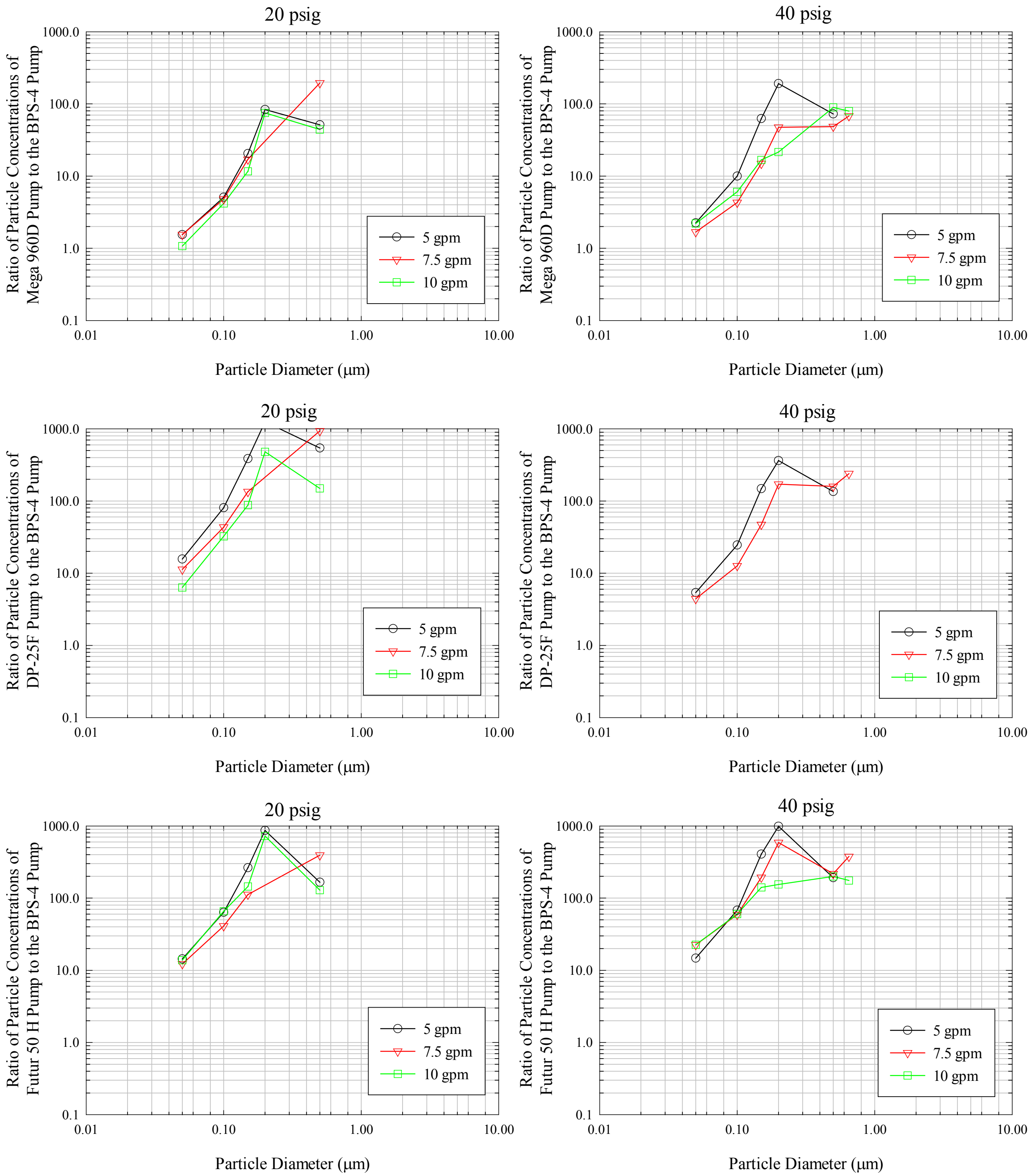


Table VI presents a summary of the data presented in Figures 8-10 at two particle size channels, ≥ 0.1 µm and ≥ 0.5 µm. The geometric mean and geometric standard deviation (GSD) are presented rather than arithmetic mean since the concentration ratios tended to be more lognormally distributed rather than normally distributed. The Trebor, Yamada, and Almatec pumps typically shed approximately 5-60 times as many particles ≥ 0.1 µm as a comparable Levitronix pump, and 40-275 times as many particles ≥ 0.5 µm.

Table VI. Comparison of the pump mean particle concentration ratios

Pump Manufacturer	Pump Type	Geometric Mean and GSD of the Concentration Ratios of the Following Pumps to the Comparable Sized Levitronix Pumps			
		≥ 0.1 µm		≥ 0.5 µm	
		Geometric Mean	GSD	Geometric Mean	GSD
Trebor	110R	17	1.6	115	1.4
	Magnum	18	1.8	133	1.5
	Mega	6	1.4	72	1.7
Yamada	DP-5F	23	1.9	48	1.7
	DP-20F	7	3.1	40	3.5
	DP-25F	32	2.0	277	2.4
Almatec	Futur 50 H	59	1.2	203	1.4

Summary

- The three Levitronix pumps consistently shed the fewest particles of the ten pumps evaluated in this study, regardless of pump operating conditions. In many cases, the particle concentrations measured downstream of the Levitronix pumps were very close to (within a factor of five) the concentrations measured without a test pump in the system.
- The slopes of the PSDs measured downstream of the Levitronix pumps were also consistently steeper than the other pumps tested and similar to the slope measured downstream of the filters. Larger differences in particle concentrations were observed between the Levitronix and other pumps at large particle sizes and smaller differences at small particles sizes because the slopes of the PSDs downstream of the Levitronix pumps were steeper.
- In general, particle shedding from the comparably sized positive displacement pumps were similar.
- Operating conditions had little effect overall on particle concentrations downstream of the pumps.
    - Pump outlet pressure had a greater effect on particle concentrations than flow rate. Particle concentrations typically remained the same or increased with increasing outlet pressure.
    - In most cases, flow rate had a minimal effect on particle concentrations. As a result, particle shedding, that is, the number of particles shed, typically increased linearly with increasing flow rate. In some cases, particle concentrations increased with increasing flow rate.