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 Three Centrifugal Pumps in Water

Submitted to:

Juergen Hahn
Levitronix GmbH

Submitted by:

Mark Litchy
Gary Van Schooneveld
CT Associates, Inc.

October 27, 2012

Introduction

Three high capacity centrifugal pumps from three different manufacturers (Levitronix, Iwaki, and Innomag) were evaluated for particle shedding in ultra pure water during operation at multiple test conditions. The pumps were tested at 15 different operating conditions. The flow rates varied from 3 to 50 gpm, while pump outlet pressures varied from 50 to 90 psig.

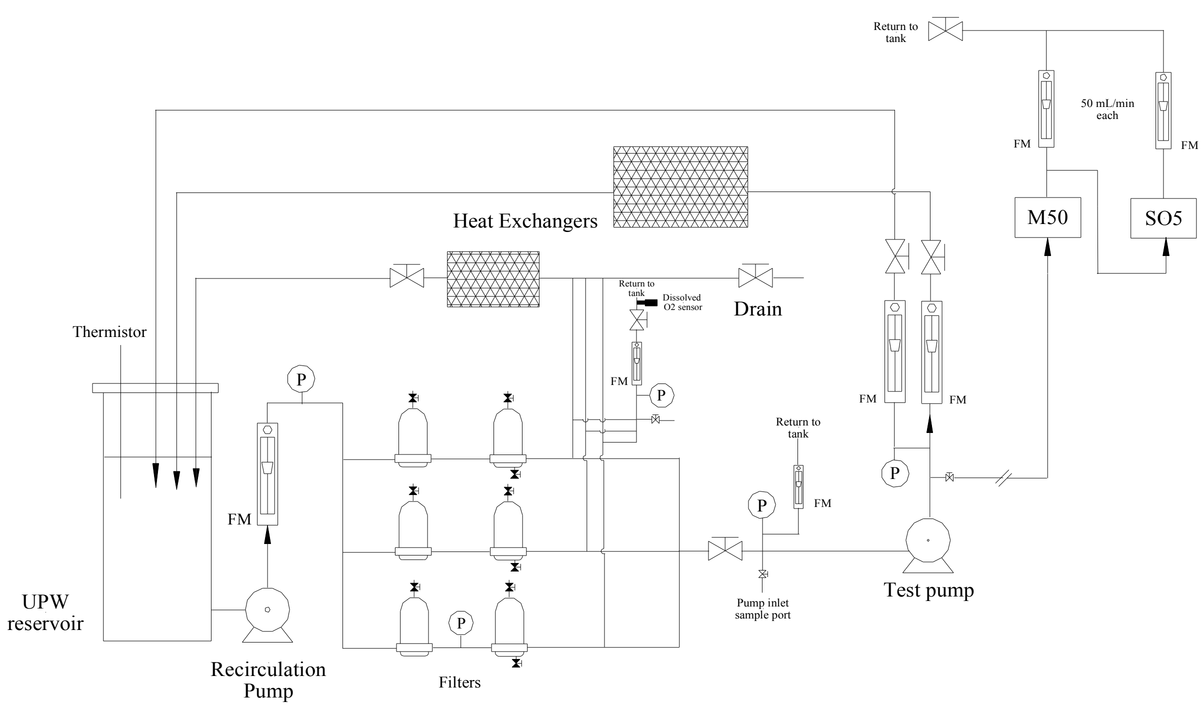
Experimental Procedure

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 Levitronix BPS-4000 pump was used to deliver filtered water to the pump under test. This pump was operated continuously to circulate water through the main loop. The water was filtered using three parallel filter banks. A filter bank consisted of one WL Gore 0.1 µm PTFE UPW filter followed by one WL Gore 0.02 µm PTFE UPW filter. The pump being evaluated drew filtered water from this supply. The pressure at the inlet of the test pump was maintained at 2 psig by adjusting the speed of the water supply pump and position of a throttle valve located in the return loop of the water system. This inlet pressure was selected as being representative of a typical flooded suction head pressure.

Table I. Comparison of pumps evaluated (from literature)

Manufacturer	Pump Type	Rated Maximum Flow Rate in water (gpm)	Rated Maximum Differential Pressure in water (psig)
Levitronix	BPS-4000	74	91
Iwaki	MDM-1518	70	78
Innomag	U-Mag-U1	175	72

Figure 1. Schematic of test system



Two water-cooled heat exchangers were used to maintain the temperature of the water in the system at 27±3°C. A Membrana Model G288 membrane contactor with an applied vacuum was used to maintain a low level of dissolved gas in the water system. The dissolved oxygen level in the water was monitored using an in-line dissolved oxygen sensor located on one of return lines to the water tank.

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.

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.

Background levels for the water system (particle concentration of the water going into the a test pump) were measured from a port installed on the inlet supply pipe to the pump. In order to supply sufficient pressure to the particle counter during measurement of the background, the supply pump speed was increased and the valves downstream of the test pump were partially closed to restrict but not shutoff the water flow through the pump. 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 the 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 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 the pumps

Flow rate (gpm)	Outlet Pressure (psig)
3	50
5	50
10	50
20	50
50	50
3	70
5	70
10	70
20	70
45	70
3	90
5	90
10	90
20	90
35	90

The desired operating conditions were achieved by either adjusting the pump speed and the pump outlet pressure with a control valve located downstream of the test pump. Since not all pumps were able to achieve 50 gpm at each outlet pressure, the pumps were operated at 45 gpm at 70 psig and 35 gpm at 90 psig. All of the pumps were capable of achieving the outlet pressures and flow rates shown in Table II, except the Innomag pump, which was only capable of achieving a maximum flow rate of 21 gpm at 90 psig.

Following the parametric study, four dry run tests were performed with each pump. To prepare the pump for the dry run test, the supply and discharge connections were removed and the water was drained from the pump. A supply of clean-dry air (CDA) was attached to the pump outlet. Air was supplied to the pump outlet as a pressure of 80 psi and the pump was operated at a low speed to help facilitate the removal of water in the pump head. After the water cleared, the CDA was run for an additional ten minutes before starting the dry run. After removing the CDA connection, each pump was then operated without liquid in the pump for a period of time at particular speed. Details of the length of time and pump speed are shown in Table III for each pump. Following each dry run, the pump was reinstalled into the test system and operated at a flow rate of 20 gpm and 70 psig for up to 5 hours. The particle concentrations downstream of each pump were monitored over time following each dry run test.

Table III. Dry run tests performed on each pump

Test	Dry Run Time (minutes)	Pump Speed (rpm)		
		Levitronix	Iwaki	Innomag
1	1	4,000	3,500	3,500
2	3	4,000	3,500	3,500
3	1	8,000	3,950	3,920
4	3	8,000	3,950	3,920

Results and Discussion

System background particle levels are presented in Table IV. The results shown represent the mean concentrations measured over a period of 24 hours.

Table IV. 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	1.1	0.3	0.06	0.02	0.0002

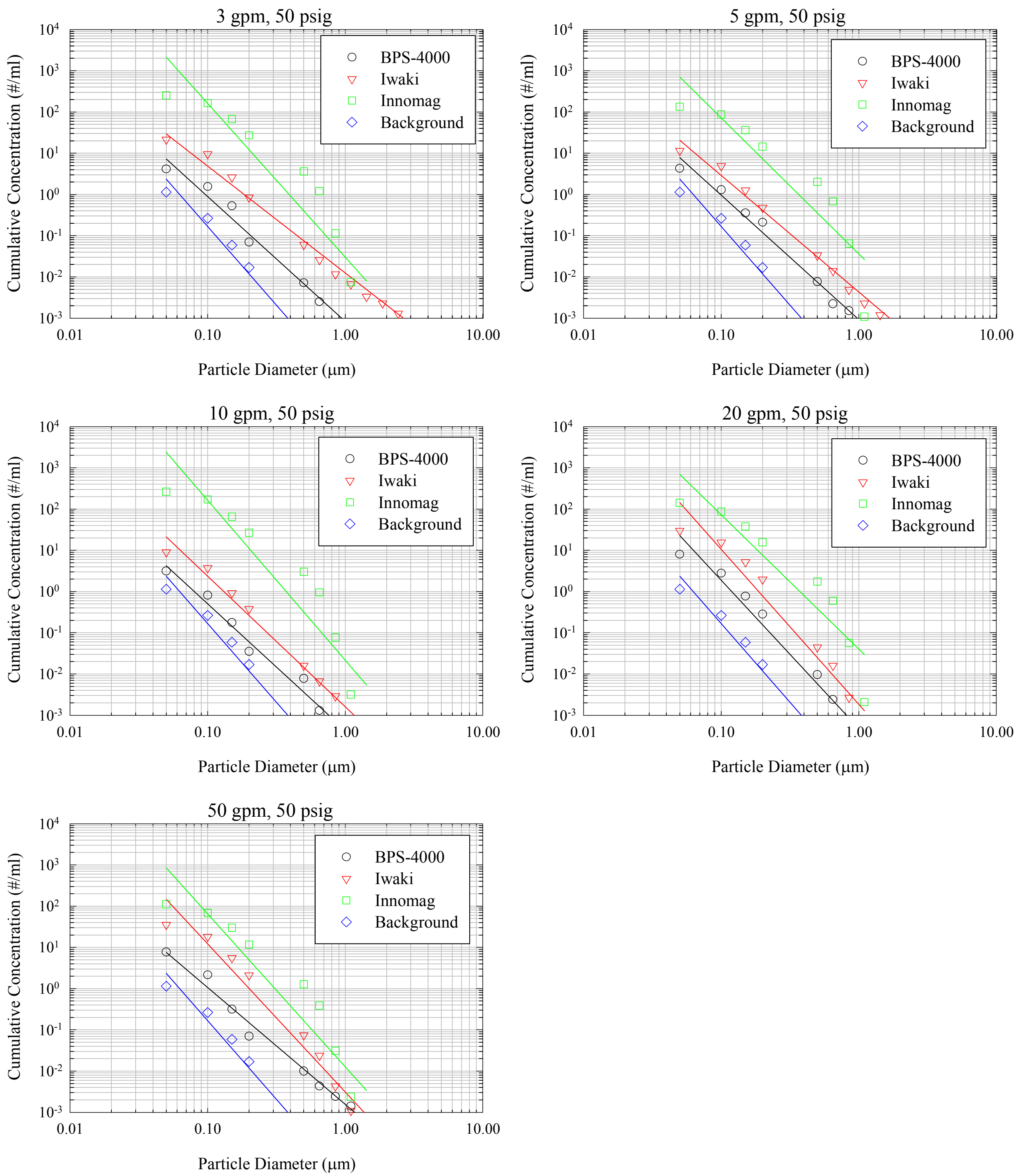
Particle Shedding during Normal Operation

The quasi steady-state particle concentrations measured downstream of each pump are presented in Figures 2-4 at 15 different operating conditions. The system background particle concentrations are also presented in each figure. Each figure presents the results from each pump at the following operating pressures, 50, 70, 90 psig, respectively. Five graphs are presented in each figure, one for each flow rate tested. (The Innomag pump was not capable of operating at the highest flow rate, 35 gpm at 90 psig, and thus the results are presented at 21 gpm.) 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.

Typically, if a pump shed fewer particles than another pump at one test condition, it shed fewer particles than the other pump at all operating conditions.

Figure 2. PSDs measured downstream the pumps at P = 50 psig at various flow rates



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 the pumps at P = 70 psig at various flow rates

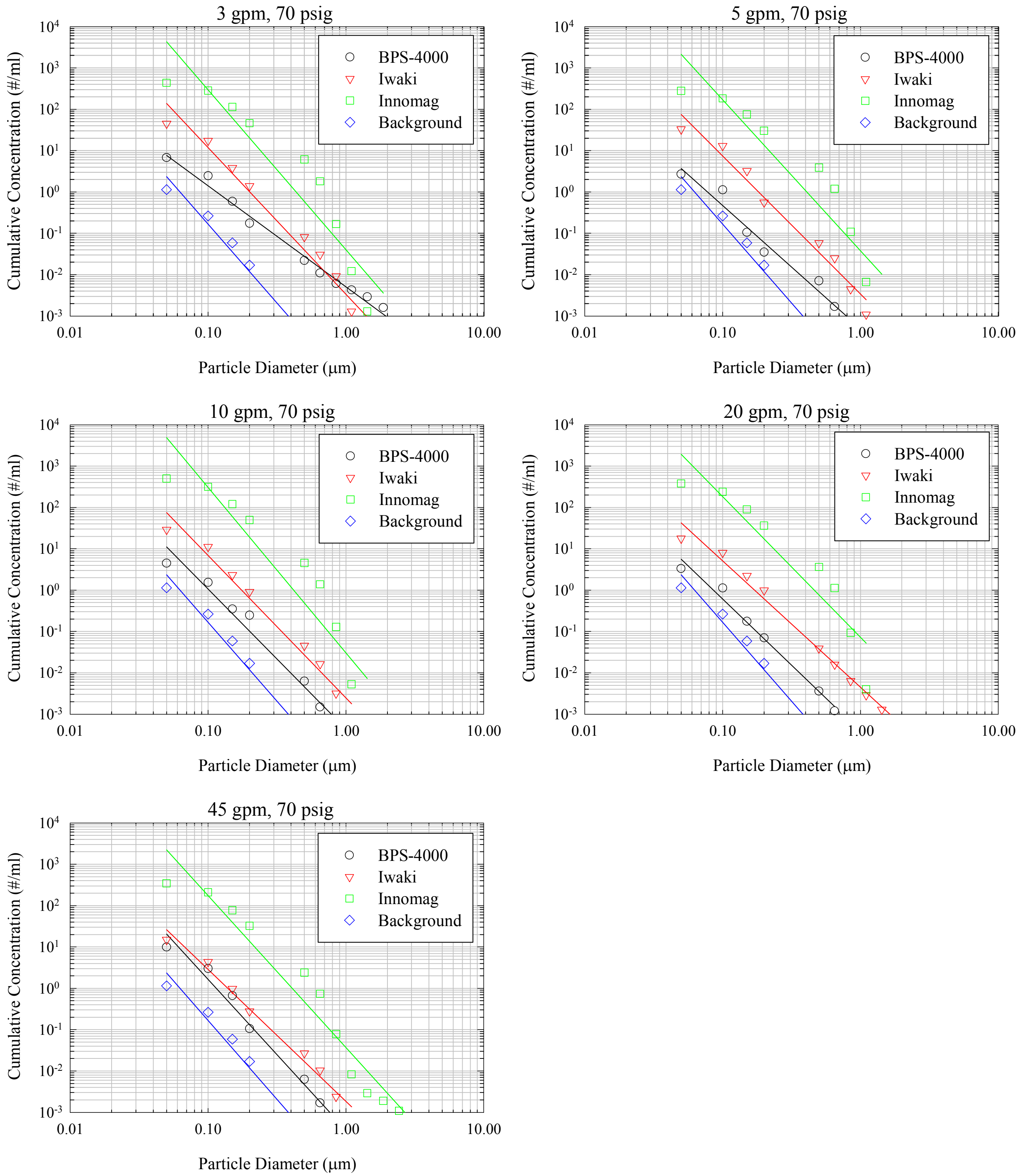


Figure 4. PSDs measured downstream the pumps at P = 90 psig at various flow rates

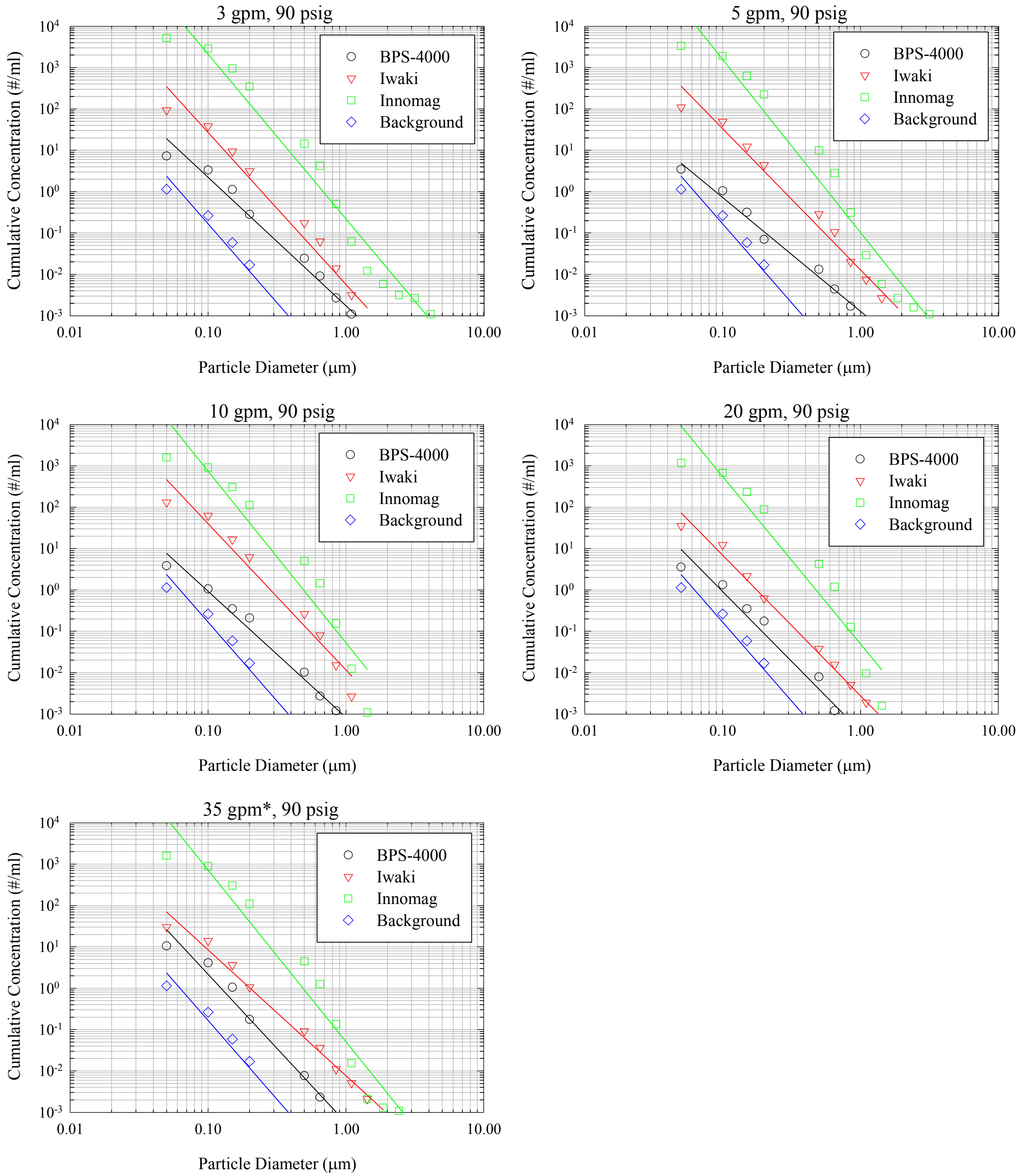


Figure 5 presents the ratios of particle concentrations measured downstream of the Iwaki and Innomag pumps to the concentrations measured downstream of the Levitronix pump as a function of particle diameter. Six graphs are presented in Figure 5; three comparing the Iwaki pump to the Levitronix pump, one for each outlet pressure tested and three comparing the Innomag pump to the Levitronix pump, one for each outlet pressure tested. Each graph contains the results at multiple flow rates that were common in the tests. Results were not presented for particles sizes larger than 1.0 µm since the concentrations of particles above this size were very low during the Levitronix pump tests. These ratios clearly show that the Levitronix pumps consistently shed the fewest particles of the pumps tested regardless of the operating conditions.

Figure 5. Pump particle concentrations relative to the Levitronix BPS-4000 pump

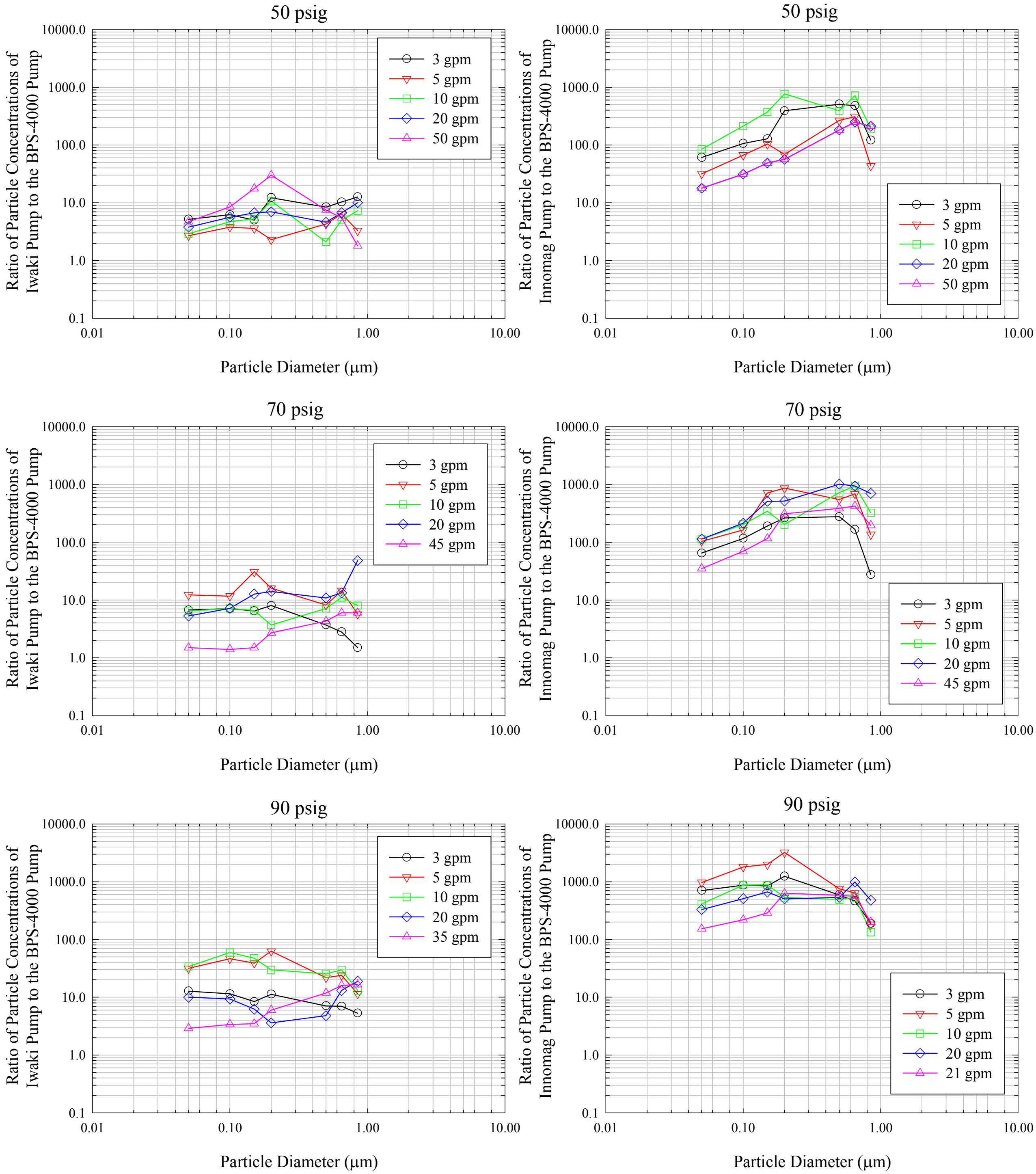


Table V presents a summary of the data presented in Figure 5. The geometric mean of the calculated concentration ratios at all 15 test conditions are presented as a function of particle size. (The geometric mean is presented rather than arithmetic mean since the concentration ratios tended to be more lognormally distributed rather than normally distributed.) Thus, on average, the Iwaki pump shed approximately 5-10 times as many particles as the Levitronix pump, while the Innomag pump shed 100-400 times as many particles as the Levitronix pump.

Table V. Comparison of the mean of the calculated concentration ratios at all 15 test conditions

Pump	Geometric Mean of the Concentration Ratios of the Following Pumps to the Levitronix Pump	
	Iwaki	Innomag
≥ 0.05 µm	6.4	100
≥ 0.10 µm	8.0	190
≥ 0.15 µm	8.5	310
≥ 0.20 µm	9.6	400
≥ 0.50 µm	7.1	430
≥ 0.65 µm	9.5	460
≥ 0.85 µm	7.9	140

Figure 6 presents the effect of flow rate and outlet pressure on particle shedding from each pump over the range of operating conditions presented in Figures 2-4. Six graphs are presented in Figure 6. The three graphs on the left present particle concentrations ≥ 0.1 µm for each of the pumps tested, while the graphs on the right present particle concentrations ≥ 0.5 µm. 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.

Table VI 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 for the Iwaki and Innomag pumps, but had little effect for the Levitronix pump. The largest effect occurred during the Innomag tests at smaller particles sizes where the particle concentrations increased significantly as outlet pressure increased. Flow rate appeared to have little effect regardless of pump type or outlet pressure over the range of flow rates evaluated in this study.

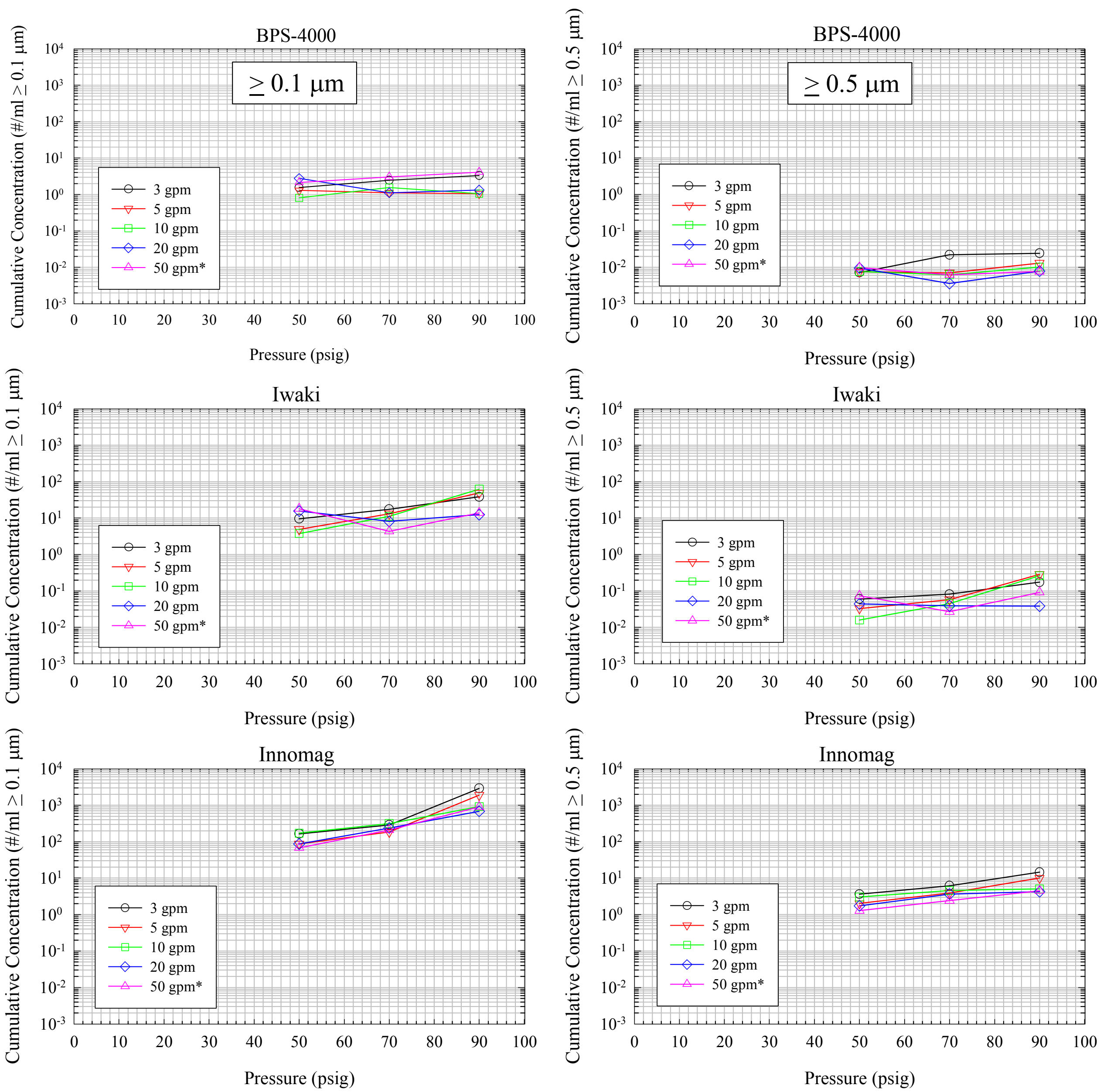
Table VI. Effect of pump outlet pressure and flow rate on particle concentrations

Pump	Increasing Pressure		Increasing Flow Rate	
	Small Particles	Large Particles	Small Particles	Large Particles
Levitronix	0	0	0	0
Iwaki	+	+	0	0
Innomag	++	+	0	-

Key:

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

Figure 6. Effect of operating conditions on particle shedding



Particle Shedding after Dry Runs

Figures 7-9 present the particle concentrations of selected size channels measured downstream of each pump following each dry run test. Particle concentration results are presented for the first five hours after the dry runs for each pump and dry run test, except the Levitronix tests. Particle concentrations typically stabilized within 10-20 minutes after the Levitronix dry run tests and concentration levels were consistently low and repeatable, thus these tests were terminated after one hour. Like the Levitronix dry run results, the Iwaki and Innomag dry run results typically took 10-50 minutes to achieve stable concentrations, but the results were not always stable over several hours. Step changes in the concentrations were observed during some of the tests. More importantly, the results following each dry run test were highly variable and even after 300 minutes the concentrations were sometimes 100 times higher than measured at the same operating conditions (20 gpm and 70 psig) prior to the dry run tests. After 300 minutes, the concentrations ≥ 0.10 µm ranged from 10 to 1,000 particles/ml for the Iwaki pump and 300 to >10,000 particles/ml for the Innomag pump. Table VII provides a summary of the dry run results for each pump after 10, 60, and 300 minutes. Furthermore, particle concentrations ≥ 0.10 µm measured five hours after dry runs resulted in 2-200 times higher particle concentrations with the Iwaki pump and 60-2,000 times higher concentrations with the Innomag pump relative to the Levitronix pump.

Figure 7. Effect of dry runs on the Levitronix pump particle shedding

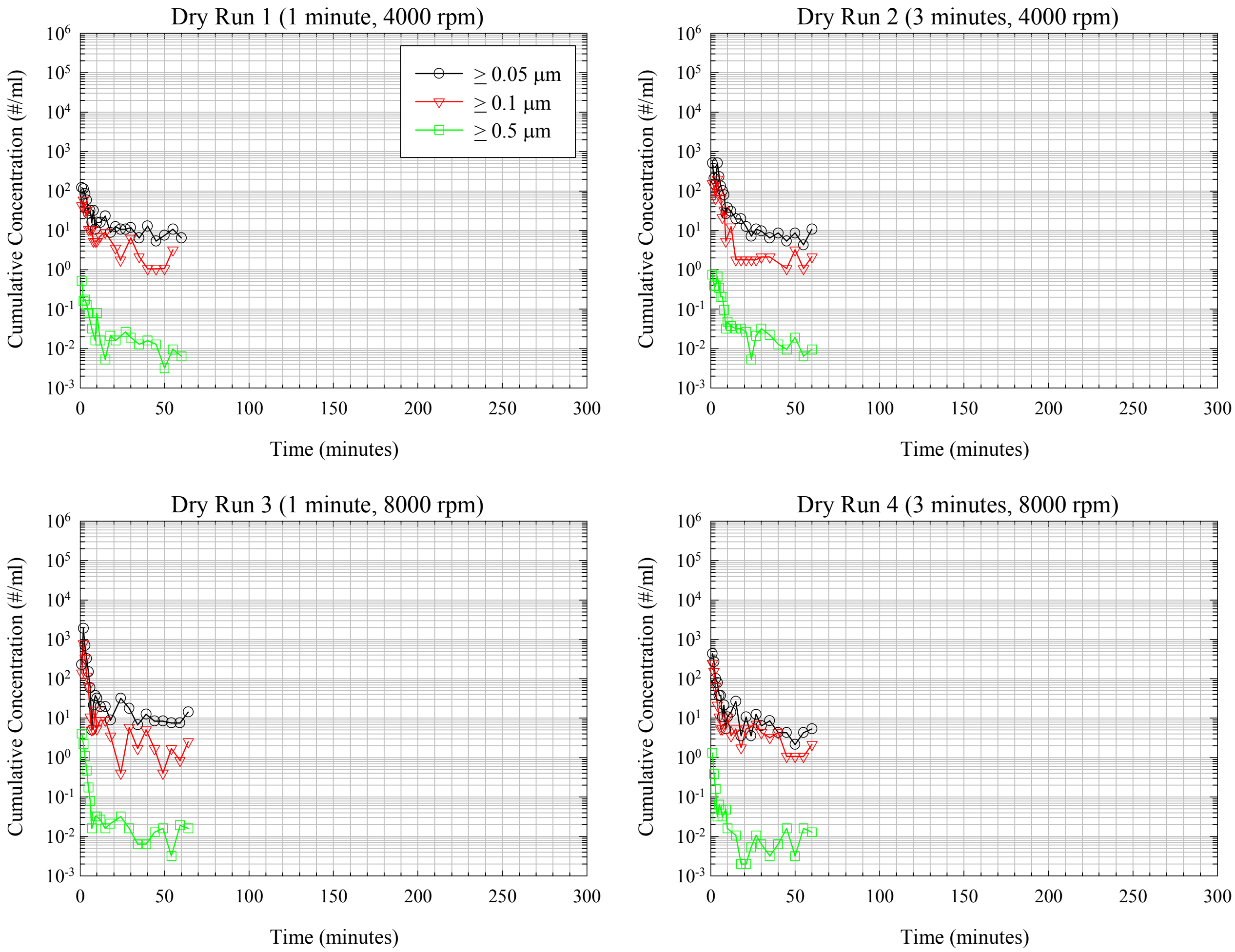


Figure 8. Effect of dry runs on the Iwaki pump particle shedding

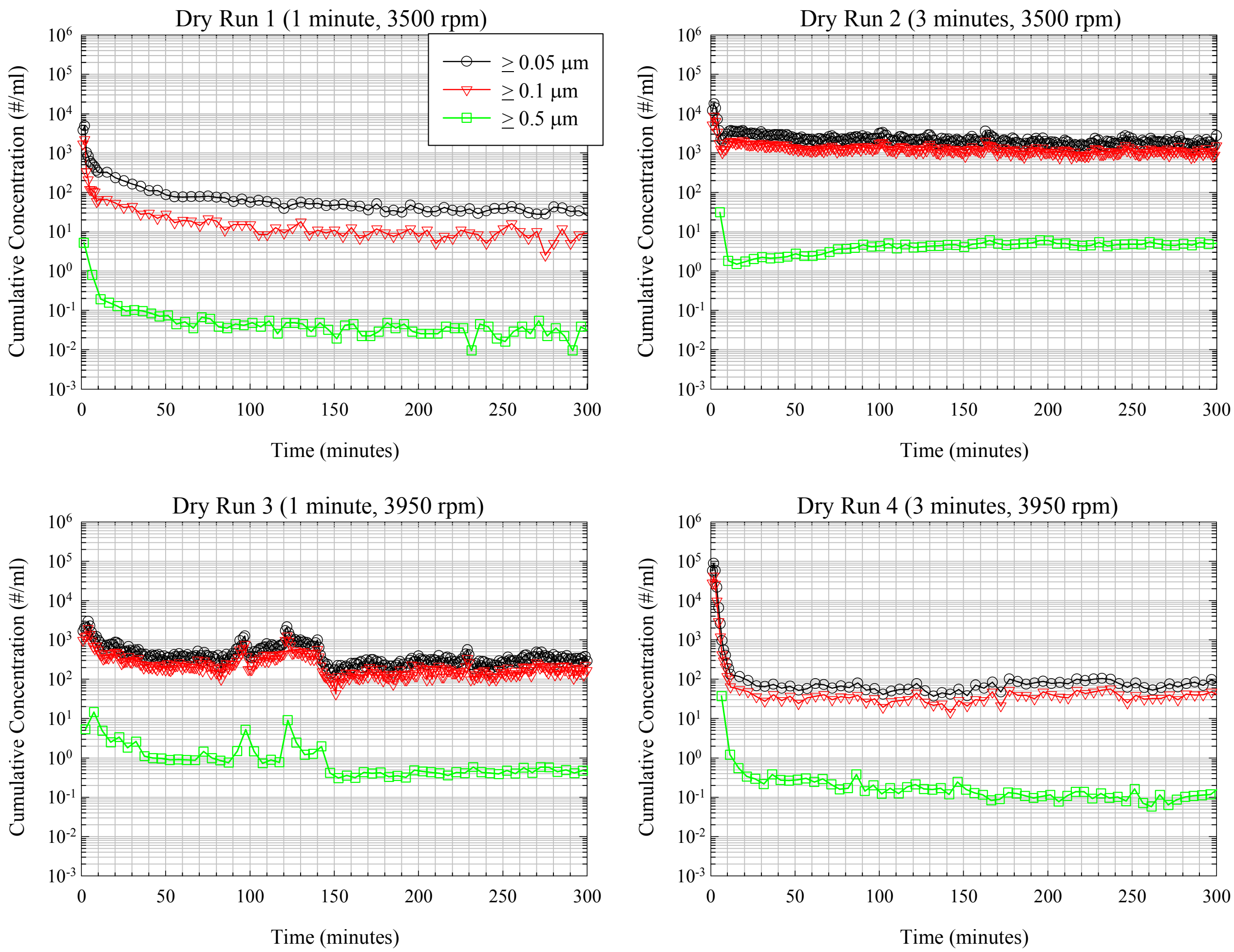
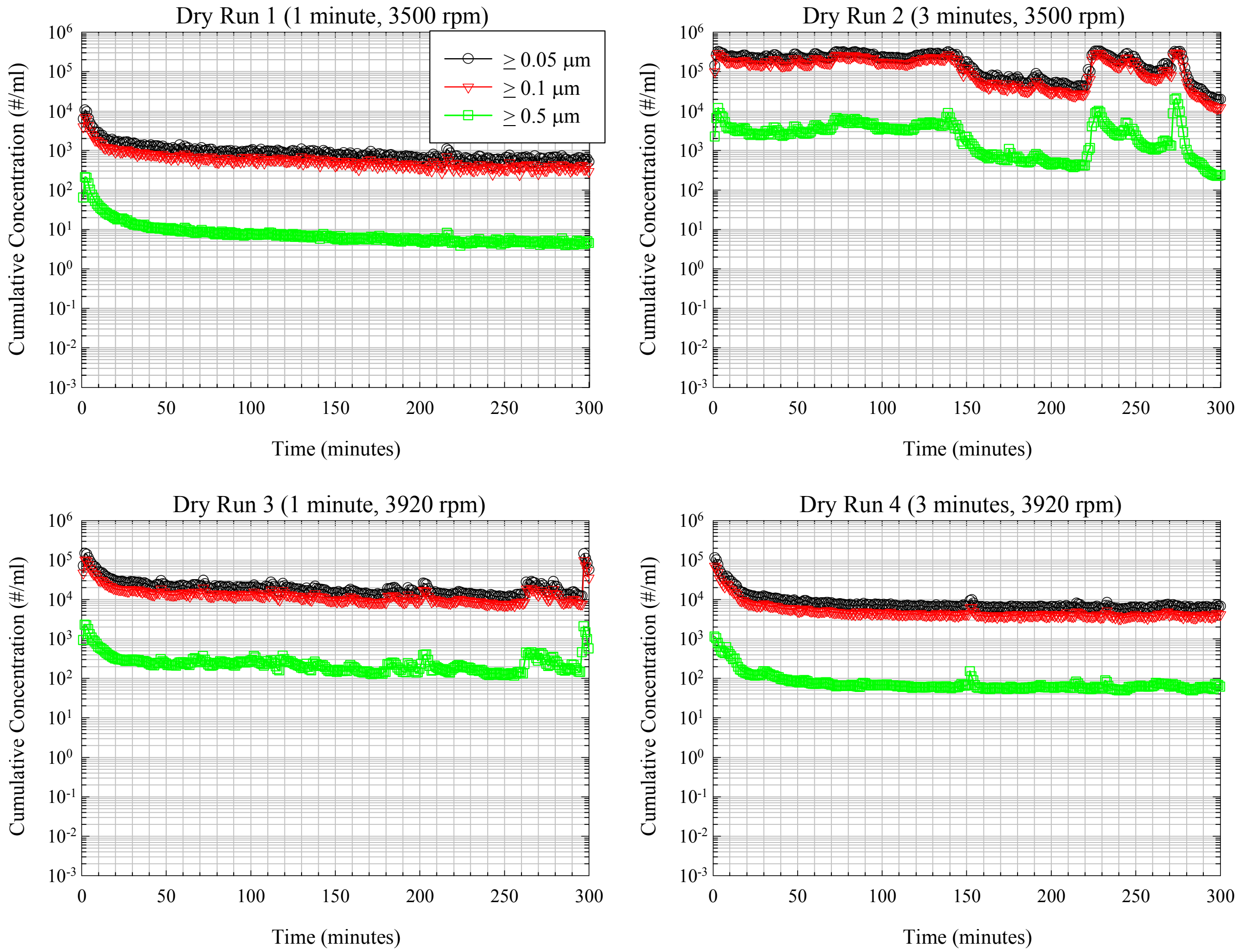


Table VII. Comparison of particle shedding after dry run tests for each pump

Dry Run Test	≥ 0.1 µm			≥ 0.5 µm		
	BPS-4000	Iwaki	Innomag	BPS-4000	Iwaki	Innomag
	At 10 minutes					
1	5	65	1,650	0.1	0.3	40
2	8	1,500	>10,000	0.05	2	3,600
3	5	550	>10,000	0.03	10	650
4	10	100	>10,000	0.02	3	400
	At 1 hour					
1	<5	20	800	<0.02	0.1	10
2	<5	1,100	>10,000	<0.02	2.5	4,000
3	<5	200	>10,000	<0.02	0.1	250
4	<5	35	5,000	<0.02	0.3	70
	At 5 hours					
1	<5	10	300	<0.02	0.03	5
2	<5	1,000	>10,000	<0.02	5	200
3	<5	150	>10,000	<0.02	0.5	200
4	<5	40	4,000	<0.02	0.1	60

Figure 9. Effect of dry runs on the Innomag pump particle shedding



Summary

- The Levitronix pump consistently shed the fewest particles of the 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 Iwaki pump typically shed approximately 5-10 times as many particles as the Levitronix pump, while the Innomag pump typically shed 100-400 times as many particles as the Levitronix pump.
- During the Iwaki and Innomag dry run tests, the results were highly variable and even after 300 minutes the concentrations were sometimes 100 times higher than measured at the same operating conditions (20 gpm and 70 psig) prior to the dry run tests. After 300 minutes, the concentrations ≥ 0.10 μm ranged from 10 to 1,000 particles/ml for the Iwaki pump and 300 to >10,000 particles/ml for the Innomag pump.
- Operating conditions had little effect overall on particle concentrations downstream of the pumps.
  - Outlet pressure appeared to have a significant effect on particle concentrations for the Iwaki and Innomag pumps, but had little effect for the Levitronix pump.
  - Flow rate appeared to have little effect regardless of pump type or outlet pressure over the range of flow rates evaluated in this study.