Comparison of Particle Shedding of High Purity Pumps

Mark Litchy
CT Associates, Inc.

Juergen Hahn
Levitronix GmbH

2013 Sematech Workshop of Nanoparticle Defectivity Issues in Solutions
July 9, 2013

Creative Technology

Introduction

- Semiconductor devices are extremely sensitive to particulate contamination.
- As feature sizes continue to decrease, the need for purity continues to increase.
- High purity pumps are used in many semiconductor processes:
  - bulk chemical delivery
  - ultra pure water systems
  - recirculating etch baths
  - and other high purity process applications
- Particulate contamination can:
  - directly reduce product yield
  - degrade the performance and lifetime of filters

Creative Technology

Test Procedure

- 12 high purity pumps from 5 different manufacturers were evaluated for particle shedding in UPW.
- Pump sizes were chosen based on similarity to Levitronix BPS-1, BPS-3, BPS-4, and BPS-4000 maglev centrifugal pumps.
- Operating conditions (outlet pressure and flow rate) were chosen such that all pumps in a group could be evaluated at similar conditions.

Pump Size	Flow rate (gpm)	Pressure (psig)
Small	1.0- 2.5	10 - 15
Intermediate	2.5 – 5.0	15 - 30
Large	5 - 10	20 - 40
Extra large	3 - 50	50 - 90

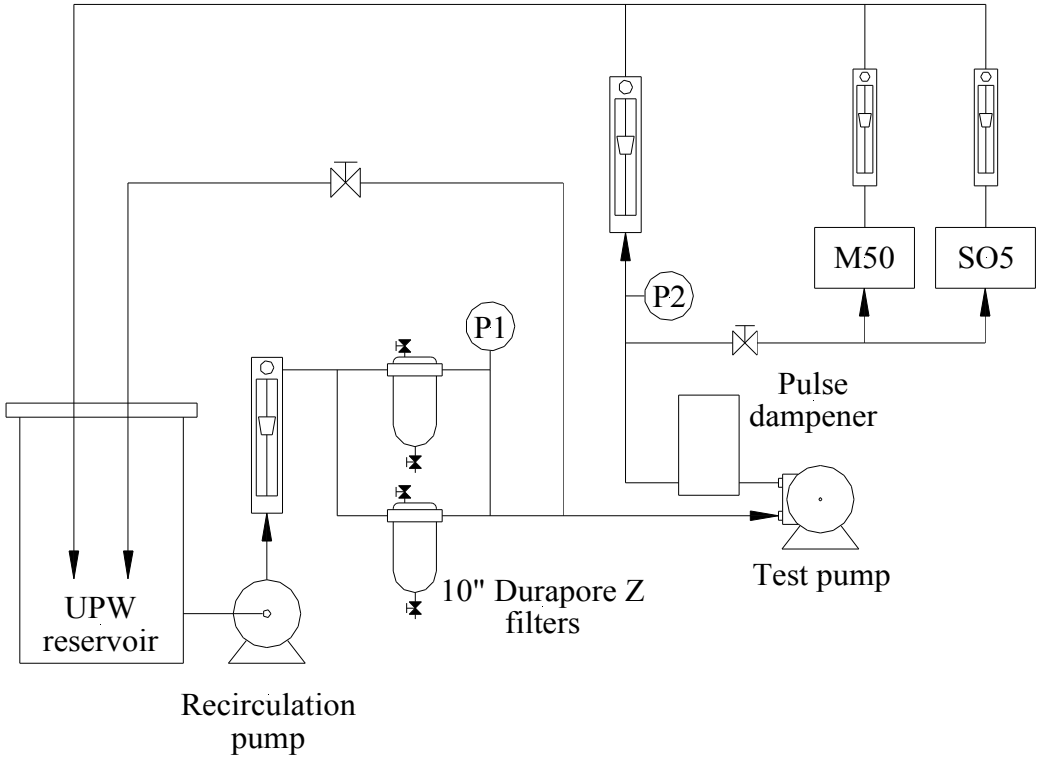
Creative Technology

Comparison of pumps evaluated

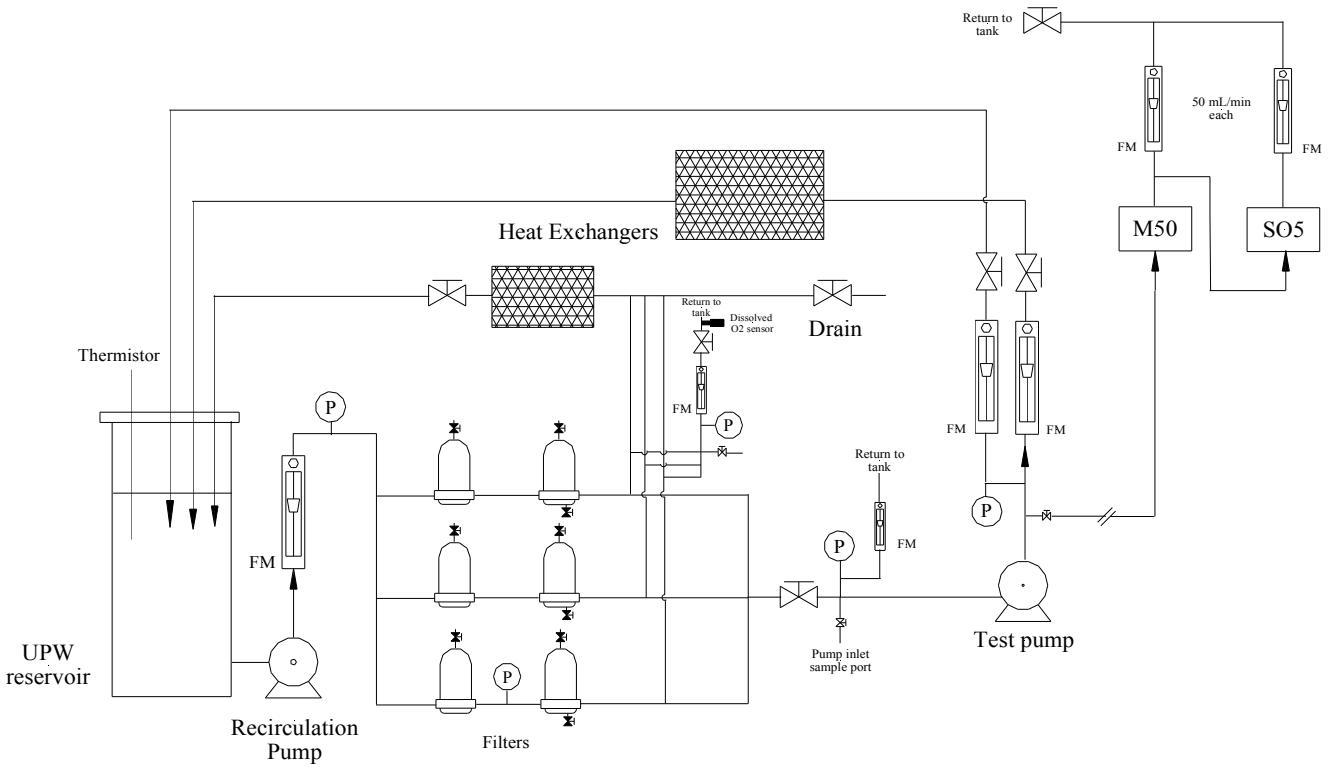
Manufacturer	Pump Type	Maximum Flow Rate (gpm)	Maximum Discharge Pressure (psig)
Small Pumps			
Levitronix BPS-1	maglev centrifugal	5.5	23
A1	diaphragm	5.3	60
B1	diaphragm	2.9	70
Intermediate Pumps			
Levitronix BPS-3	maglev centrifugal	20	36
A2	diaphragm	11	80
B2	diaphragm	14	45
Large Pumps			
Levitronix BPS-4	maglev centrifugal	37	65
A3	diaphragm	22	80
B3	diaphragm	17	70
Extra Large Pumps			
Levitronix BPS-4000	maglev centrifugal	74	91
C1	magnetic drive centrifugal	70	78
D1	magnetic drive centrifugal	175	72

Creative Technology

Schematic of particle shedding test system (other pumps)



Schematic of particle shedding test system (extra large pumps)



ITRS Requirements for 2011 and Beyond

Table YE3 Technology Requirements for Wafer Environmental Contamination Control

Year of Production	2011	2012	2013	2014	2015	2016
Flash ½ Pitch (nm) (un-contacted Poly)(f)	28	25	23	20	18	15.9
DRAM ½ Pitch (nm) (contacted)	40	36	32	28	25	22.5
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)	38	32	27	24	21	18.9
MPU Printed Gate Length (nm) ††	35	31	28	25	22	19.8
MPU Physical Gate Length (nm)	24	22	20	18	17	15.3
Critical particle size (nm) [1]	25	22.5	20	17.9	15.9	14.2
Ultrapure Water [29]						
Resistivity at 25°C (MOhm-cm)	18.2	18.2	18.2	18.2	18.2	18.2
Total oxidizable carbon (ppb) [22]	<1	<1	<1	<1	<1	<1
Critical Organics as C (ppb) [41]	TBD	TBD	TBD	TBD	TBD	TBD
Non-polar Organics as C (ppb) [41]	TBD	TBD	TBD	TBD	TBD	TBD
Polar Protic Organics as C (ppb) [42]	TBD	TBD	TBD	TBD	TBD	TBD
Polar Aprotic Organics as C (ppb) [42] [43]	TBD	TBD	TBD	TBD	TBD	TBD
Bacteria (CFU/liter) [38]	<1	<1	<1	<1	<1	<1
Total silica (ppb) as SiO_2 [18]	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Colloidal Silica (ppb) s SiO2 (add note)	TBD	TBD	TBD	TBD	TBD	TBD
Number of particles >critical particle size (see above) (#/L) [26]	4000	4000	4000	4000	4000	4000
Dissolved oxygen (ppb) (contaminant based) [16]	<10	<10	<10	<10	<10	<10
Dissolved nitrogen (ppm) [10]	8–18	8–18	8–18	8–18	8–18	8–18
Metals (ppt each) (Co, Cr,Ga,Ge,Mn,Mo,Sr,Ti,)	<10	<10	<10	<10	<10	<10
Critical metals (ppt, each) (Ag,Al,Au,Ba,Ca,Cu,Fe,Hf,K,Li,Mg,Na,Ni,Pt,Zn)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Other critical ions (ppt each) [24]	<50	<50	<50	<50	<50	<50

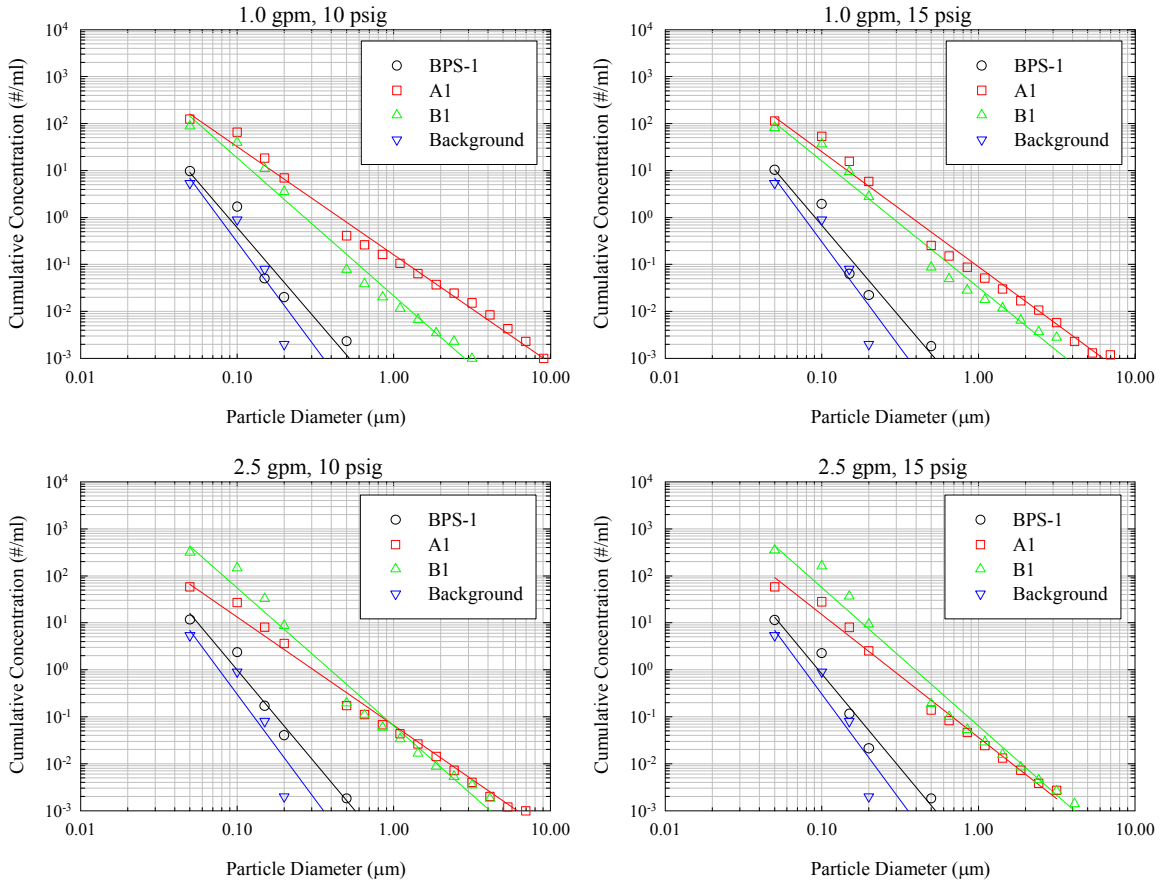
Creative Technology

Problems associated with optical particle counters

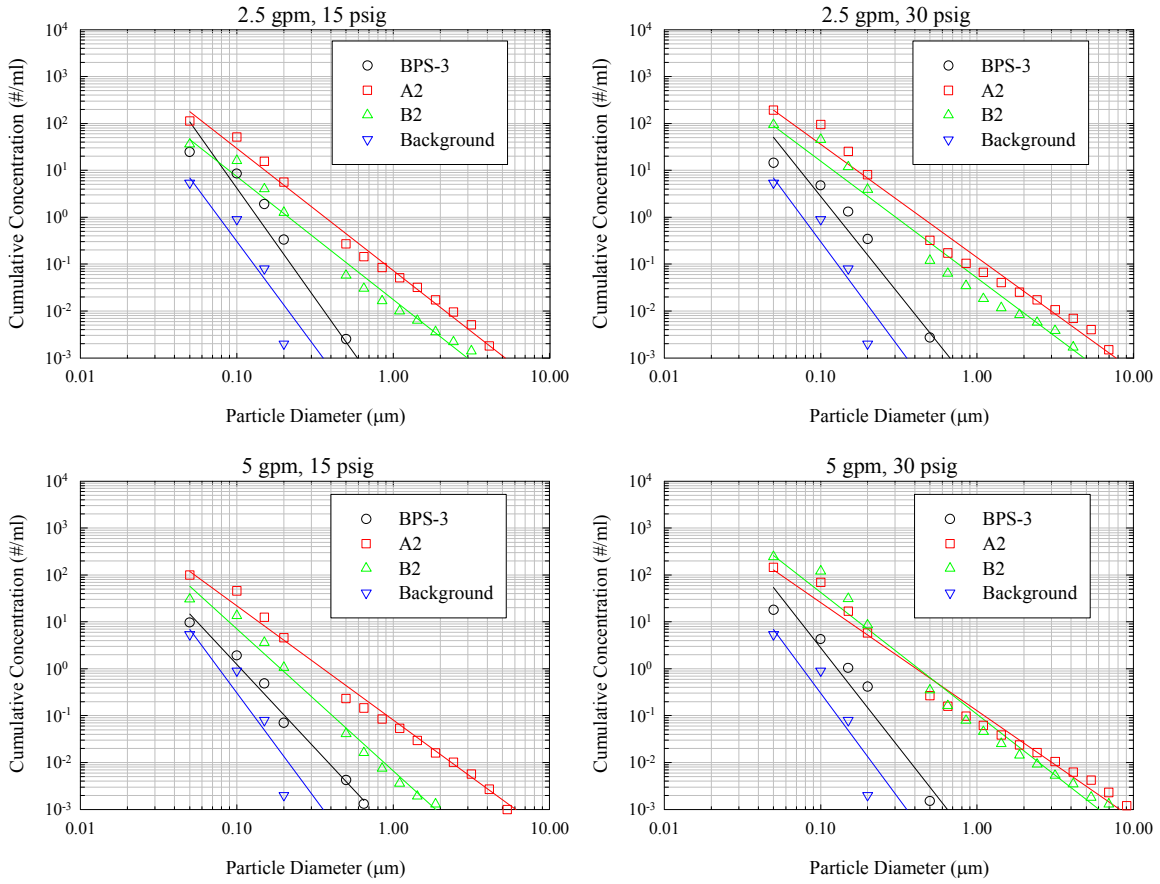
- Sensitivity
  - Current technology: 25-40 nm particle detection
- Low inspection flow rates
  - 0.25-3.75 ml/min
- False counts
  - Cosmic rays, electronic noise, stray scattering, molecular scattering, etc.
- Gas bubbles
- Index contrast
- Particle coincidence

Creative Technology

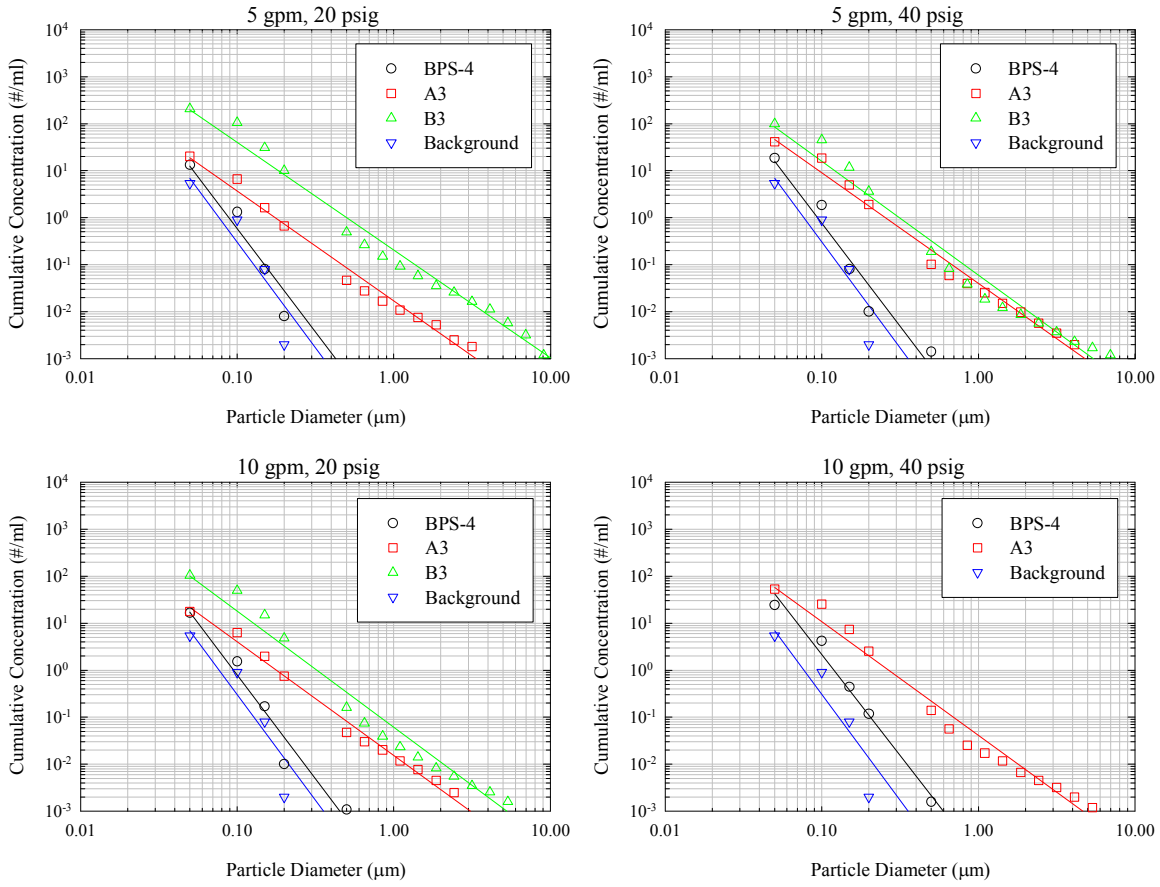
PSDs: Small pumps



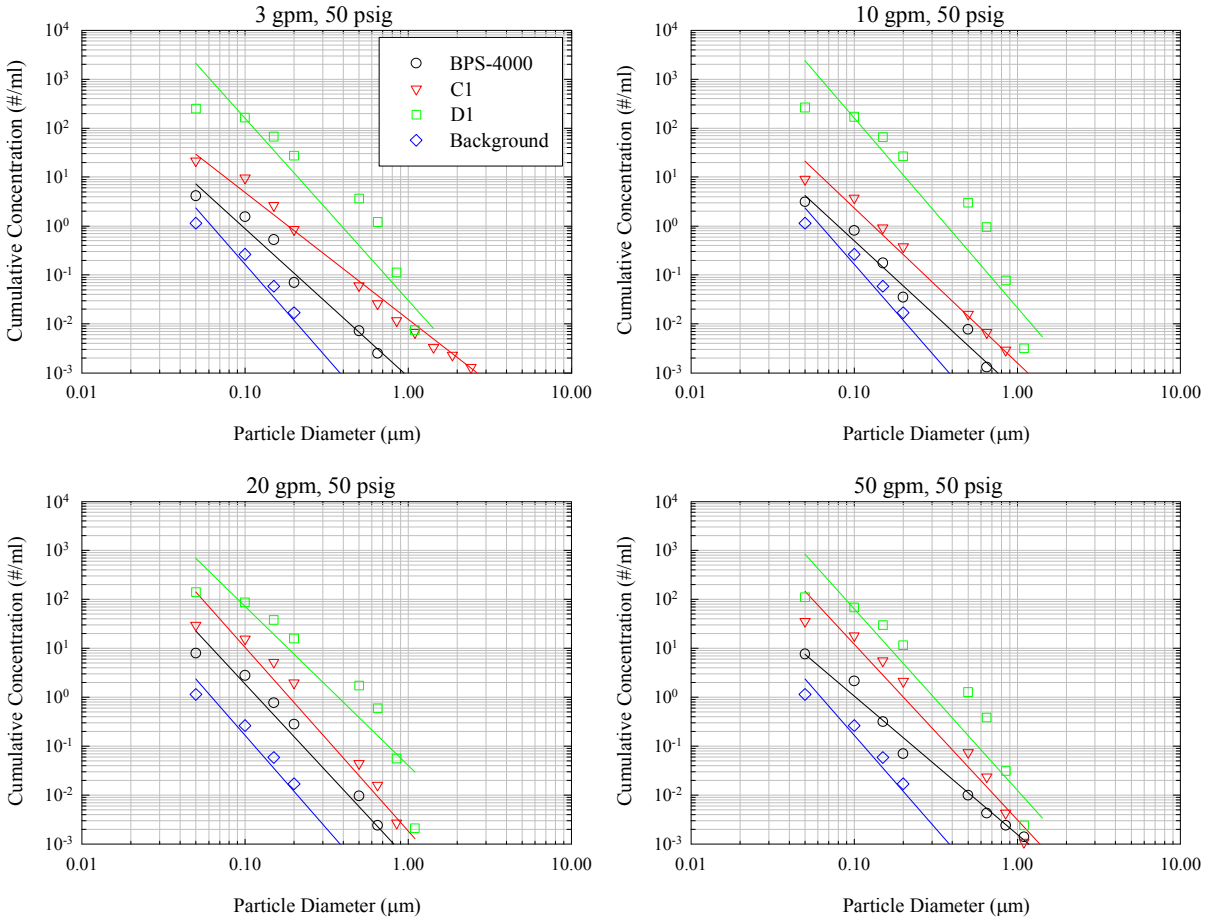
PSDs: Intermediate pumps



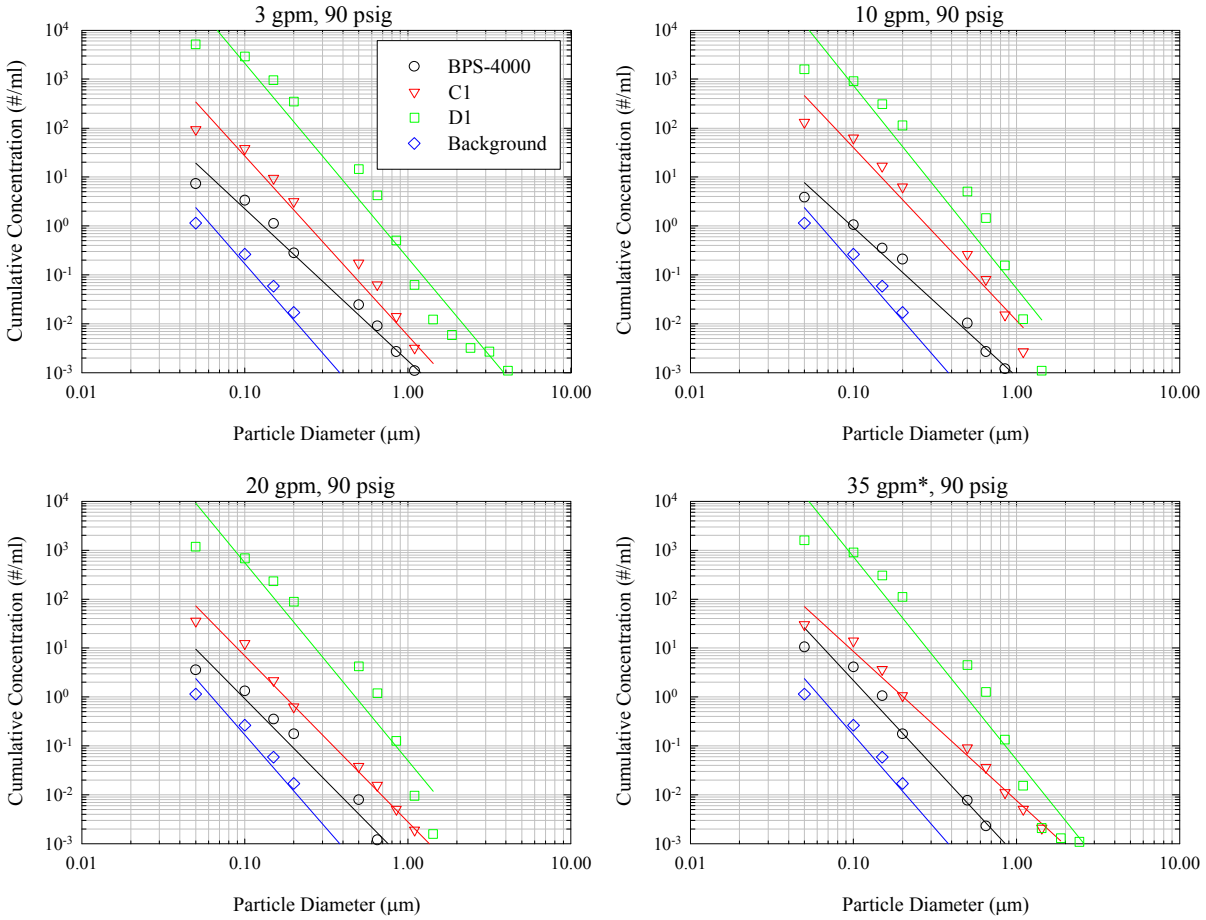
PSDs: Large pumps



PSDs: Extra large pumps @ 50 psig

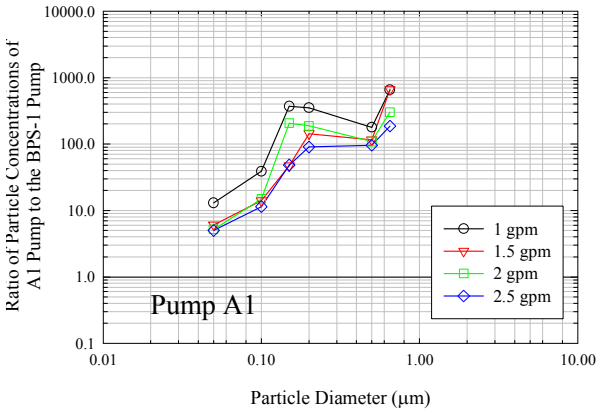


PSDs: Extra large pumps @ 90 psig

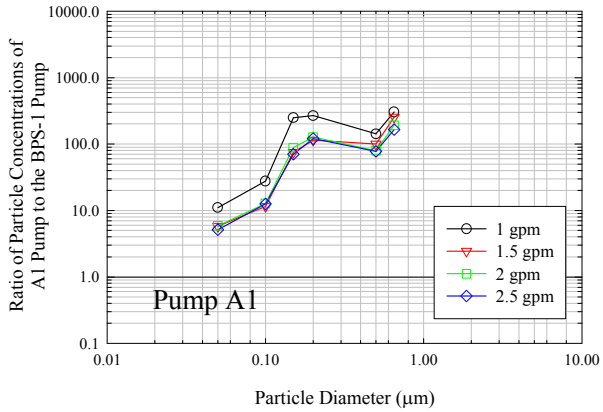


Small pump particle concentrations relative to BPS-1

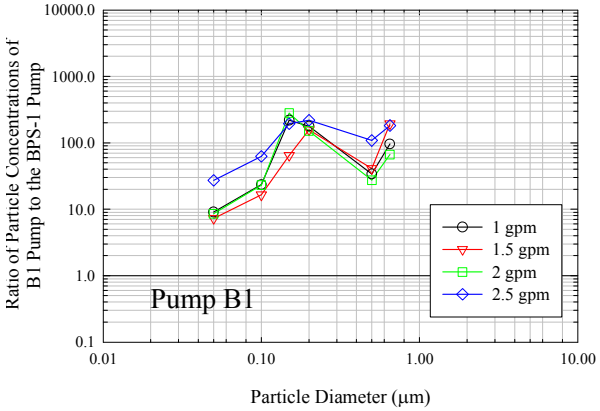
10 psig



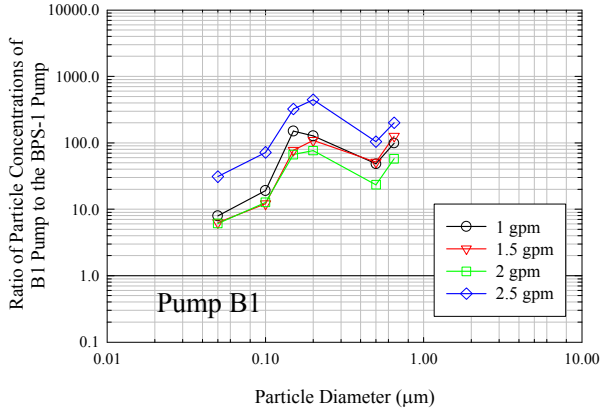
15 psig



10 psig

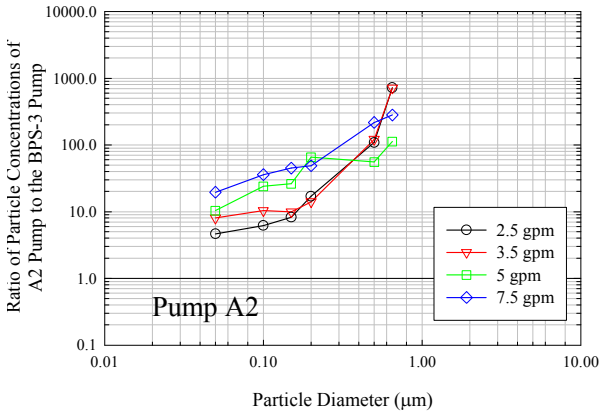


15 psig

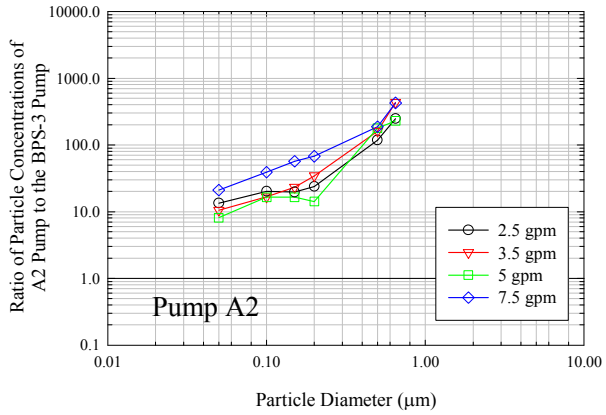


Intermediate pump particle concentrations relative to BPS-3

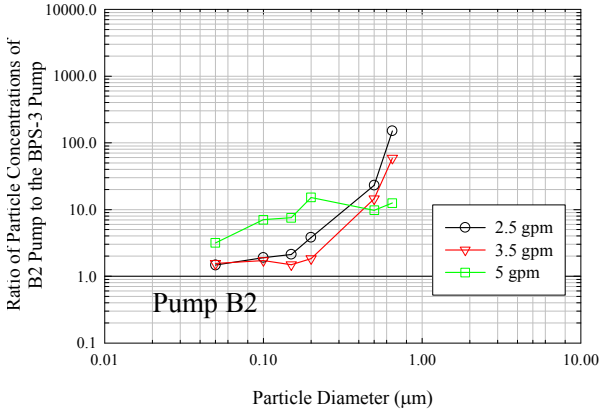
15 psig



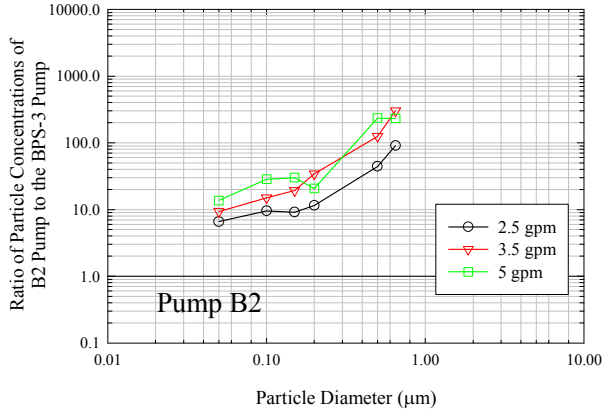
30 psig



15 psig

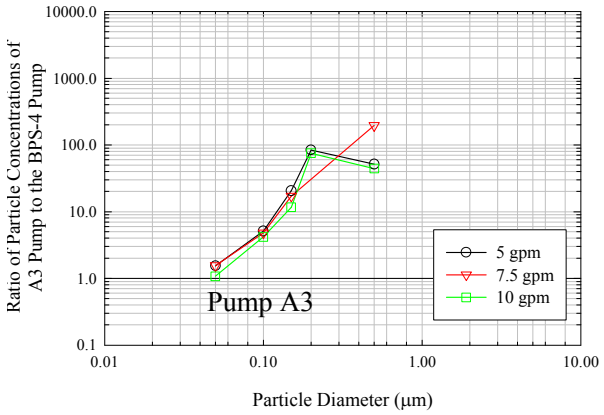


30 psig

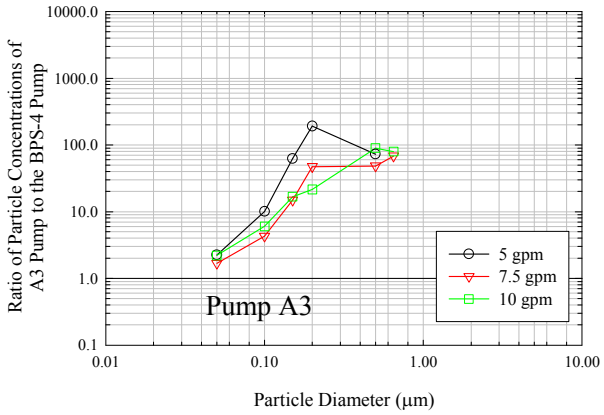


Large pump particle concentrations relative to BPS-4

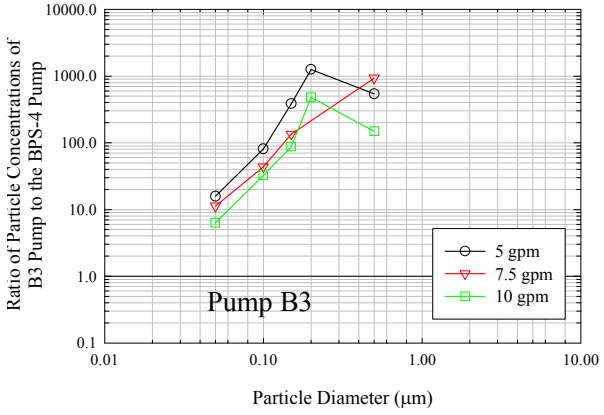
20 psig



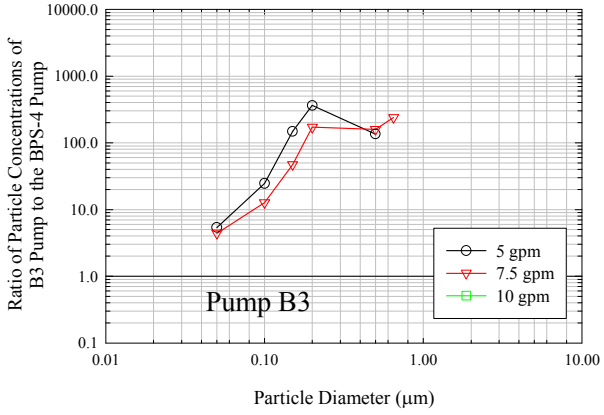
40 psig



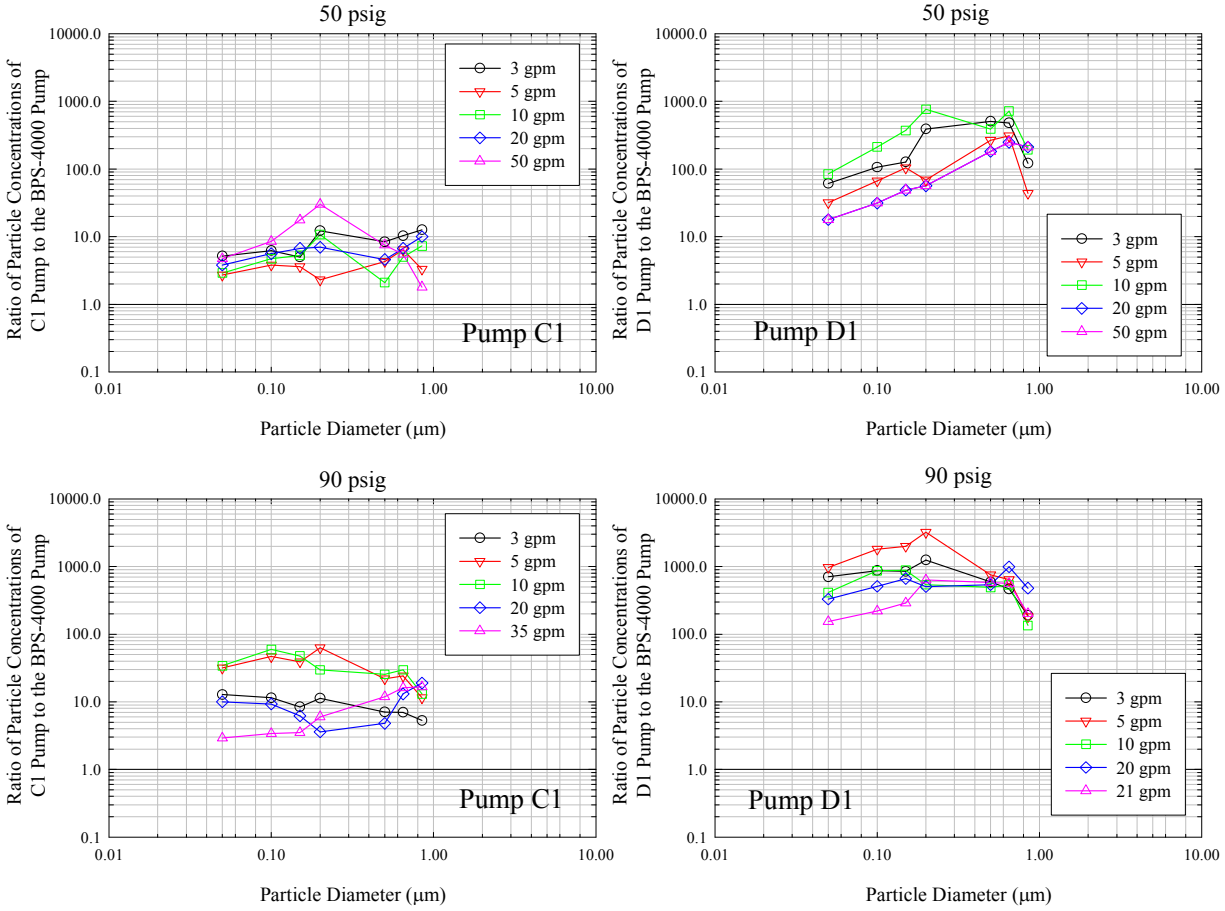
20 psig



40 psig



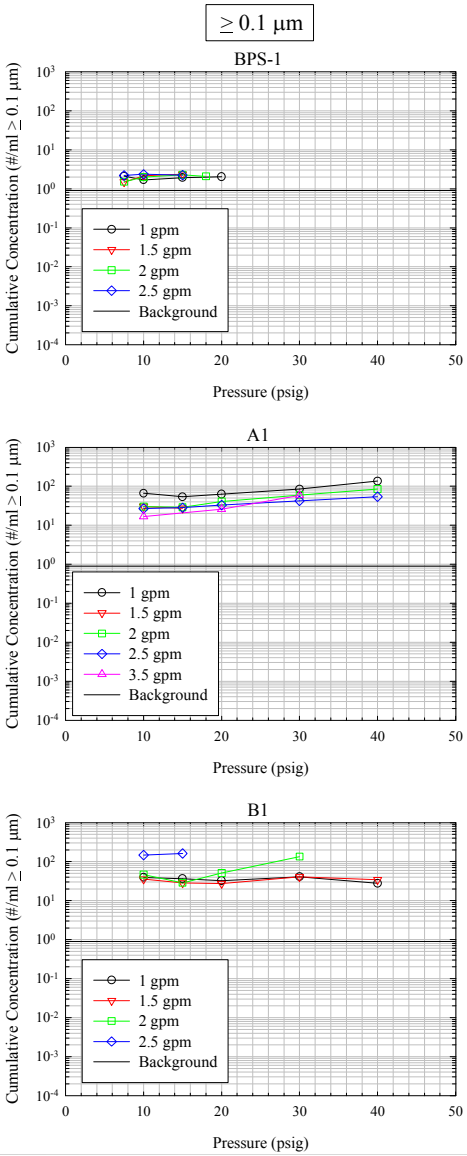
Extra large pump particle concentrations relative to BPS-4000



Comparison of pump mean concentration ratios at all test conditions

Pump Manufacturer	Pump Type	Geometric Mean of the Concentration Ratios of the Following Pumps to the Comparable Sized Levitronix Pumps	
		≥ 0.1 µm	≥ 0.5 µm
A	1	17	120
	2	18	130
	3	6	72
B	1	23	48
	2	7	40
	3	32	280
C	1	8	7
D	1	190	430

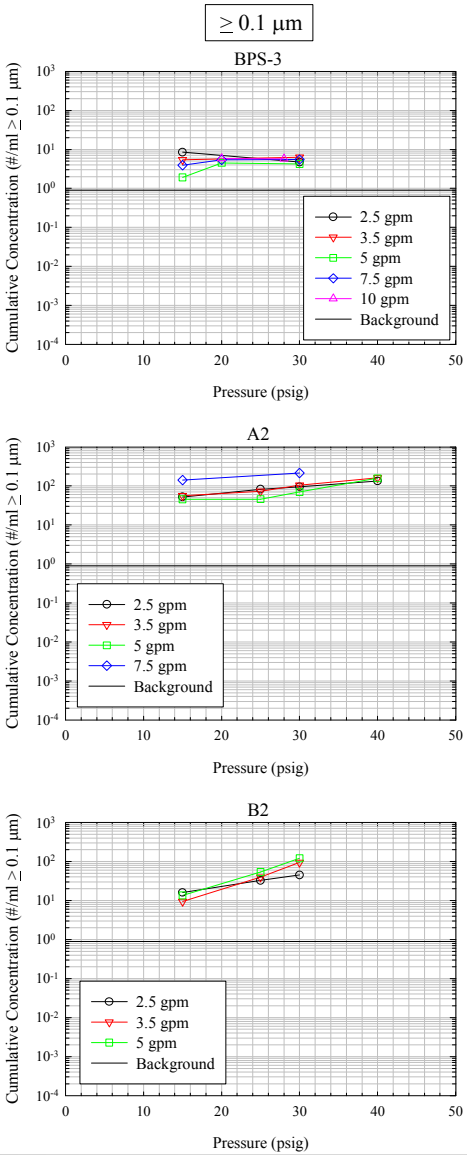
Creative Technology



Effect of operating conditions:

Small pumps

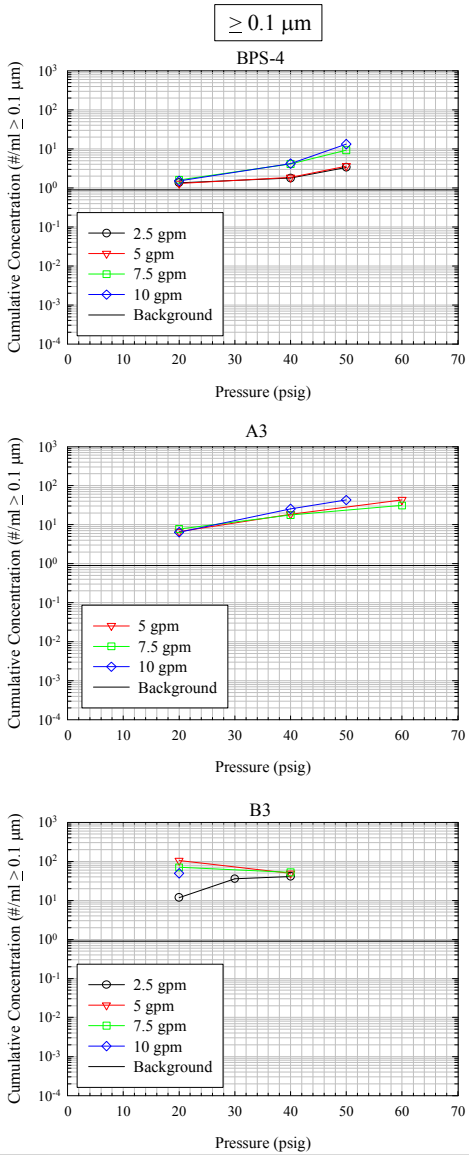
≥ 0.1 µm



Effect of operating conditions:

Intermediate pumps

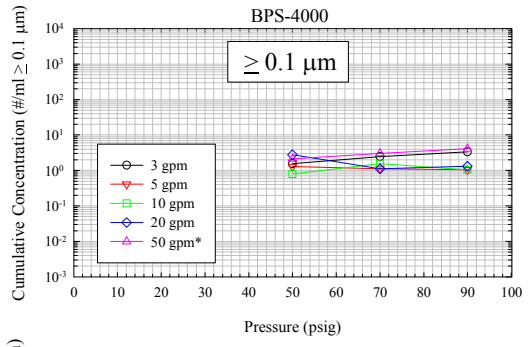
≥ 0.1 μm

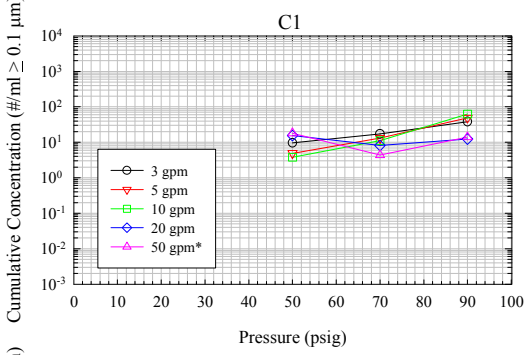


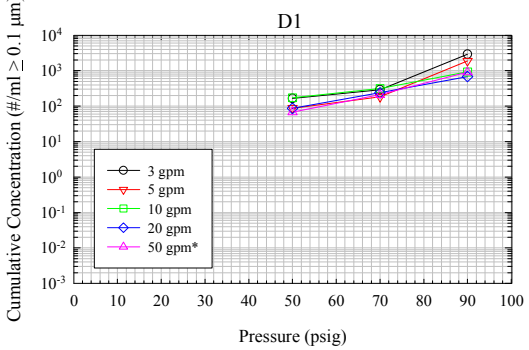
Effect of operating conditions:

Large pumps

≥ 0.1 µm







Effect of Operating Conditions

Extra large pumps

≥ 0.1 µm

Summary of effect of operating conditions on particle shedding

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
A	1	+	0	-	-
B	1	0	0	+	+
Intermediate Pumps					
Levitronix	BPS-3	0	0	0	0
A	2	+	0	+	+
B	2	++	++	0	0
Large Pumps					
Levitronix	BPS-4*	+	+	+	0
A	3	+	+	0	0
B	3	0	0	0	0
Extra Large Pumps					
Levitronix	BPS-4000	0	0	0	0
C	1	+	+	0	0
D	1	++	+	0	0

*Although a small increase was observed as outlet pressure increased, in absolute values, shedding from this pump was still lower than comparably sized pumps

Key:

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

Particle Concentrations after 1-3 minute long dry runs (#/mL)

Dry Run Test	≥ 0.1 μm			≥ 0.5 μm		
	BPS-4000	C1	D1	BPS-4000	C1	D1
	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

Creative Technology

Summary

- The 4 maglev centrifugal pumps shed the fewest particles of the 12 pumps evaluated, regardless of operating conditions.
  - In most cases, the particle concentrations measured downstream of the Levitronix pumps were very close to the concentrations (within a factor of five) measured without a test pump.
  - The slopes of the PSDs downstream of the Levitronix and mag drive centrifugal pumps were steeper than the slopes of the diaphragm pumps and were similar to the slope measured without a test pump.
    - Therefore, the ratios of concentrations of the diaphragm to the Levitronix pumps generally increased as particle size increased.
      - The diaphragm pumps shed up to 1000 times as many particles as a comparably sized Levitronix pump and was strongly dependent on both particle size and pump type.
    - The ratios of concentrations of the mag drive centrifugal to the Levitronix pumps was relatively constant with increasing particle size.
      - C1 typically shed 3-30 times as many particles as the BPS-4000.
      - D1 typically shed 20-2000 times as many particles as the BPS-4000.

Creative Technology

Summary

- Operating conditions had smaller effects on particle concentrations than pump type and particle size.
  - Pump outlet pressure had a greater effect on particle concentrations than flow rate.
    - Particle concentrations typically remained the same or increased with increasing pressure.
    - Particle shedding typically increased as outlet pressure increased for both the centrifugal pumps and for some of the diaphragm pumps. Little effect of outlet pressure was observed for the Levitronix pumps.
  - Flow rate appeared to have little effect regardless of pump type or outlet pressure over the range of flow rates evaluated in this study.
- During the mag drive centrifugal pump dry run tests, the results were highly variable and even after 5 hours concentrations were sometimes 100 times higher than measured at the same operating conditions prior to the dry run tests.
- During the BPS-4000 dry run tests, particle concentrations typically stabilized within 20 minutes and particle concentrations were consistently low and repeatable.

Creative Technology