In-Depth Survey Report

Single Letter Particle Expulsion Comparison of an Existing Advanced Facer Canceller System (AFCS) and an AFCS 200 Configuration

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Abstract

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation to compare particle expulsion from letters sent through United States Postal Service (USPS) mail processing equipment - the Advanced Facer Canceller System (AFCS) and the production AFCS 200 configuration under the Biohazard Detection System (BDS) hood and in the BDS area. The AFCS 200 was developed to update the approximately 20 year old AFCS fleet of mail processing machines. The testing described in this report evaluated changes to the AFCS 200, such as belt speeds and pulley sizes, which might negatively impact the release of particles from mail pieces processed on the machine. The AFCS agitates and compresses mail pieces during initial mail processing operations to expel any biological hazards that could be contained in a mail piece. A BDS, located over initial hard pinch points on the AFCS, samples and analyzes the air for the presence of biohazards thereby preventing the delivery of a tainted letter to a target destination address.

To compare particle expulsion, an existing AFCS and AFCS 200 were tested side-by-side at Siemens Industry, Mobility USA, Infrastructure Logistics Postal Solutions in Arlington, TX. Each machine had a BDS hood ventilation system that captured expelled particles and allowed for sample collection from the exhaust stream of the BDS hose. Comparisons were based on particle count measurements taken from the sample hose of the BDS after each individual letter loaded with dry polystyrene latex (PSL) spheres was processed by each machine. A total of 780 envelopes (195 envelopes on each machine at BDS flow rates of 200 LPM and 400 LPM) were each stuffed with two tri-folded letters and loaded with 1.5 mg of PSL spheres. Total particle counts from each single envelope were corrected by counts from a preceding single unloaded envelope. The ratio of the geometric mean particle counts from loaded envelopes sent through the AFCS 200 divided by the geometric mean particle counts from loaded envelopes sent through the existing AFCS were 1.75 and 1.84 for BDS flow rates of 200 and 400 LPM, respectively. The lower 95% confidence limits for BDS flow rates of 200 and 400 LPM were 1.4 and 1.53, respectively. Based on the results of this testing, it can be stated, with 95% confidence, that the mean particle counts from a loaded envelope sent through the AFCS 200 were at least 40% higher than the mean particle count of a loaded envelope sent through the existing AFCS. This is true for testing at BDS flow rates of 200 and 400 LPM.

Introduction

The National Institute for Occupational Safety and Health (NIOSH) is located in the Centers for Disease Control and Prevention, within the Department of Health and Human Services. NIOSH was established in 1970 by the Occupational Safety and Health Act at the same time that the Occupational Safety and Health Administration (OSHA) was established in the Department of Labor. The OSHAct legislation mandated NIOSH to conduct research and education programs separate from the standard-setting and enforcement functions conducted by OSHA. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical, biological, and physical hazards.

The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) has been given the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness. Since 1976, EPHB (and its forerunner, the Engineering Control and Technology Branch) has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique. The objective of each of these studies has been to develop, evaluate, and document the performance of control techniques in reducing potential health hazards in an industry or for a specific process.

This report documents an evaluation to determine whether a new generation of United States Postal Service (USPS) mail processing machines will provide the same or better performance at preventing future biological attacks through the mail, when compared to the existing equipment. To compare particle expulsion, an existing Advanced Facer Canceller System (AFCS) and production AFCS 200 configuration under the Biohazard Detection System (BDS) hood and in the BDS area, were tested side-by-side at Siemens Industry, Mobility USA, Infrastructure Logistics Postal Solutions in Arlington, TX from February 16th – March 1, 2010. Each machine had a BDS hood ventilation system that captured expelled particles and allowed for sample collection from the exhaust stream of the BDS hose. Comparisons were based on particle count measurements taken from the sample hose of the BDS after each individual letter loaded with dry polystyrene latex (PSL) spheres was processed by each machine.

The USPS AFCS 200 program has been developed to update the approximately twenty year old AFCS fleet. The AFCS 200 program deals with machine obsolescence, reduces maintenance and integrates additional functionality of the AFCS fleet. The USPS has added several external systems to the AFCS in recent years including the BDS. The testing described here is to validate that changes to the AFCS 200 do not negatively impact particle expulsion.

Background

In 2001, researchers from NIOSH were requested to assist the USPS in the evaluation of particulate controls for various types of mail processing equipment. These controls have been installed to significantly reduce operator exposure to any potentially hazardous biological agents emitted from mail during normal mail processing and to detect these biological agents during initial mail processing operations thereby preventing their delivery to a target destination address. This effort is driven by the terrorist attacks in the fall of 2001 which used the mail as a delivery system for anthrax. Since 2001, NIOSH researchers have tested the effectiveness of the designed controls for the AFCS and other mail processing machinery at USPS Processing and Distribution Centers (P&DCs) in Ohio [Beamer et al. 2004], California [Hammond et al. 2009], Texas [Hammond et al. 2010], and the Washington DC area [Topmiller et al. 2003; Beamer et al. 2005].

Description of Mail-Processing Equipment

The AFCS is an automated mail-processing system that culls, orients, cancels, scans, and sorts standard size (5 to 11.5 inches long by 3.5 to 6.125 inches high) mail pieces. When installed at USPS facilities, mail is delivered to the AFCS from another mail processing machine referred to as the 010 loose mail distribution system. The AFCS culls the mail to remove flats such as large envelopes, newsletters, and magazines, and over-thick (greater than 0.25 in.) mail pieces. The mail is then properly oriented so it may be cancelled. Optical character recognition technology is used to read the addresses on the mail piece which is then sorted and distributed to numbered bins for further automated processing.

Hoods/enclosures were fitted around areas that have higher potential for agitating or compressing mail pieces. The agitation and compression of mail was the major cause of contaminant release from tainted mail pieces. The BDS was designed to draw air from an area of the AFCS that would most likely contain a biological contaminant emitted from an envelope due to agitation or compression. On the AFCS, this area is located just after the shingler at the singulator. As mail pieces move through the shingler, they are forced into an overlapping position, similar to roof shingles on a house. The mail stream continues to move toward the singulator. In this assembly, the mail stream is separated into individual pieces with a constant gap between the pieces. The mail pieces are tightly compressed and abruptly accelerated in a process that causes them to move as individual pieces.

The hood of the BDS is shaped like a tunnel and fits over the singulator area. The hood is approximately 4 inches wide by 5.5 inches high by 32 inches long. Air is drawn from the hood through a flexible duct into the detector which then analyzes the air for potential biological agents. If a hazard is detected, an alarm sounds and appropriate steps may be taken.

The existing AFCS and AFCS 200 BDS hood configurations were the same as the respective configurations tested by NIOSH researchers for hood capture efficiency using tracer gas at the Coppell, TX, P&DC [Hammond et al. 2010]. The BDS hood over the AFCS 200 included an upstream hood referred to as a pre-hood mounted over the shingler. The area downstream of the BDS hood on the AFCS 200 machine was entirely enclosed with removable lids. The Ventilation and Filtration System (VFS) was not installed and the diffuser was not activated during the test.

For this evaluation, an existing AFCS machine and an AFCS 200 machine were tested side-by-side at the Siemens Industry, Mobility USA, Infrastructure Logistics Postal Solutions in Arlington, TX. Instead of installing the entire mail processing machine, only the relevant modules of each machine were installed. The modules consisted of a flats extractor, shingler, singulator, and feeder for each mail processing machine. A test room was built around each machine separated by a weighing room and waste storage room. A schematic of the test room is shown in Figure 1.

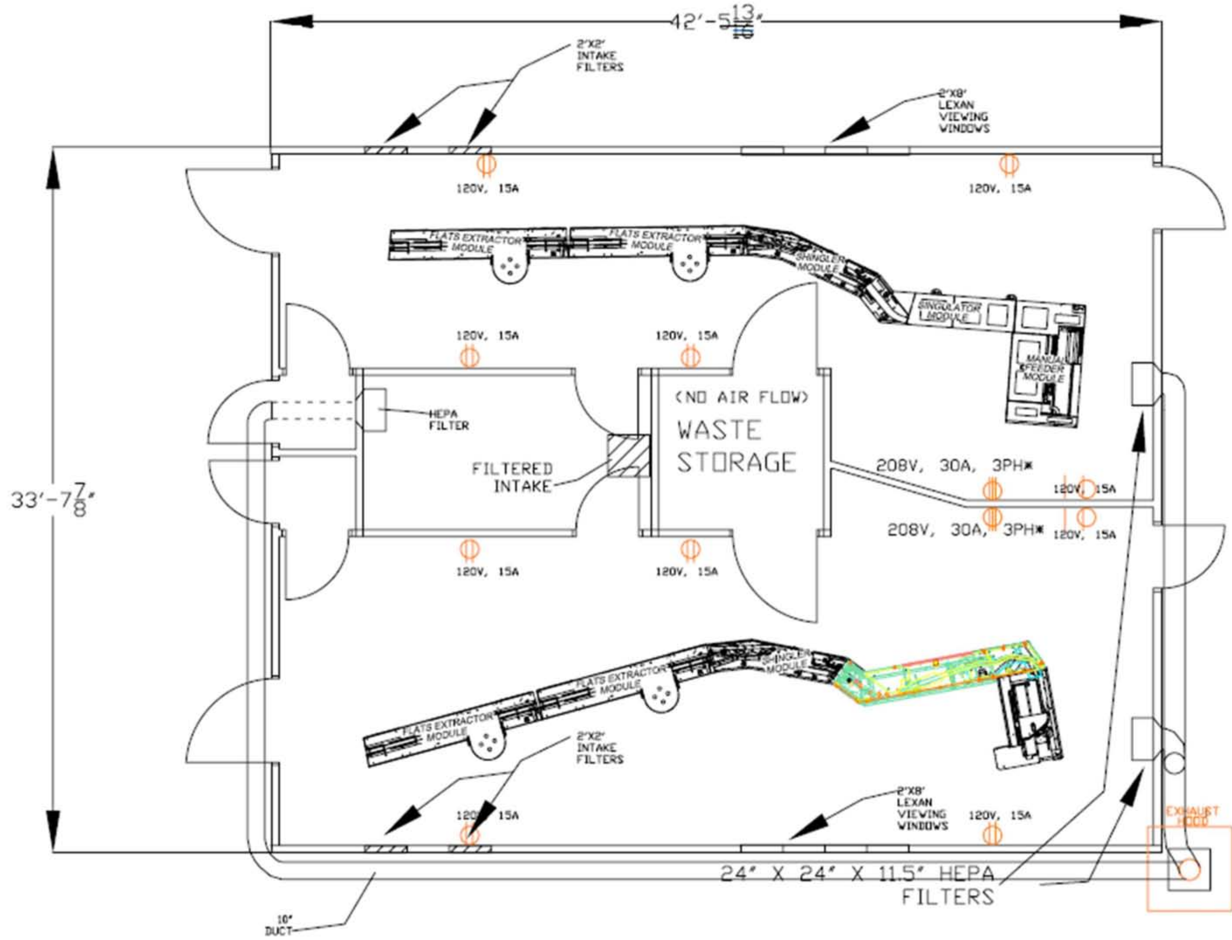

Figure 1: Test room

Experimental Design

The aim of the experiment was to compare the particle counts from the two machines at two BDS flow rates. The comparison was set up as a one-sided statistical test as follows:

- Null Hypothesis: AFCS 200 collects fewer particles than existing AFCS
- Alternative hypothesis: AFCS 200 collects at least as many particles as the existing AFCS

The reason to set up the hypotheses this way was that if the AFCS 200 was more efficient than the existing AFCS, then the null hypothesis should be rejected and it will be determined that the AFCS 200 collected at least as many particles as the existing AFCS. For each BDS flow rate, an experiment was set up so that there were enough replicates of each machine to reject with at least 90% probability the null hypothesis that the AFCS 200 particle count mean was less than the existing AFCS particle count mean, based on a t-test at the 95% confidence level. In addition, a 95% lower confidence limit for the ratio of new machine to old machine particle counts is presented for each of the BDS flow rates. Rejection of the null hypothesis is equivalent to obtaining lower confidence limits for the ratio (AFCS 200/existing AFCS) for each flow rate that exceeded a ratio of 1.

Methods

Test Aerosol

To quantitatively evaluate the release of particles from envelopes sent through mail processing equipment, a particle expulsion test method was developed and used. The test aerosol consisted of 2.5 µm dry PSL microspheres (Phosphorex Inc., Fall River, MA). Phosphorex, Inc. measured the particle size of the test aerosol on a Beckman-Coulter LS 13 320 Laser Diffraction Particle Size Analyzer and a Joel JSM-5610 Scanning Electron Microscope (SEM). Figure 2 shows the average particle size of 2.5 µm from the SEM picture. The particle size as measured by laser diffraction was consistent with the SEM picture with a mean of 2.5 µm and a standard deviation of 0.045 µm.

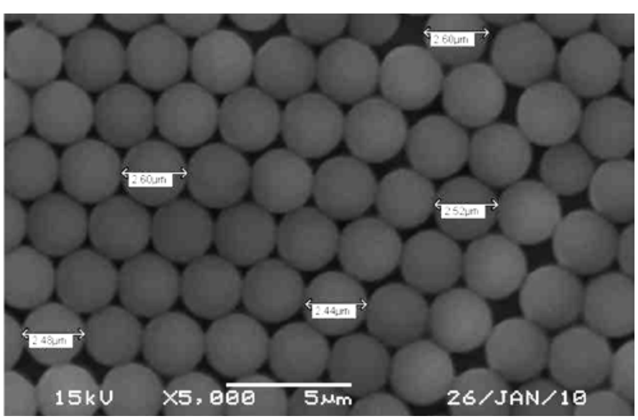

Figure 2: Image from the SEM of the dried microspheres.

Weighing Procedures

An analytical balance manufactured by A&D Company (model HR-120, A&D Company, Limited, Tokyo, Japan) was used to weigh the dry PSL spheres. The analytical balance was used with a marble table to eliminate vibration. Nitrile gloves were worn during all weighing procedures and tweezers were used during all handling of weighing dishes. PSL spheres were weighed using disposable anti-static polystyrene weighing dishes manufactured by Fisher Scientific (Cat No. 08-732- 16, Thermo Fisher Scientific, Inc.). The weighing dishes remained in front of a static neutralizer (model # AD 1683, A&D Company, Limited, Tokyo, Japan) before and during weighing. An ionizing brush (model 1C200, NRD LLC, Grand Island, NY) was used to eliminate static and to remove dust from both sides of a weighing dish before an empty dish was weighed. An empty weighing dish was then placed on the scale and the doors of the weighing chamber were closed. After it reached a stabilized value, the scale was zeroed, establishing the tare weight of the dish. The weighing dish was removed from the scale and a small scoop was used to add 1.5 mg of 2.5 µm dry PSL spheres to the dish. The dish was reweighed to verify the mass of spheres. The dish was removed from the scale and the spheres were loaded into the front of two tri-folded 8.5” x 11” sheets of paper in an envelope (No. 10 Grip-Seal Security Envelopes, Columbian Envelopes) by turning the dish over above the letter and tapping on the back of the dish. The weighing dish was placed on the scale again and the stabilized value was subtracted from the previous weight to account for any spheres left in the dish. The weighing dish was then discarded. If the final weight was 1.5 mg ± 0.1 mg, the Grip-Seal envelope was sealed by peeling off the release strip and folding over the flap to form a seal then placing the envelope in a portable rack. If the final weight was outside of the 1.5 mg ± 0.1 mg range, the envelope was discarded and the procedures were repeated until 15 envelopes loaded with PSL spheres were prepared for a run on one machine. The set up for the weighing process is shown in Figure 3.

Figure 3: Set up for the weighing process

Test Apparatus and Equipment

Sampling was conducted directly from the BDS hose which was connected to the BDS hood over the singulator portion of the machine. Testing was conducted at both 200 LPM and 400 LPM flow rates through the BDS hose. The flow through the BDS hose was maintained by a BDS pump (Model 117417-05 Type H Windjammer, Ametek Inc.) and checked between every test run using a rotary meter (Model 11C175 ROOTS® Rotary Meter, Dresser Inc.). The inner diameter of the BDS hose was 30.7 mm. Calculations using the Reynolds number revealed turbulent flow through the BDS hose at both 200 LPM and 400 LPM flow rates. Three meters of flexible BDS hose length connected the BDS hood to a 1 m long 1-1/4 in inner diameter aluminum pipe. This provided more than 50 hose diameters of mixing in the BDS hose before the air entered the straight aluminum pipe. The aluminum pipe provided 25 additional upstream and 10 downstream diameters of smooth pipe at the point where an isokinetic sample was drawn. This allowed for a uniform velocity profile of the well mixed air at the point where the sample was drawn. The isokinetic sampling probe was inserted through a 90° 1-1/4 in inner diameter aluminum elbow. An isokinetic probe with an inner diameter at the inlet of 1.7 mm was used to sample from the aluminum pipe when the BDS flow was set to 400 LPM. An isokinetic probe with an inner diameter at the inlet of 2.4 mm was used when the BDS flow was set to 200 LPM. Drawings of the 1.7 mm and 2.4 mm isokinetic probes inserted through the 90° elbow are provided in Appendix A. The configuration of the sample line was the same on both machines. Since the two machines were tested as randomized pairs, it required moving back and forth between machines several times per day. All sampling equipment including the instrument and BDS hood were moved back and forth between machines to reduce the potential for bias based on differences in instrumentation or sampling equipment. The isokinetic sample probe from the aluminum pipe in line with the BDS hose is shown in Figure 4.

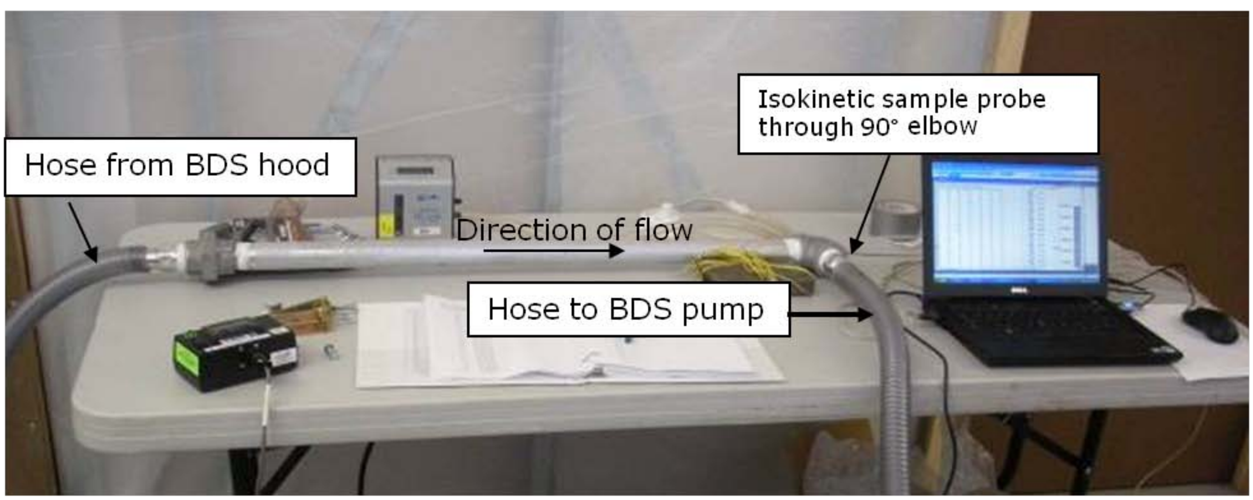

Figure 4: Sample location from the BDS hose

Particle counts from each machine were measured using a Grimm aerosol spectrometer (model 1.108SS, Grimm Aerosol Technik GmbH & Co. KG, Ainring, Germany). The Grimm aerosol spectrometer counts individual particles and sizes each particle, based upon the amount of light scattered, into one of fifteen particle size channels or bins between 0.3 and 20 µm. For this experiment, the Grimm was used in fast mode to log data at one second intervals in the 2-3 µm, 3-4 µm, 4-5 µm, 5-7.5 µm, 7.5-10 µm, 10-15 µm, and 15-20 µm size bins. The data collected in the 2-3 µm size bin were used for the 30 second sum of particle counts for both a loaded and unloaded envelope. The count range of the Grimm is from 1 to 2,000,000 particles per liter. The Grimm maintains a flow rate of 1.2 LPM using a built in volume controller that varies the RPM of a motor to maintain consistent flow through the instrument. The flow through the Grimm was checked in between every run for flow verification using a DryCal® DC-Lite dry flow meter (Model DCLT 12K Rev 1.08, DryCal®, Bios International Corporation).

Test Procedures

The existing AFCS and AFCS 200 machines were compared using individual envelopes stuffed with two tri-folded letters loaded with PSL spheres. The loaded envelopes were filled in batches of 15 which were prepared immediately before each test run on a machine. The 15 loaded envelopes were staged in a rack designed to avoid envelope compression shown in Figure 5. A single unloaded envelope was staged in between every loaded envelope in the rack starting with an unloaded envelope. This was done so that the sum of the 30 second particle count in the 2-3 µm size bin from each unloaded envelope could be subtracted from the sum of the 30 second particle count in the 2-3 µm size bin of the following loaded envelope. The single envelopes were sent through the machine with a time gap between each envelope of 30 seconds following an unloaded envelope and 90 seconds following a loaded envelope to allow for the decay of particle counts before the next envelope was sent through the singulator of the machine. The belts ran continuously until all 30 envelopes (15 unloaded alternating with 15 loaded) were sent through the machine one at a time. Siemens Industry Field Service Specialists cleaned the machine after each set of 30 envelopes were processed. The cleaning procedures are provided in Appendix B. The two machines were tested as randomized pairs. All unloaded and loaded envelopes were used one time and then discarded.

Figure 5: Unloaded and loaded envelopes staged on a rack before testing

Results

For a run on a given machine, there were 15 alternating empty and loaded envelope particle count totals. Each loaded envelope particle count was corrected using the preceding empty envelope particle count. Appendix C contains the particle count data in the 2-3 µm size bin for every unloaded and loaded envelope tested during the evaluation. The geometric mean was then calculated for the fifteen background adjusted measurements on each machine. The particle count data were collected in 13 randomized blocks for each BDS flow rate randomly choosing which machine was evaluated first in each block. Table I provides the background-corrected geometric mean particle count and ratio (AFCS 200 / existing AFCS) by machine and BDS flow rate for each set of 15 individual envelopes.

Table I: Geometric mean and ratios for each machine at 200 LPM and 400 LPM

	BDS Flow Rate Set to 200 LPM			BDS Flow Rate Set to 400 LPM		
Block	Existing AFCS Geometric Mean	AFCS 200 Geometric Mean	Ratio	Existing AFCS Geometric Mean	AFCS 200 Geometric Mean	Ratio
1	19665	33436	1.7	14580	30578	2.1
2	12875	63362	4.9	13863	26792	1.9
3	31827	41236	1.3	22081	50701	2.3
4	19812	24124	1.2	12989	28740	2.2
5	19202	39053	2.0	25484	45222	1.8
6	41797	65248	1.6	38541	131966	3.4
7	24844	61255	2.5	26681	40669	1.5
8	31862	58515	1.8	24342	31443	1.3
9	56639	92215	1.6	25467	31152	1.2
10	59523	80084	1.3	39930	61612	1.5
11	62200	95706	1.5	35680	44170	1.2
12	32971	64974	2.0	16276	29891	1.8
13	54989	65193	1.2	14424	37066	2.6
Geometric means*	***32110***	***56340***	***1.75***	***22183***	***40754***	***1.84***

*These are the overall geometric means for the 195 loaded envelope particle counts by machine and by flow rate.

Table II presents maximum and minimum measurements of temperature and humidity for each machine room during each block of testing at BDS flow rates of 200 LPM and 400 LPM. The maximum change in room temperature during testing of a set of 15 individual envelopes was 0.7 °F. The maximum change in room temperature within a block of testing was 2.7 °F. The maximum change in room humidity during testing of a set of 15 individual envelopes was 1.5 % relative humidity. The maximum change in room humidity within a block of testing was 4.1 % relative humidity.

Table II: Temperature and humidity for each machine room by block

		BDS flow rate set to 200 LPM				BDS flow rate set to 400 LPM			
		Temperature (°F)		Humidity (%RH)		Temperature (°F)		Humidity (%RH)	
		max	min	max	min	max	min	max	min
AFCS 200	Block 1	71.8	71.8	18.7	17.9	72.5	72.5	17.9	17.5
Existing AFCS	Block 1	71.8	71.8	18.2	17.8	73.2	72.5	17.8	17.3
AFCS 200	Block 2	70.4	70.4	19.2	18.7	73.2	73.2	19.2	18.7
Existing AFCS	Block 2	71.8	71.8	17.8	17.3	74.5	73.8	17.8	17.3
AFCS 200	Block 3	72.5	71.8	18.7	18.3	73.2	72.5	20	19.6
Existing AFCS	Block 3	73.2	73.2	17.8	17.3	73.8	73.8	18.6	17.8
AFCS 200	Block 4	72.5	72.5	20.4	20	73.2	73.2	19.6	19.2
Existing AFCS	Block 4	73.2	73.2	19.8	19.4	73.8	73.8	19	18.2
AFCS 200	Block 5	71.8	71.8	24.9	24.4	73.2	72.5	36.9	35.4
Existing AFCS	Block 5	72.5	71.8	22.9	22	73.8	73.8	34.6	33.6
AFCS 200	Block 6	72.5	71.8	31	30.5	73.2	73.2	35.9	35.4
Existing AFCS	Block 6	74.5	73.8	28.8	28.4	73.8	73.2	33.1	33.1
AFCS 200	Block 7	73.2	72.5	31.5	30.5	73.8	73.8	35.4	34.4
Existing AFCS	Block 7	73.8	73.8	29.8	29.3	73.8	73.2	33.1	32.6
AFCS 200	Block 8	72.5	72.5	33.4	32.4	73.2	72.5	34.4	33.9
Existing AFCS	Block 8	74.5	73.8	29.8	29.3	73.8	73.8	32.6	31.7
AFCS 200	Block 9	71.8	71.8	35.4	34.9	73.2	73.2	33.9	32.9
Existing AFCS	Block 9	73.2	72.5	33.1	32.6	73.8	73.2	32.6	32.2
AFCS 200	Block 10	73.2	73.2	35.4	34.9	71.8	71.8	27.2	26.7
Existing AFCS	Block 10	73.8	73.8	32.6	32.2	72.5	72.5	26	25.6
AFCS 200	Block 11	72.5	72.5	34.4	33.9	72.5	72.5	26.7	26.3
Existing AFCS	Block 11	73.8	73.8	32.6	32.2	73.2	73.2	25.6	25.1
AFCS 200	Block 12	73.2	72.5	34.4	33.9	72.5	72.5	25.8	25.3
Existing AFCS	Block 12	73.8	73.2	33.1	31.7	73.2	72.5	25.1	24.7
AFCS 200	Block 13	73.2	72.5	34.9	33.9	73.2	72.5	26.3	25.3
Existing AFCS	Block 13	73.8	73.8	32.2	31.2	73.2	73.2	25.1	24.7

Analyses were done separately for the two BDS flow rates. Analysis of variance models were fitted to the natural log-transformed geometric means of the fifteen background adjusted measurements in each trial. Thus, each model used 26 geometric means, and each model adjusted for block effects and estimated means for each machine type. The residuals from the fitted model were approximately normally distributed. In other words, the original scale data are approximately log-normally distributed. For each model, 95% confidence intervals for the ratio of new machine counts to old machine counts were computed. When testing at 200 LPM, the lower and upper 95% confidence limits were 1.40 and 2.20, respectively. When testing at 400 LPM, the lower and upper 95% confidence limits were 1.53 and 2.21. Testing conducted at both 200 and 400 LPM flow rates give lower 95% confidence limits on the ratio (AFCS 200/existing AFCS) greater than 1; therefore, the statistical criterion (reject the hypothesis that the AFCS 200 is less than the existing AFCS) is satisfied for the test.

Discussion

In order to verify that the particle count from a loaded envelope was not overly influenced by background particle counts, it was necessary to calculate signal to noise ratios. For the purpose of this testing, signal to noise ratios were calculated based on the peak one second particle count during the 30 seconds following the release of a loaded envelope divided by the peak one second particle count during the 30 seconds following the release of the preceding unloaded envelope. Individual signal to noise ratios were calculated for all 780 envelopes (195 envelopes on each machine at BDS flow rates of 200 LPM and 400 LPM). The data were approximately log-normally distributed. The geometric mean and 95% confidence intervals for the signal to noise ratios are presented in Table III.

Table III. Mean and 95% confidence intervals for the signal to noise ratios

Experiment	Geometric mean	Upper 95% confidence limit	Lower 95% confidence limit	Arithmetic mean
AFCS 200 at 200 LPM	30.4	38.5	24.0	39.2
Existing AFCS at 200 LPM	23.6	31.3	17.7	32.3
AFCS 200 at 400 LPM	33.0	40.7	26.7	42.1
Existing AFCS at 400 LPM	26.0	33.9	19.9	34.6

Conclusions

For this testing, a total of 780 envelopes (195 envelopes on each machine at BDS flow rates of 200 LPM and 400 LPM) were each loaded with 1.5 mg of PSL spheres. Particle counts from each individual envelope were analyzed one at a time to result in a total particle count from each loaded envelope corrected by a preceding single unloaded envelope. All 780 loaded envelopes released PSL spheres at a reasonable signal to noise ratio. The ratios of the geometric mean particle counts from the AFCS 200 divided by the geometric mean particle counts of the existing AFCS were 1.75 and 1.84 for the 200 and 400 LPM BDS flow rates, respectively. The lower 95% confidence limits when testing at 200 and 400 LPM were 1.4 and 1.53, respectively. Based on the results of this testing, it can be stated, with 95% confidence, that the mean particle counts from an envelope sent through the AFCS 200 were at least 40% higher than the mean particle count of an envelope sent through the existing AFCS. This is true for testing at BDS flow rates of 200 and 400 LPM.

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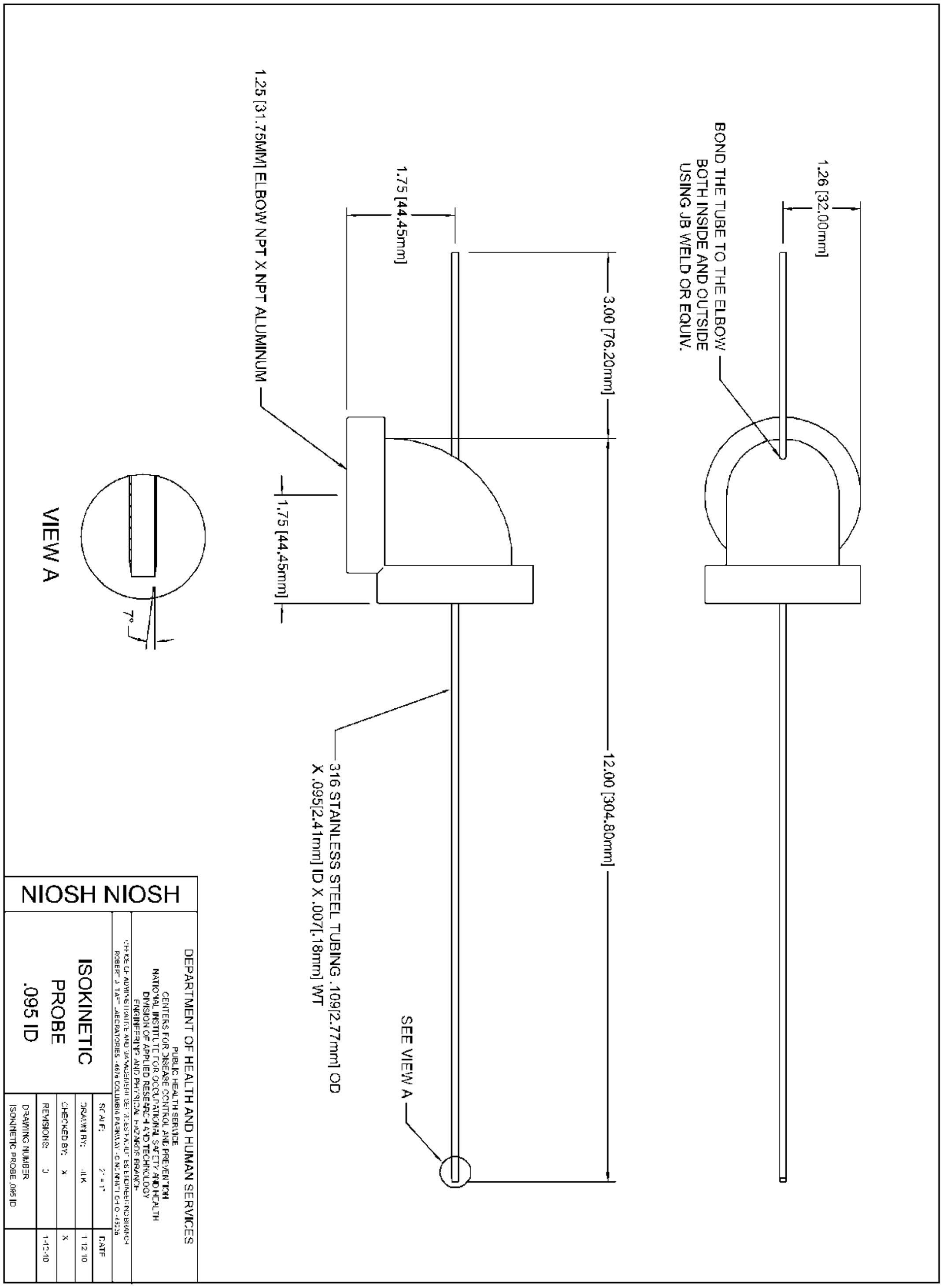
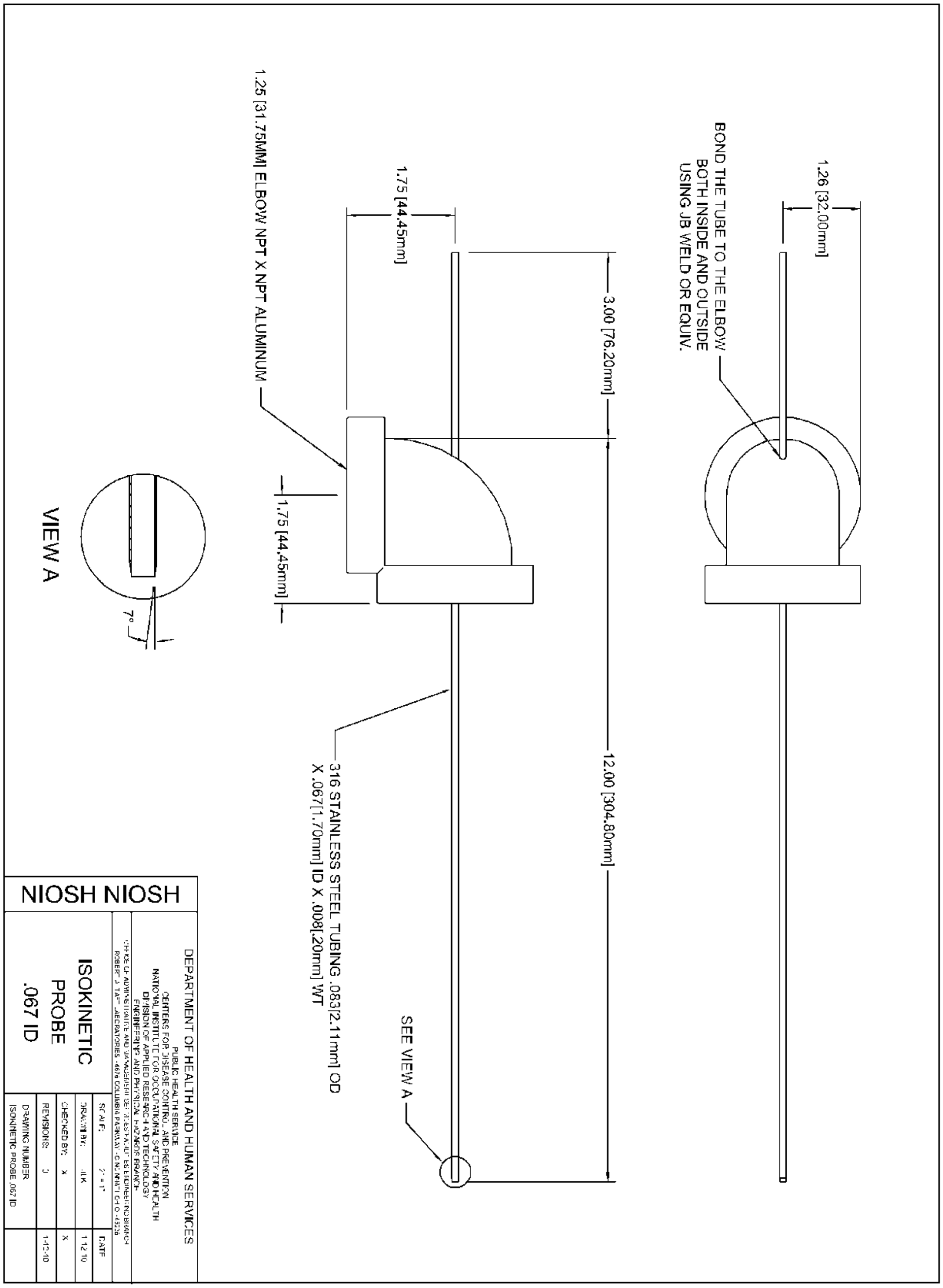
Appendix A

2.4 mm ID Isokinetic probe for testing at 200 LPM



1.7 mm ID Isokinetic probe for testing at 400 LPM



Appendix B

The following cleaning procedures were used after every 30 envelopes (15 unloaded followed by 15 loaded envelopes) were processed on a machine.

1. All workers present in the test rooms wore safety glasses and half-mask respirators with P100 cartridges at all times including cleaning and testing.

2. To begin the cleaning procedures, Siemens Field Service Specialists adjusted the knob to rotate the BDS hood on its hinge to expose the inside of the BDS hood.

3. The inside of the BDS hood was cleaned using compressed air.

4. The BDS hood was removed to increase access to the singulator area of the machine.

5. The areas in and around the belts in the shingler and singulator portion of the machine were HEPA vacuumed to remove particles.

6. The areas in and around the belts of the shingler and singulator that were previously cleaned using a HEPA vacuum were also lightly sprayed with compressed air to further remove particles.

7. After cleaning, the BDS hood was attached and closed over the singulator portion of the machine.

Appendix C

Existing AFCS at 200 LPM

PSL loading	Block1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10	Block 11	Block 12	Block 13
0 mg	3900	3750	3550	5950	4150	3600	4750	3300	5950	4700	4050	5500	3400
1.5 mg	76640	56630	41070	32960	30400	34900	27900	31810	53680	37010	37350	49180	45510
0 mg	3700	3650	3100	4250	3050	3500	3550	4000	4500	3650	5000	5250	2400
1.5 mg	56830	23250	31200	32350	36360	65950	19300	37370	116290	106810	24050	35020	69460
0 mg	2800	2500	1900	3100	2100	3500	3650	4250	4250	3700	4400	7150	2700
1.5 mg	26100	37860	20500	8300	12800	66550	47110	28650	126100	109510	35300	34860	38610
0 mg	3000	1850	2400	5000	3250	3650	3650	4100	3400	3700	4250	5400	2600
1.5 mg	33860	34850	55090	28560	28650	47260	40060	27800	36670	97150	143720	26150	24500
0 mg	2850	3350	3050	5250	2050	5150	3050	3700	3100	4250	4050	6050	2950
1.5 mg	12950	39250	43310	30410	68400	48160	57680	22900	20850	67330	101550	49870	50620
0 mg	2750	1750	3000	2700	1800	4400	4550	4100	2000	4050	3650	5200	2000
1.5 mg	16050	8700	57270	17550	35100	80450	55640	35260	132720	122230	36300	38810	78000
0 mg	3050	2950	2950	3050	2050	2850	3300	4000	3100	4400	3500	3350	2650
1.5 mg	21700	36260	47620	18450	27100	29050	16750	49170	49470	56470	46270	42810	109660
0 mg	3150	2700	3300	3450	2550	5250	3100	4050	2900	4400	3100	4100	2900
1.5 mg	18300	23700	40650	14800	67530	58040	20900	41320	126890	25850	116300	40420	68700
0 mg	3600	3700	3850	3300	2700	3550	3600	3550	3050	5650	4400	3350	2900
1.5 mg	11100	17300	21900	11200	10850	55540	12050	23250	30800	21100	118310	26850	128920
0 mg	3350	3550	2650	3800	2350	2800	5050	3900	3300	4350	2600	5050	2650
1.5 mg	12500	33310	15100	18550	3600	28910	40720	32900	97700	100090	49270	41060	35660
0 mg	3600	3450	2450	3000	2100	4250	3600	4350	2700	5000	3350	3450	3350
1.5 mg	18400	12300	34110	33610	11950	86830	52620	63800	32400	152590	165160	25600	51310
0 mg	2750	3400	2450	3750	2700	3150	2350	3850	2950	4850	2900	3150	3400
1.5 mg	20900	4900	13500	51720	55450	34610	26350	48020	63590	74510	71750	37610	57280
0 mg	4200	2950	3550	3800	1550	5050	3650	4250	3600	4700	5200	3900	3000
1.5 mg	29400	10300	42770	25000	9900	50380	23850	23400	49310	63230	66480	29810	70880
0 mg	5400	2850	1800	3050	2300	3550	3350	4250	3350	5100	3000	3450	1900
1.5 mg	26750	4650	96820	58830	20300	16200	45400	85680	40550	47670	77560	37120	52780
0 mg	4700	3100	2050	3000	2300	3750	3900	5650	2500	4700	3650	3850	3000
1.5 mg	29010	6050	33610	26150	28460	45960	11200	32960	88050	44820	74420	70360	63430

AFCS 200 at 200 LPM

PSL loading	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10	Block 11	Block 12	Block 13
0 mg	3700	7250	3050	4200	3450	5150	3300	2950	7150	5600	4550	2900	4800
1.5 mg	24900	118380	36450	47060	120930	72850	88880	47810	124710	102200	76590	43450	143810
0 mg	2900	5600	2850	3900	4950	3950	3250	2550	4100	4600	3800	2250	4200
1.5 mg	62820	59030	50310	51010	50650	118890	110700	91290	132590	85840	77480	55960	77420
0 mg	2550	3900	3250	2800	3600	4250	2450	3750	4600	4650	2300	3700	3700
1.5 mg	29400	88230	59010	39170	40650	198280	106200	39560	48850	13600	151160	72210	135690
0 mg	3100	2750	2100	2000	4350	4800	2450	3400	4100	3750	3850	2800	3700
1.5 mg	95310	64130	45650	28700	55520	60110	46710	46450	91730	81240	128410	67280	67520
0 mg	2950	3650	2400	2550	3300	3800	2050	3450	4650	3750	2700	2900	3100
1.5 mg	68570	38050	43800	23250	73420	42000	95930	182080	98330	152320	141860	54150	169920
0 mg	4150	4450	1550	2700	3150	2650	2700	4050	4650	3400	2850	2250	2650
1.5 mg	27100	63080	40000	24550	48750	315530	43960	44910	89370	112510	72610	69610	140370
0 mg	3900	3150	2650	2400	3100	3050	2200	3200	4400	4200	2000	3200	2150
1.5 mg	71860	97870	58520	16500	69550	201440	32950	48620	178070	183960	157250	92380	75410
0 mg	3200	3750	2250	2300	2250	3750	2300	4600	2950	3600	3050	2500	2200
1.5 mg	17450	103920	44050	20050	33150	71730	45600	86100	105360	123810	33600	128250	19150
0 mg	2550	3200	1700	1750	2600	2100	2100	3500	2800	4300	3000	2300	2550
1.5 mg	42450	38860	99650	32700	31450	57700	50520	32850	61270	82790	193880	122750	99390
0 mg	2750	1800	2250	2100	3000	2750	3150	5300	3400	4400	3050	3800	2850
1.5 mg	31350	65700	49550	21800	28000	47250	55210	65620	60710	101460	41050	43810	58650
0 mg	2850	4250	1800	2500	3100	4100	1800	3800	2450	3950	2500	2300	2650
1.5 mg	17300	43700	21050	22850	60150	41510	57100	70130	126390	47260	177560	41710	32750
0 mg	1950	2450	1950	1350	2600	2000	2650	4500	3550	3300	3300	1400	2350
1.5 mg	35550	55280	15150	15350	77250	23300	98700	67990	124720	51510	54010	63450	87440
0 mg	2550	3350	2100	1800	2150	2600	2700	3800	4250	3300	2550	2350	2150
1.5 mg	41050	115230	53280	51620	36750	35910	100570	51410	118530	133240	270240	98250	29150
0 mg	2100	3300	2050	1850	2350	2500	2300	3050	3300	2750	3050	2850	2300
1.5 mg	32300	40450	53050	17450	25050	73240	42650	148310	58800	129830	163350	49250	61950
0 mg	3050	3200	1450	2500	2650	2450	2250	6200	3400	4100	2700	1650	1650
1.5 mg	27750	94960	40000	20700	7300	28900	57950	43960	115760	75470	44050	81140	31600

Existing AFCS at 400 LPM

PSL loading	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10	Block 11	Block 12	Block 13
0 mg	3750	2000	3350	3150	2650	2500	3100	2100	3850	2650	3150	2150	4700
1.5 mg	17000	9000	20650	17050	26910	14300	71320	43730	32760	43360	54790	25200	30020
0 mg	2450	2300	2800	1800	1950	2200	2750	2050	3550	1700	2600	2050	3200
1.5 mg	16600	17800	40090	22950	22050	35770	35260	18800	37160	91760	62530	12550	21450
0 mg	2650	3150	2550	2100	1450	1400	2900	2500	2300	2050	2250	2400	2600
1.5 mg	13950	12800	33360	28660	24150	40330	19350	46310	32560	74090	51980	20950	14000
0 mg	2300	2100	2200	1700	2450	2150	2000	2600	2800	2250	2050	1800	3450
1.5 mg	34620	15050	27960	12650	71780	81090	17950	47720	16200	31800	16950	21400	10550
0 mg	1950	2350	2550	6800	2000	2100	2250	2600	2950	2050	1500	2100	2600
1.5 mg	13150	13750	25610	27350	49590	21600	28760	40920	24360	58430	40670	33760	17400
0 mg	2250	2050	2400	2200	2300	1600	1950	2200	2350	3550	2050	1800	3400
1.5 mg	19300	15200	37070	11650	47570	71920	22960	22600	32960	34110	50870	52800	18900
0 mg	2400	1900	2100	3300	2600	2150	2350	2350	2050	1750	1850	3050	3650
1.5 mg	26850	16750	20350	19900	18500	22300	53820	19400	12950	33450	9100	18260	10900
0 mg	1900	2450	2050	2800	2650	1600	2100	2700	2700	2200	2300	2150	2300
1.5 mg	10850	25610	16650	11250	6650	66490	23900	12200	23160	63630	63580	12250	16100
0 mg	2800	2700	2200	2800	2350	1850	2950	2400	2300	2000	2500	1950	2550
1.5 mg	19100	25500	20250	13600	57540	36960	31150	21650	23300	57600	88910	16050	7750
0 mg	2500	2350	2400	3400	2900	2150	2450	2000	3350	2350	1700	2150	1900
1.5 mg	20060	11900	24700	12900	22600	46180	47620	19150	29550	67040	32210	22050	18350
0 mg	1800	2200	2800	1550	1850	1850	2150	1950	2650	2150	1650	1550	2300
1.5 mg	10600	17700	25410	10100	55300	43230	24260	87530	21710	43430	57420	12450	17850
0 mg	1600	2100	2900	1600	2300	2700	2900	1500	2800	2450	2250	2800	2300
1.5 mg	8300	20600	13450	10300	15300	26400	16800	37070	46680	18750	44120	11400	21810
0 mg	1800	2200	3000	2250	1500	1900	2550	3300	2450	1900	2000	1900	2550
1.5 mg	38710	15550	25310	12600	39130	101530	49030	14400	35710	25310	38310	19850	41890
0 mg	2250	2200	4100	2600	3150	2350	2450	2400	1400	1900	2200	2400	2750
1.5 mg	12150	32720	34360	22650	30560	33160	22860	16250	38380	22300	19500	5650	15550
0 mg	1900	2050	3600	1500	2350	1900	2500	2100	2500	2200	1800	2150	1900
1.5 mg	18100	9600	24060	15200	17500	62440	20800	25250	40210	36760	27460	46650	23600

AFCS 200 at 400 LPM

PSL loading	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10	Block 11	Block 12	Block 13
0 mg	2500	2700	4300	2550	3750	6100	2900	4000	4200	3500	3000	3050	2500
1.5 mg	52670	47580	146210	41820	45870	80790	64830	30500	42800	107420	38300	31950	48750
0 mg	2050	2350	2950	1800	3000	4350	2300	1650	4050	3350	1600	2400	1950
1.5 mg	43750	25800	74630	38150	85120	153880	61520	30810	37300	141330	86700	50910	30410
0 mg	1050	2350	3250	1900	1900	4500	1600	3150	3050	2450	1050	1900	2500
1.5 mg	23150	24800	76680	22850	18300	149610	29750	35650	94920	46410	42100	42000	30400
0 mg	1700	1800	2050	1650	2500	3600	2000	3100	3650	1900	1750	2150	1900
1.5 mg	40360	28350	65980	24250	15700	209140	37500	34870	33350	107300	37560	28300	37960
0 mg	1850	2450	1700	2200	2100	3250	2000	2400	4100	2100	1300	2750	2600
1.5 mg	19600	21700	22700	38010	64080	165540	40010	45250	44110	85260	58530	47100	73700
0 mg	1600	2500	2950	2400	2350	3000	1900	2900	2650	2850	1650	1950	2950
1.5 mg	23450	27560	55790	24650	59810	153230	27700	58590	37050	52170	79320	34900	92170
0 mg	2800	2100	1750	2950	2700	2150	2850	2200	4000	1950	1700	2700	2650
1.5 mg	32450	33120	71970	26900	24000	215630	29100	29000	28700	57470	41660	21000	61340
0 mg	1400	1700	1850	1700	2600	4700	2900	3200	3600	1700	1500	1400	2300
1.5 mg	72720	17300	41960	28050	35050	130830	34450	40000	21750	29650	22950	29600	42050
0 mg	2150	1550	2600	1600	2050	2550	2300	2850	3000	1850	2050	2150	1850
1.5 mg	35400	35320	85880	32750	54850	139540	38860	36460	33050	84740	45520	60100	30160
0 mg	2250	1750	2600	1650	2550	2300	1500	3000	3350	2600	1450	2200	1700
1.5 mg	37360	32660	46160	41860	53120	246610	60890	26960	16150	75610	42820	37350	54610
0 mg	2300	1650	2200	1550	2100	2400	2950	3100	2550	2350	1650	1300	3200
1.5 mg	17850	20900	31050	27310	37150	151780	49680	22200	17650	75620	37550	13800	46760
0 mg	700	1900	2100	1600	2050	1950	1850	2100	4050	2100	2000	1750	2050
1.5 mg	34400	28800	30010	24150	62650	125160	28860	40510	24650	47960	64820	20100	22000
0 mg	2600	2050	3300	2200	1950	2750	2600	2200	3000	2200	1600	1800	2700
1.5 mg	29860	159870	52330	54810	67100	92300	77320	37910	58310	34060	47160	39860	32350
0 mg	1950	2050	1650	2200	2050	2950	2150	2600	8050	1750	1650	2300	2400
1.5 mg	37550	21550	60870	28900	86110	69550	64740	31860	63210	72210	41760	41450	17150
0 mg	1550	2200	2000	2300	2250	1800	1500	2950	3450	2050	1200	1900	1700
1.5 mg	23500	13000	31710	24000	120420	81600	37600	28000	35460	38300	39310	19500	32400

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