In-Depth Survey Report

Comparison of Biohazard Detection System Capture Efficiencies of an Existing Advanced Facer Canceller System and a Prototype Advanced Facer Canceller System 200 Configuration at the Santa Ana Processing and Distribution Center

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Abstract

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of the Biohazard Detection System (BDS) and the Ventilation/Filtration System (VFS) developed for the United States Postal Service (USPS) mail processing equipment - the Automated Facer Canceller System (AFCS). The testing described in this report is to validate that changes to the new prototype AFCS 200 such as belt speeds, pulley sizes, and enclosures, do not negatively impact BDS and VFS functionality. To evaluate this, an existing AFCS and prototype AFCS 200 were tested side by side at the USPS P&DC in Santa Ana, California. The BDS and VFS were developed and installed by private contractors hired by the USPS to reduce the potential for employee exposure to harmful substances that could be contained in mail processed by the equipment. The VFS for the AFCS was designed to be used with a BDS that samples and analyzes air from the AFCS to determine if a biohazard is present. This effort is in response to terrorist attacks in the fall of 2001 that used the mail as a delivery system for anthrax. Since 2001, NIOSH researchers have tested the effectiveness of controls for the AFCS and other mail processing machinery at USPS Processing and Distribution Centers (P&DC) in Ohio and in the Washington DC area.

Evaluations were based on a variety of tests including tracer gas experiments, air velocity measurements, and smoke release observations. The experiments showed that capture efficiencies measured from both the BDS and VFS were statistically significantly higher for the prototype AFCS 200 than for the existing AFCS. On each machine, BDS capture efficiencies were statistically significantly higher when the BDS flow rate was set to 400 liters per minute (lpm) compared to when it was set to 200 lpm. However, the lowest mean BDS capture efficiency of the prototype AFCS 200 was 59%, which is still higher than the highest mean BDS capture efficiencies of the existing AFCS at either BDS flow rate which was 51%. The higher capture efficiencies of the prototype AFCS 200 compared to the existing AFCS were likely due to the more enclosed design, baffles, and modifications to air flow outside of the BDS hood. Based on the results of this testing, it is expected that the prototype AFCS 200 design would have improved capabilities of detecting a biological hazard and protecting workers compared to the existing AFCS design. Smoke release experiments and velocity measurements were consistent with the results of tracer gas testing. The USPS should consider additional tracer gas, smoke, and air velocity testing if a production AFCS 200 is developed from the prototype AFCS 200.

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 is for a project to evaluate controls that were put in place by the United States Postal Service (USPS) to control the release of contaminants into the work area of postal employees. This report describes the evaluation of the capture efficiencies of the Biohazard Detection System (BDS) and the Ventilation/Filtration System (VFS) for an existing Automated Facer Canceller System (AFCS) machine and a prototype AFCS 200 machine.

The USPS AFCS 200 program has been developed to update the nearly 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 and VFS. The testing described here is to validate that changes to the new prototype AFCS 200 do not negatively impact BDS and VFS functionality. This testing was conducted at the Santa Ana, California Processing and Distribution Center (P&DC) during a field surveys that took place from April 17th – May 4, 2009.

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 contaminants emitted from mail during normal mail processing. 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 P&DCs in Ohio and in the Washington, D.C. area. Technical reports from those studies are free and available to the public at the following website: http://www.cdc.gov/niosh/surveyreports/

Description of Controls and Equipment

The controls evaluated in this report are the BDS and VFS for two AFCS machines. During this evaluation, the BDS and VFS of an existing AFCS machine and a new prototype AFCS 200 machine were tested and compared. The controls were designed and installed by USPS contractors to significantly reduce the potential for operator exposure to bacterial contaminants that could be contained in mail processed by this 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. 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. An overview of the current AFCS system is shown in Figure 1.

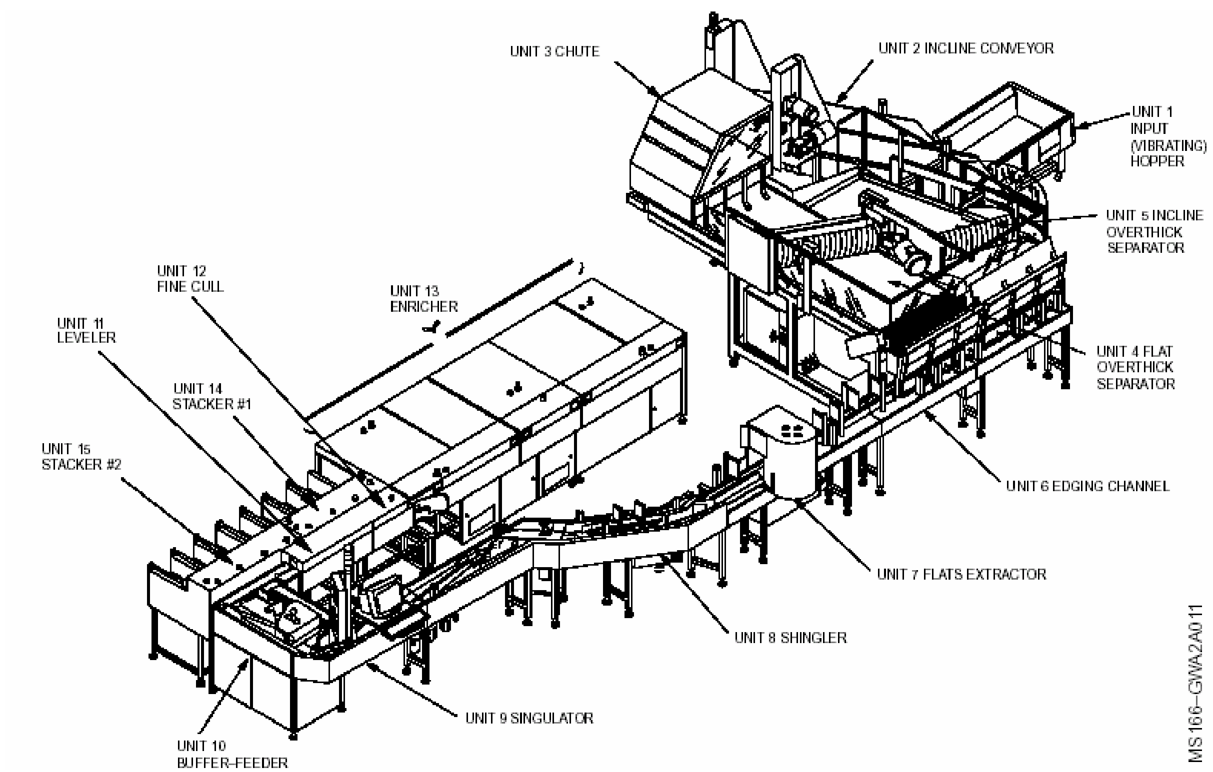

Figure 1. Overview of Automated Facer Canceller System

The VFS for the AFCS consisted of an air handling/filtration unit that provided exhaust for locations of possible contaminant release. The air handling unit was fitted with three stages of filtration composed of a pre-filter, a Minimum Efficiency Reporting Value (MERV) 14 filter, and a High Efficiency Particulate Air (HEPA) filter. The effectiveness of the VFS was enhanced by enclosures put in place on the AFCS by the contractor. Hoods/enclosures were fitted around areas that have higher potential for agitating or compressing mail pieces. This is the major cause of contaminant release from tainted mail pieces.

The biohazard detection system was designed to draw air from an area of the AFCS that would most likely contain a 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. Figures 2 and 3 show the shingler and singulator of the existing AFCS.

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.

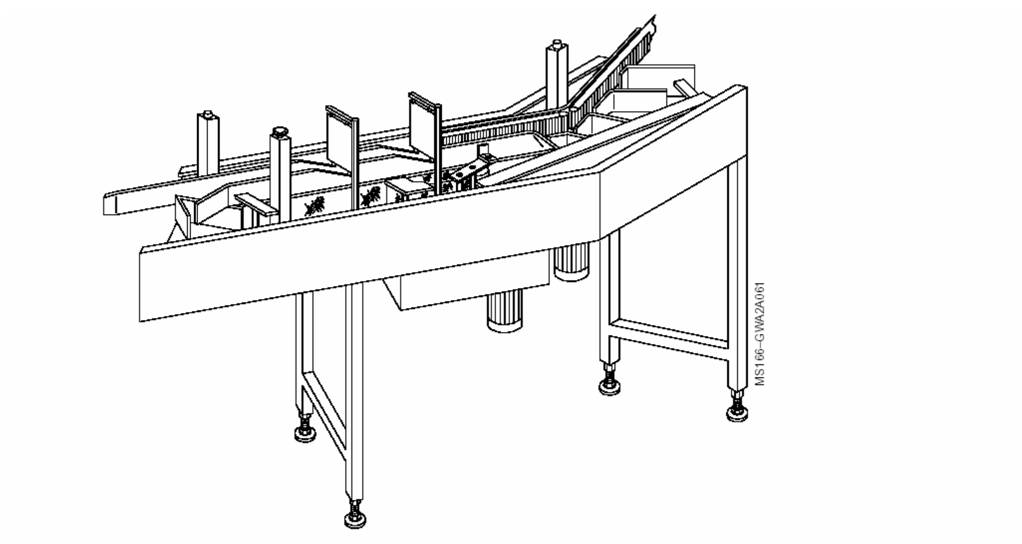

Figure 2. Shingler Area of the AFCS.

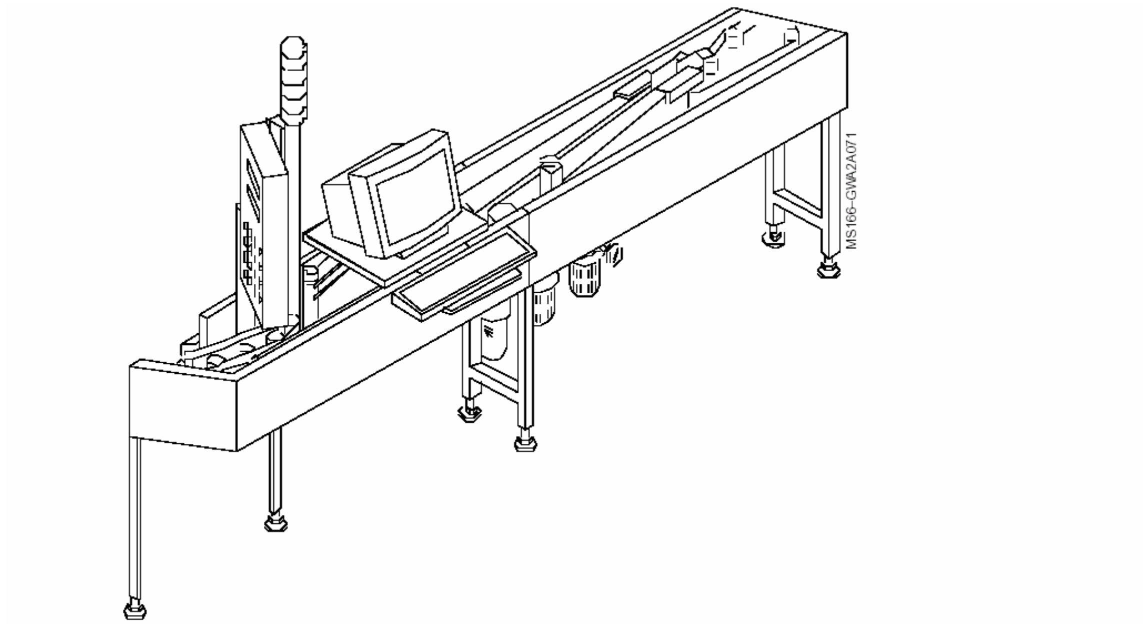

Figure 3. Singulator Area of the AFCS.

Figures 4 and 5 show the BDS hood over the singulator area of the existing AFCS and the prototype AFCS 200 respectively. The configuration of the BDS hood over the existing AFCS was the same configuration as tested in previous NIOSH reports (Topmiller et al. 2003; Beamer et al. 2005].

Figure 4: BDS Hood on the Existing AFCS

Figure 5: BDS Hood on the Prototype AFCS 200

Before testing occurred on either machine, the production BDS hood was removed and the BDS test hood was installed. The BDS test hood was identical in design to the production hoods on both machines except that the BDS test hood had three predrilled holes for injecting tracer gas.

Although the same BDS hood was tested on each machine, the prototype AFCS 200 machine had several changes near the hood that were designed to improve containment at specified locations. The area downstream of the BDS hood on the prototype AFCS 200 machine was entirely enclosed with removable lids which are shown above in Figure 5. Figure 5 also shows an upstream hood mounted over the shingler to reduce the influence of room air currents on capture efficiencies near pinch points at locations upstream of the BDS hood. Figure 6 shows the baffle arrangement downstream of the singulator area at the first removable cover. Figure 7 shows the baffle arrangement that is further downstream of the singulator at the second removable cover. Figure 8 shows the low flow backwash orifice added to direct air into the downstream face of the BDS hood.

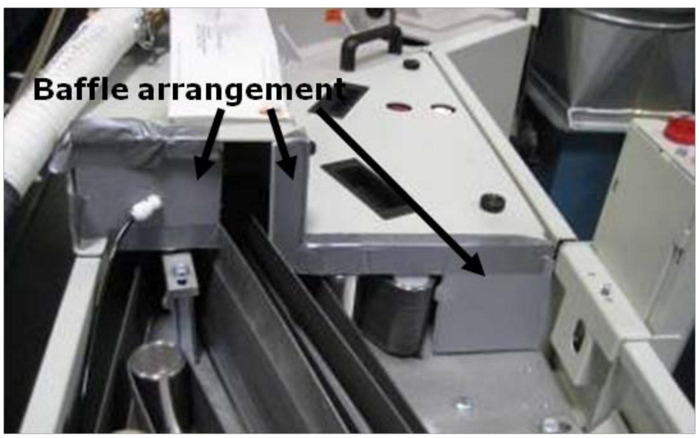

Figure 6: Baffle Arrangement on the Prototype AFCS 200 machine 1st cover

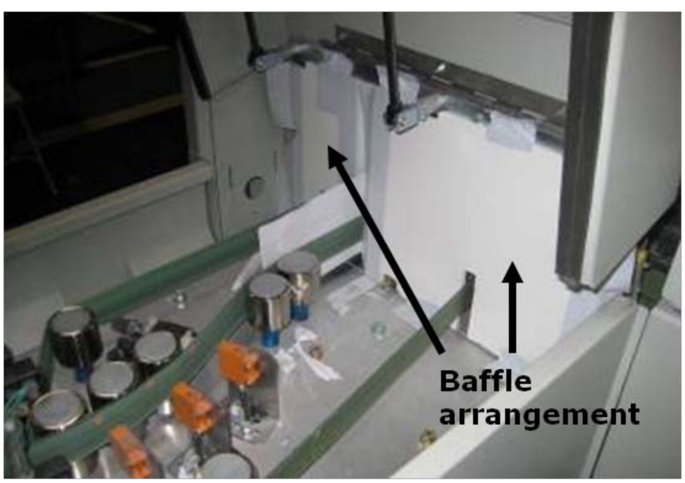

Figure 7: Baffle Arrangement on the Prototype AFCS 200 machine 2nd cover

Figure 8: Low Flow Backwash Orifice added to the Prototype AFCS 200 machine

These temporary changes to the prototype AFCS 200 were made at the beginning of this testing as a result of some preliminary tests conducted under a variety of configurations to determine the optimal configuration. The temporary modifications described in Figures 5 through 8 were in place for all of the data that is presented in this report on the prototype AFCS 200 machine.

The general building ventilation system was on for all tests on both machines. The general building ventilation system had multiple supply air diffusers near both evaluated machines and cross drafts were measured in the range of 50 – 100 ft/min. Figure 9 shows some supply diffusers that were located near the evaluated machines.

Figure 9: General building ventilation supply diffuser locations

During previous NIOSH tests the VFS was located directly above the AFCS and was only connected to a single AFCS. For the testing described in this report, two AFCS machines were connected to a single VFS which had double the capacity and was located across the aisle on a mezzanine as shown in Figure 10.

Figure 10: VFS location and configuration for the NIOSH testing in Santa Ana

The BDS was manufactured by a different USPS contractor than the AFCS and access to the actual BDS pump was not provided during this testing. One end of the BDS hose was connected to the BDS hose inlet within the BDS hood while the other end of the BDS hose was connected to a filter (model D-71631, Filterwerk MANN + HUMMEL GmbH, Ludwigsburg, Germany) and vacuum pump (model D-97616, vacuum pump/compressor, nash elmo Industries, GmbH, Bad Neustadt, Germany) to simulate BDS flow. The exhaust of the pump used to simulate BDS flow was routed to the enclosure adjacent to the flats extractor. The speed of the BDS simulation pump was controlled using an adjustable speed AC motor controller (SPEEDMASTER® SM Basic Series, Leeson Electric Corporation, Grafton, Wisconsin). Figure 11 shows the configuration of the BDS simulation pump and AC motor controller.

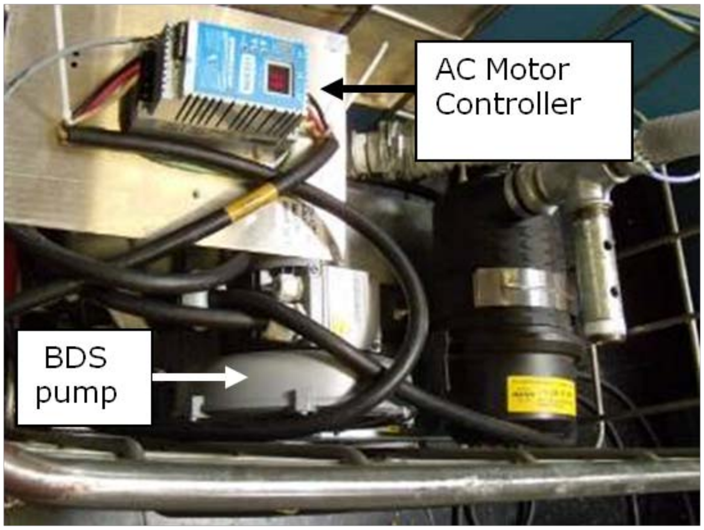

Figure 11: BDS simulation pump

All tests were conducted with the BDS simulation pump adjusted so that the flow rate through the BDS hose was either 200 or 400 lpm. The pump speed corresponding to a flow rate of either 200 or 400 lpm was determined by releasing the tracer gas sulfur hexafluoride (SF_6) at a constant rate directly into the BDS hose while the tracer gas detector was positioned downstream of the airflow in the BDS hose. The BDS simulation pump was then adjusted until the concentration of tracer gas passing through the hose was diluted to match a flowrate of either 200 or 400 lpm. A more detailed explanation of the tracer gas release and detection equipment is provided in the methods section of this report.

After the flow through the BDS hose was adjusted at either 200 or 400 lpm, the flow rate was checked by measuring the face velocity at the BDS hose inlet with a hot wire anemometer and multiplying by the area of the hose inlet face. In all instances the flow rate set using tracer gas compared well with the flow rate calculated by measuring the face velocity and multiplying by the open area at the BDS hose inlet. Additionally, several measurements were taken when the BDS simulation pump was removed and the actual BDS pump was in place. The face velocities and calculated flow rates compared well between the simulation pump and actual BDS pump.

All tests on both machines were conducted while the AFCS processed test mail. The VFS of the AFCS was on during all tests on both machines. Simulations of a “Dirty Filter” condition were not conducted during any of the tests. The general building ventilation system was on for all tests results reported in this document.

Methods

Tracer Gas

Tracer gas is commonly used to evaluate capture efficiencies of local exhaust ventilation systems even when those systems are designed to control a hazard in particulate form. Tracer gas has been used to evaluate local exhaust on asphalt paving machines where the hazard contains diesel particulate [Mickelson et. al. 1999]. Tracer gas has been used to evaluate hoods designed to capture particles generated from grinding wheels [Fletcher, 1995]. Probably the most common application of tracer gas occurs in fume hood testing for local exhaust ventilation hoods [ANSI/ASHRAE 1985] that are designed to capture both gases and particles.

Past NIOSH testing has resulted in the development of a model that uses tracer gas to evaluate local exhaust ventilation of mail-processing equipment [Beamer B, 2004]. The model for using tracer gas followed a thorough literature review which found multiple sources that indicated tracer gas is an appropriate evaluation method to test the capture efficiency of a hazard in particulate form. In ANSI/ASHRAE Standard 110-1985 the point is made that "fine dust, small enough to be of health significance will be carried along with the hood air currents in a fashion similar to the transport of a gas." In Hemeon's "Plant and Process Ventilation," the author states that "to control small particle motion, one must control the motion of the air in which the small particles are suspended [Hemeon, 1999]." The authors in "Risk Assessment of Chemicals," describe how "small particles tend to behave like gases [Leeuwen et al. 2007]." Probably the most compelling study compared capture efficiencies measured by tracer gas and aerosol tracer techniques and concluded that the transfer of aerosol to a local exhaust system was "nearly identical to that of a gas" for particles with diameters less than 30 micrometers (µm) [Beamer D, 1997]. This indicates that tracer gas testing will adequately represent the efficiency of a local exhaust system designed to capture B. anthracis spores.

Equipment

To quantitatively evaluate the capture efficiency of the ventilation system, a tracer gas method was used. The tracer gas was 99.5% minimum purity Sulfur Hexafluoride (SF_6) when capture efficiencies of the VFS were tested and 1% gravimetric grade SF_6 When capture efficiencies of the BDS were tested. A dual stage series 200 brass regulator with a CGA 590 inlet was connected to the tracer gas cylinders. The gas was supplied through ¼ in. diameter Teflon tubing and controlled using a mass flow controller shown in Figure 12 set to produce about 2.5 parts per million (ppm) in the exhaust outlet of the system. The mass flow controller for the 99.5% SF_6 was manufactured by Aalborg (model GFC17, Aalborg Instruments and Controls, Inc., Aalborg, Denmark) and had a flow range of 0-1000 milliliters per minute (ml/min) when calibrated to SF_6.The mass flow controller for the 1% SF_6 was manufactured by Omega (model FMA 5400/5500, Omega

Engineering, Inc., Stamford, Connecticut) and had a flow range of 0 – 500 ml/min when calibrated to nitrogen.

Figure 12: Aalborg and Omega Mass Flow Controllers

When evaluating capture efficiencies of the VFS, the concentration of the SF_6 was measured in the exhaust duct. In order to sample this air stream, the exhaust air was sampled through a 20 in. long ¼ in. diameter copper tube, the same length as the duct diameter. Six 3/32 in. diameter holes were drilled uniformly across the length of the tube, and it was inserted into and perpendicular to the exhaust duct. Figure 13 shows the copper tube inserted into the exhaust duct. When evaluating capture efficiencies of the BDS, the SF_6 concentration was measured in the BDS hose by pulling air from the hose through ¼ in. Teflon tubing using an MNPT fitting with a Swagelok connection as shown in Figure 14. The fitting was installed directly upstream of the pump.

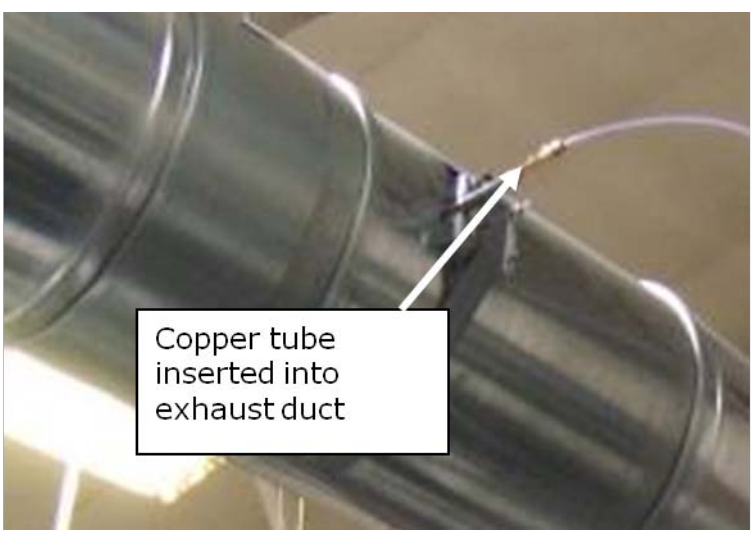

Figure 13: Copper tube to sample tracer gas from exhaust duct

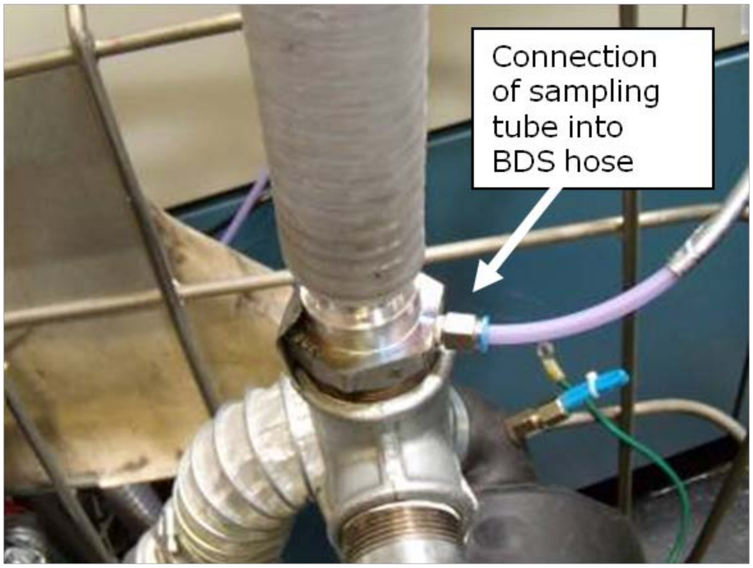

Figure 14: Connection of sampling tube to the BDS hose

After the sample was drawn from the duct or BDS hose, the air was first filtered (HEPA Capsule Filter, Model #12127, Gelman Sciences, Incorporated, Ann Arbor, Michigan, 48106) to remove dust and then pulled through a MIRAN® Sapphire Specific Vapor Analyzer (Thermo Environmental Instruments, 8 West Forge Parkway, Franklin, MA 02038), using an external pump (Zefon High Volume Rotary Vane Pump, Serial No. 02668, Zefon International, Inc. Ocala, Florida) at approximately 30 lpm, and using Teflon tubing throughout the sampling system. After exiting the pump, the sampled air was released through Tygon tubing to a hood on the machine not being tested. The analog output signal from the MIRAN® was routed to a USB 12-bit analog and digital I/O module (Measurement Computing Corp, Norton, MA) and displayed at one-second intervals in real-time on a portable computer.

Procedures

Each measurement of capture efficiency was recorded for a 4 to 5 minute interval. The MIRAN® concentration corresponding to 100% capture was measured by releasing the SF_6 directly into the 14 in. duct for VFS capture and directly into the BDS hose for BDS capture. This measurement was made both immediately before and after the rest of the capture efficiency measurements as well as between every three to five efficiency measurements, to detect and correct for drift in the 100% concentration. All tracer gas measurements were made with the building ventilation system on and with both the BDS and the VFS on. All tracer gas measurements were also made while the AFCS processed test mail.

Tracer gas was released at a constant rate at the following locations in and around the BDS hood.

A About 7.5 inches downstream of the downstream face of the BDS hood

B At the downstream face of the BDS hood

C: Inside the BDS hood about 8 inches from the downstream face

D Inside the BDS hood about 15.25 inches from the downstream face

E Inside the BDS hood about 8.5 inches from the upstream face

F At the upstream face of the BDS hood

G About 2.5 inches upstream of the upstream face of the BDS hood

H About 6 inches upstream of the upstream face of the BDS hood

I About 17 inches upstream of the upstream face of the BDS hood

The ¼ in. diameter Teflon tubing was inserted approximately ¾ in. through pre-drilled holes at each of the nine locations. Each location was covered with electrical tape when not in use to prevent additional air from being pulled in through the holes. Locations C through I are shown in Figure 15 and locations A and B are shown in Figure 16 covered with electrical tape.

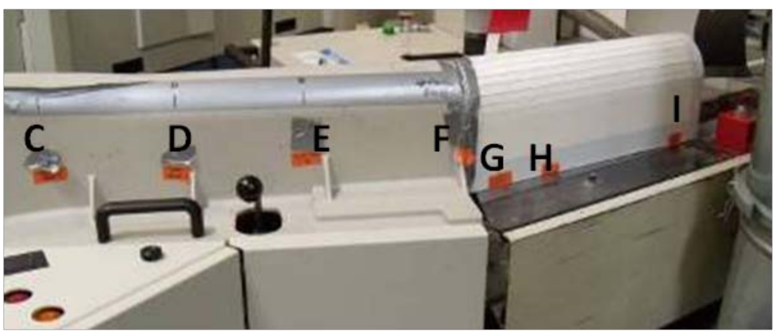

Figure 15: Tracer gas release locations C through I for the BDS hood

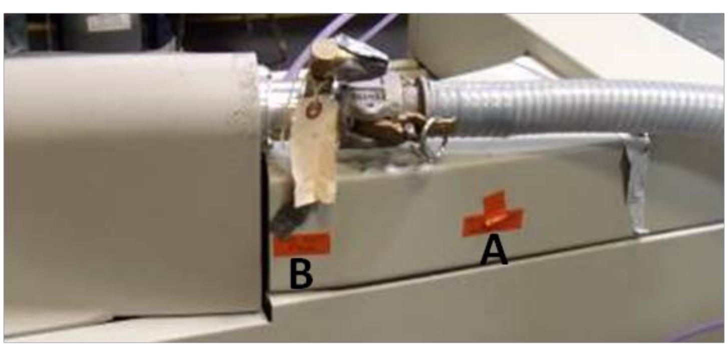

Figure 16: Tracer gas release locations A and B for the BDS hood

Tracer gas was released at each of the nine locations A through I individually with the sequence randomized for every scenario tested. Tracer gas release locations on the existing AFCS and the prototype AFCS 200 were the same for locations inside the hood and at the face. The release locations outside the hood on the existing AFCS were at the same locations as corresponding locations on the prototype AFCS 200 except that the tracer gas supply hose was taped to the machine instead of the enclosure since locations outside the BDS hood were not enclosed on the existing AFCS. For each machine, capture efficiencies at the nine locations were tested for the following scenarios.

Existing AFCS (Belt speed at 2.5 m/s):

- Tracer gas detector positioned in the BDS hose with the BDS flow set at 200 lpm
- Tracer gas detector positioned in the BDS hose with the BDS flow set at 400 lpm
- Tracer gas detector positioned in the VFS duct with the BDS flow set at 200 lpm
- Tracer gas detector positioned in the VFS duct with the BDS flow set at 400 lpm

Prototype AFCS 200 (Belt speed set to 2.5 m/s):

- Tracer gas detector positioned in the BDS hose with the BDS flow set at 200 lpm
- Tracer gas detector positioned in the BDS hose with the BDS flow set at 400 lpm
- Tracer gas detector positioned in the VFS duct with the BDS flow set at 200 lpm
- Tracer gas detector positioned in the VFS duct with the BDS flow set at 400 lpm

Prototype AFCS 200 (Belt speed set to 3.0 m/s):

- Tracer gas detector positioned in the BDS hose with the BDS flow set at 200 lpm
- Tracer gas detector positioned in the BDS hose with the BDS flow set at 400 lpm
- Tracer gas detector positioned in the VFS duct with the BDS flow set at 200 lpm
- Tracer gas detector positioned in the VFS duct with the BDS flow set at 400 lpm

Each of the twelve test scenarios were evaluated three times for a total of 36 sets of nine tracer gas capture efficiency measurements. The 36 sets of nine capture efficiency measurements were randomized within replication.

When testing the capture efficiency of the VFS, tracer gas was released at a constant rate into the base of the 14 in. duct which led to a 20 in. duct where the tracer gas detector drew a sample of air to represent 100% capture concentration (C100). The outlet to the BDS hose was routed to the flats extractor which was partially enclosed by a hood that was under the influence of the VFS. The orange hose shown in Figure 17 shows the configuration of the BDS hose outlet to the flats extractor enclosure and the black hose which provides exhaust to the VFS.

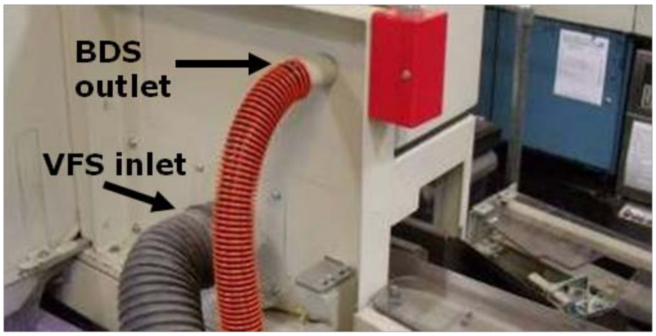

Figure 17: BDS outlet and VFS inlet locations on the flats extractor

When testing the capture efficiency of only the BDS hood, tracer gas was released at a constant rate directly into the BDS hose. At the same time, the tracer gas detector measured a sample of air drawn from a downstream location in the same hose until a desirable baseline C100 concentration was achieved. For this experiment, a concentration of 2.5 ppm of SF_6 as measured by the MIRAN® was used since it was slightly above half of the 0 to 4 ppm range of the instrument.

For both the BDS and VFS measures of capture efficiency, the stabilized value when gas was released directly in the hose or duct corresponded to the C100 concentration. Once the concentration corresponding to C100 stabilized, data logging began and the average of the stabilized C100 values was used as the denominator of the capture efficiency ratio. The SF_6 concentration when released at a location A through I provided a value for the numerator C in the ratio C/C100 which was the measure of capture efficiency at that location. Baseline C100 measurements were typically made before and after three measurement locations. An interpolation line was drawn as the average of these two stabilized values. The baseline C100 value was the point on the interpolated line corresponding to the midpoint of stabilized values for the experiment of interest.

Tracer gas efficiency for any location was computed as the ratio:

$$\frac{[\mathit{average\ of\ stabilized\ values\ for\ a\ location}]}{[C100\,\mathit{value}]}\times 100$$

The tracer gas detector was calibrated by the manufacturer before the testing. Additionally, field span checks were performed using a 1.04 ppm SF_6 standard.

A 5 liter Tedlar bag was filled with the 1.04 ppm SF_6 standard and the bag was connected to the MIRAN® using tygon tubing.

Smoke Release

Equipment

A smoke machine shown in Figure 25 (Mini Fogger, Model F-800, Chauvet USA, 3000 North 29th Court, Hollywood, Florida, 33020) was used to visualize air movement when a large quantity of smoke was needed. A second smoke machine also shown in Figure 18 (Wizard Stick, Zero Toys, Concord, MA) was used to observe capture at the hood face when a smaller amount of smoke was needed.

Figure 18: Fog machine for larger quantity smoke release

Procedures

By releasing smoke at points in and around the BDS hood with the BDS and VFS operating, the path of the smoke, and thus any airborne material potentially released at that point, could be qualitatively determined. If the smoke was captured quickly and directly by the VFS, it was a good indication of acceptable control design and performance. If the smoke was slow to be captured when released at a certain point, or took a circuitous route to the hood or air intake to the exhaust, the BDS or VFS design was considered marginal at that point. Smoke release observations were made at the upstream and downstream face of the BDS hood and along the mail path of the AFCS upstream of the BDS hood. All smoke release observations were recorded while the AFCS processed test mail.

Capture Velocity

Equipment

An anemometer shown in Figure 19 was used to measure air speeds at exhaust openings on the AFCS and BDS (Velocicalc Plus Anemometer, Model 8388, TSI Incorporated, P.O. Box 64394, St. Paul, Minnesota, 55164).

Figure 19: Hot wire anemometer used to measure capture velocity

Procedures

To measure the velocities achieved by the control at critical points, the anemometer was held perpendicular to the air flow direction at those points. Velocity measurement points included upstream and downstream face velocities and several locations to measure room air currents and cross drafts.

Results

Tracer gas

The mass flow controller was set to produce a 2.5 ppm concentration of SF_6 in the ventilation system exhaust or BDS hose when 100% of the gas was captured. The capture efficiency of each point under the BDS hood was calculated from the measured concentrations.

Appendix A and B contain detailed capture efficiency results for the BDS and VFS respectively. The Appendices include the three efficiency measurements and the mean of these measurements at each of the nine locations A through I for all evaluated test conditions for the existing AFCS and prototype AFCS 200. Table I below presents the mean of the three individual BDS and VFS capture efficiency measurements at each of the nine locations A through I for all evaluated test conditions. Table II presents the overall mean of the 27 measurements (three measurements at nine locations) of capture efficiency for the BDS and VFS under each evaluated test condition along with standard deviation, minimum, and maximum values.

Table I: Mean BDS and VFS capture efficiency data for the existing AFCS and prototype AFCS 200 at location A through I.

Machine	VFS Mean Capture Efficiency						BDS Mean Capture Efficiency					
	Existing AFCS		Proposed AFCS 200 2.5 m/s belt speed		Proposed AFCS 200 3.0 m/s belt speed		Existing AFCS		Proposed AFCS 200 2.5 m/s belt speed		Proposed AFCS 200 3.0 m/s belt speed	
BDS Flow (ALPM)	200 ALPM	400 ALPM	200 ALPM	400 ALPM	200 ALPM	400 ALPM	200 ALPM	400 ALPM	200 ALPM	400 ALPM	200 ALPM	400 ALPM
A	91%	86%	77%	74%	85%	74%	8%	9%	48%	66%	43%	45%
B	77%	72%	80%	77%	90%	77%	7%	21%	61%	86%	65%	89%
C	60%	69%	80%	75%	82%	72%	83%	89%	91%	94%	88%	94%
D	63%	67%	79%	76%	75%	73%	76%	85%	83%	93%	77%	94%
E	66%	69%	78%	76%	79%	72%	65%	84%	77%	91%	73%	93%
F	65%	66%	76%	72%	72%	66%	54%	78%	54%	86%	60%	83%
G	64%	66%	72%	74%	78%	74%	36%	55%	46%	70%	53%	77%
H	77%	80%	89%	86%	90%	89%	22%	34%	33%	47%	32%	52%
I	98%	95%	92%	87%	95%	91%	6%	8%	42%	61%	39%	59%
Mean Capture	73%	74%	80%	77%	83%	77%	40%	51%	59%	77%	59%	76%

Table II: Mean, standard deviation, minimum, and maximum capture efficiency summary data for the BDS and VFS of the existing AFCS and prototype AFCS 200.

Hood	Machine	BDS Flow Rate (ALPM)	Mean Capture	n	Standard Deviation	Min	Max
VFS	Existing AFCS	200	0.73	27	0.14	0.52	0.99
VFS	Existing AFCS	400	0.74	27	0.12	0.53	1.00
VFS	Proposed AFCS 200 (2.5 m/s belt speed)	200	0.80	27	0.09	0.67	1.00
VFS	Proposed AFCS 200 (2.5 m/s belt speed)	400	0.77	27	0.10	0.64	0.98
VFS	Proposed AFCS 200 (3.0 m/s belt speed)	200	0.83	27	0.08	0.66	0.98
VFS	Proposed AFCS 200 (3.0 m/s belt speed)	400	0.77	27	0.09	0.63	0.96
BDS	Existing AFCS	200	0.40	27	0.30	0.05	0.86
BDS	Existing AFCS	400	0.51	27	0.33	0.05	0.94
BDS	Proposed AFCS 200 (2.5 m/s belt speed)	200	0.59	27	0.24	0.17	0.98
BDS	Proposed AFCS 200 (2.5 m/s belt speed)	400	0.77	27	0.17	0.38	0.96
BDS	Proposed AFCS 200 (3.0 m/s belt speed)	200	0.59	27	0.20	0.27	0.92
BDS	Proposed AFCS 200 (3.0 m/s belt speed)	400	0.76	27	0.20	0.23	1.00

Statistical Analysis:

The data were analyzed for the VFS capture efficiencies and BDS hood capture efficiencies separately. A two-way analysis of variance (ANOVA) procedure was used to test for differences in mean capture efficiency among machines, belt speeds, and flow rates. Interactions between machines, belt speeds, and flow rate were also tested. The general normality assumption required for ANOVA was tested and met.

VFS Capture Efficiencies:

- Statistically significant difference were found among machine ($p=0.01$). Based on Tukey's multiple comparison, the mean VFS capture efficiencies of the prototype AFCS 200 (at both belt speeds) were statistically significantly higher than the mean VFS capture efficiencies of the existing AFCS machine.
- No statistically significant differences in VFS capture efficiencies were found between belt speeds of the prototype AFCS 200.
- No statistically significant difference in VFS capture efficiencies were found between BDS flow rates of 200 lpm and 400 lpm on either machine.
- A statistical test was also performed to determine if there were any interactions between independent variables. No statistically significant interactions between machine, belt speed, and flow rate were found for the VFS capture efficiency data.

BDS Hood Capture Efficiencies:

- Statistically significant differences in capture efficiencies of the BDS hood were found among machine ($p < 0.0001$). Based on Tukey's multiple comparison, the mean BDS capture efficiencies of the prototype AFCS 200 machine were statistically significantly higher than the mean BDS capture efficiencies measured from the existing AFCS machine.
- No statistically significant differences in BDS capture efficiencies were found between belt speeds of the prototype AFCS 200.
- Statistically significant difference in BDS capture efficiencies were found between the two evaluated flow rates ($p<0.0001$). Tukey multiple comparison indicated that the mean BDS capture efficiencies at 400 lpm were statistically significantly higher than the mean BDS capture efficiencies at 200 lpm.
- No statistically significant interaction between machine, belt speed, and flow rate were found for the BDS capture efficiency data. For flow rates of 200 lpm and 400 lpm, BDS capture efficiencies of the prototype AFCS 200 machines at both belt speeds were consistently higher than the BDS capture efficiencies of the existing AFCS.

BDS Exhaust Location (Enclosure Adjacent to the Flats Extractor):

Although it was not the focus of this testing, some limited additional capture efficiency measurements were collected from the enclosure adjacent to the flats extractor where the BDS hose exhausts air following analysis. This testing was conducted out of concern that room cross drafts that seemed to be affecting capture efficiency results of the BDS hood relative to previous NIOSH studies, might also affect containment of the enclosure where the BDS exhausted air. This additional testing was done by releasing tracer gas at a constant rate into the duct of the VFS with the tracer gas detector in the VFS duct to obtain a C100 value. While the AFCS processed test mail, tracer gas was then released into the BDS hose with the tracer gas detector in the VFS duct to obtain a value for the numerator in the capture efficiency ratio. A final C100 in the duct was conducted and the midpoint on the interpolation line of the pre and post C100 values was used as the denominator in the capture efficiency ratio. Capture efficiencies were measured for the enclosure adjacent to the flats extractor at 200 lpm and 400 lpm on both the existing AFCS and prototype AFCS 200 machines. The results shown in Table III indicate that between 28% and 37% of the air exhausted from the BDS hose into the enclosure adjacent to the flats extractor was not captured by the VFS.

Table III: Capture efficiency of the enclosure adjacent to the flats extractor

	200 ALPM	400 ALPM
Proposed AFCS 200	66%	63%
Existing AFCS	69%	72%

This affect was shown visually through smoke release observations. Smoke was released at the inlet to the BDS as shown previously in Figure 18 and pictures were taken of the enclosure adjacent to the flats extractor as shown in Figure 20.

Figure 20: Smoke escaping from the enclosure adjacent to the flats extractor

The capture capability of the enclosure adjacent to the flats extractor did not influence the results of BDS capture efficiencies using the methods in this report since for those measurements the tracer gas detector sampled directly from the BDS hose which is upstream of the air flow from the enclosure adjacent to the flats extractor. It is, however, important to note that the results of the VFS capture efficiency data were dramatically influenced by the capture capability of the enclosure adjacent to the flats extractor. Unlike BDS capture efficiency measurements where the detector sampled from the BDS hose, when measuring

VFS capture efficiencies the detector sampled from the VFS duct to measure capture of both systems working together. This helps to explain the results in Table I which show that the mean VFS capture efficiencies at locations under the hood such as C, D, and E were lower than locations outside of the BDS hood such as G, H, and I. The higher the capture efficiency of the BDS hood, the more tracer gas escaped from the enclosure adjacent to the flats extractor which explains the lower total capture results for the VFS at locations under the BDS hood.

The same tracer gas and smoke release tests were repeated with the BDS hose routed to a port at the base of the 14 in. VFS duct on the prototype AFCS 200 as shown in Figure 21. Smoke did not escape under this condition and tracer gas capture efficiencies were near 100% for both 200 lpm and 400 lpm conditions. However, the high airflow through the 14 in. duct decreased the pressure drop which increased the flowrate due to the reduced pressure drop. The speed on the AC motor controller had to be reduced to achieve 200 lpm and 400 lpm compared to the previous settings. Therefore, if the USPS decides to route the BDS exhaust of all AFCS machines to the 14 in. duct, it would be important to make sure that all BDS pumps are calibrated accordingly.

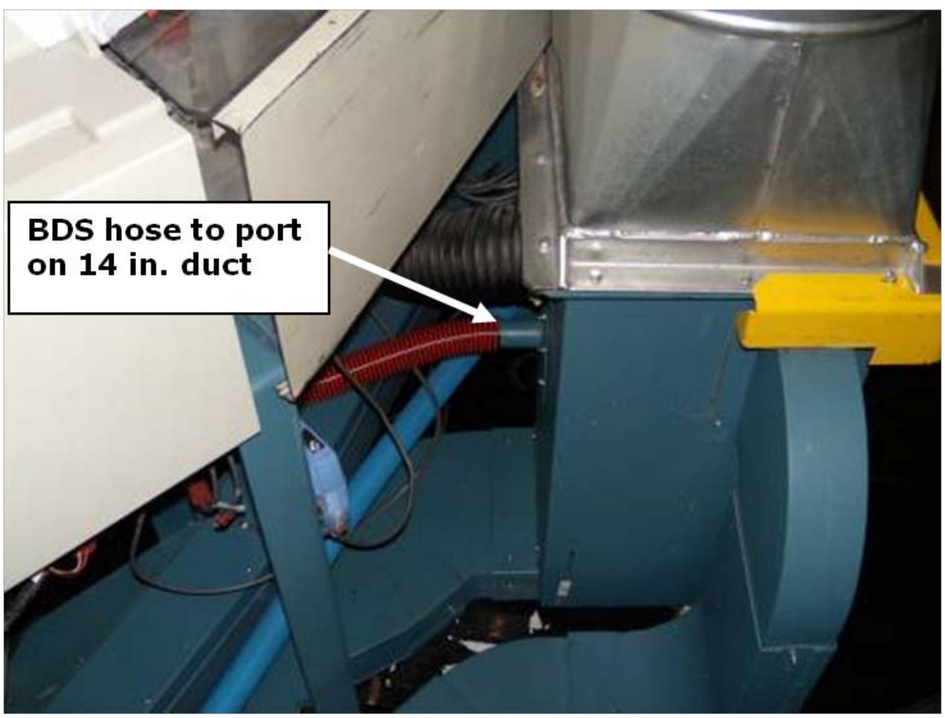

Figure 21: BDS hose (in orange) routed to a port near the base of the 14 in. VFS duct

Smoke Release

Smoke release experiments were conducted to visually determine how effective the BDS hood is at the upstream and downstream face, pinch points A, G, H, and I outside the hood, and the enclosure adjacent to the flats extractor for both the existing AFCS and the prototype AFCS 200. Smoke release observations were not noticeably different between BDS flow rates of 200 lpm and 400 lpm.

Smoke release observations on the existing AFCS:

- At location A, most of the smoke entered the VFS and very little if any smoke was entrained by the BDS hood.
- At the downstream face of the BDS hood, the flow of mail seemed to prevent smoke from entering the BDS hood. When interruptions occurred in the flow of mail, smoke changed directions and entered the BDS hood as shown in Figure 22.
- At the upstream face of the BDS hood and at location G, smoke appeared to enter the BDS hood as shown in Figure 23.
- At location H, some smoke appeared to escape the influence of any exhaust depending on the orientation of the smoke release and the size and spacing between letters passing the location. Additionally, room air currents appeared to carry the smoke in a single direction across the machine once it escaped the capture by the VFS.
- At location I, the smoke results were nearly identical to those of location H. Figure 24 shows some smoke captured by the VFS and some smoke being carried away by room air currents. Figure 25 shows another orientation of smoke release at location I where smoke appears to pass over the location and continue on with room air currents.

Smoke release observations of the prototype AFCS 200:

- Locations A through I including both the upstream and downstream face of the BDS hood were enclosed. Therefore, smoke release observations were made at the opening to the upstream hood extension which was located just upstream of location I.
- Smoke release observations from the upstream face of the hood extension indicated that some smoke generally entered the enclosure at this location as shown in Figure 26.

Figure 22: Smoke entering the downstream face of the BDS hood when the flow of mail was interrupted.

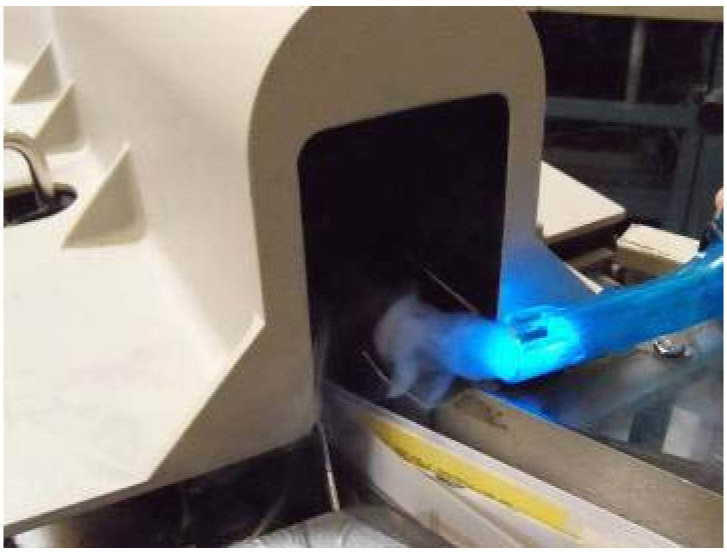

Figure 23: Smoke entering the BDS hood near the upstream face and location G

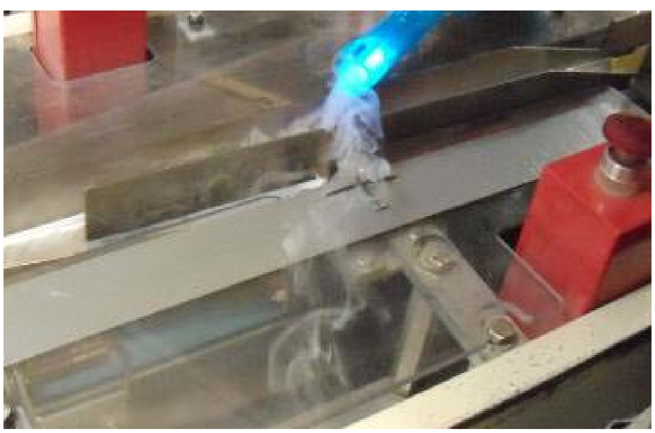

Figure 24: Some smoke captured by the VFS at location I

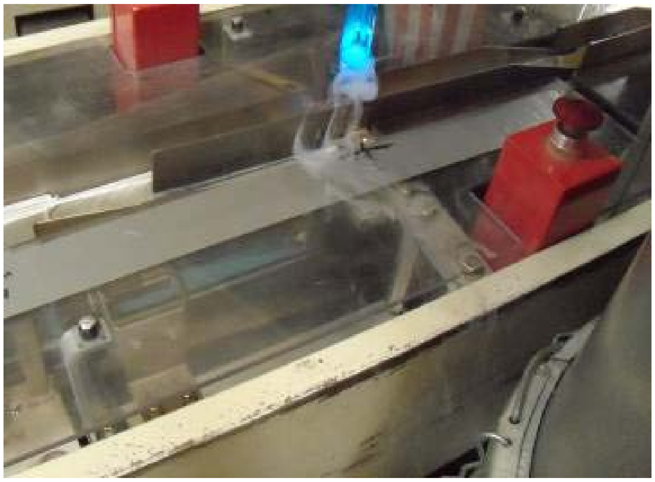

Figure 25: Smoke passing over location I

Figure 26: Smoke entering the influence of the hood extension on the prototype AFCS 200 machine

Capture Velocity

Air velocities collected at the upstream and downstream face of the BDS hood are shown in Table IV. These results are consistent with other findings in this report. It should be noted that the BDS air handling system was designed to have low capture velocities at the hood faces so as not to interfere with the proper function of the VFS for the AFCS.

Table IV: Capture velocities of the BDS hood

Machine	BDS EXHAUST	TEST LOCATION	Measurement 1 (ft/min)	Measurement 2 (ft/min)	Measurement 3 (ft/min)
Existing AFCS	200 alpm	Upstream face	2	3	6
Existing AFCS	200 alpm	Downstream face	10	1	2
Existing AFCS	400 alpm	Upstream face	11	18	10
Existing AFCS	400 alpm	Downstream face	35	33	29
Prototype AFCS 200	200 alpm	Upstream face	7	10	2
Prototype AFCS 200	200 alpm	Downstream face	53	56	59
Prototype AFCS 200	400 alpm	Upstream face	9	5	8
Prototype AFCS 200	400 alpm	Downstream face	42	59	53

Discussion

The findings in this report were based on side by side testing of the existing AFCS and prototype AFCS 200 conducted at the Santa Ana, California P&DC and may not necessarily compare directly with similar testing conducted under different plant configurations or VFS designs. For example, past evaluations may have been conducted in plants where ceilings were higher or where supply diffusers from the general building ventilation system were farther from the BDS hood. This would have the effect of lowering cross drafts which could influence capture efficiencies. Additionally, the VFS configuration tested during this survey was different than past NIOSH studies. For this study, the VFS was located across the aisle on a mezzanine above the maintenance area and two AFCS machines were ducted to the same VFS. In past NIOSH studies, a single AFCS was ducted to a single VFS which was located directly above the AFCS machine. Since the VFS is contained in a large enclosure, it would likely have the effect of blocking or redirecting room air currents compared to a design located across the aisle. For these and other reasons, it may be inappropriate to compare the test results of the prototype AFCS 200 from this evaluation with previous tests of the existing AFCS conducted at other facilities several years earlier. Instead, it is more appropriate to draw comparisons between the prototype AFCS 200 and existing AFCS as tested side by side at the Santa Ana P&DC.

In addition to high room cross drafts, some issues related to the BDS simulation pump were encountered during this testing. For this and previous NIOSH tests, the pump used to simulate the BDS flow rate was not the same type, manufacturer, or model number as the pump used for the actual BDS. However, a significant effort was made to ensure that the flow rates simulated during this testing were as close to 200 lpm and 400 lpm as possible. The flow rate of the simulation pump was controlled by using an adjustable speed motor controller and tracer gas was used to set the flow rate at either 200 lpm or 400 lpm. Additionally, the flow rate was checked by measuring the air velocity at the BDS hose inlet using a hot wire anemometer and calculating flow by multiplying the measured velocity by the open area at the hose inlet to verify the flow rate was at 200 lpm or 400 lpm. The hot wire measurement for the BDS simulation pump was also checked and compared to the actual BDS pump at the beginning of testing to verify that the BDS simulation pump matched the flow rate of the actual BDS pump. Using this method, the flow rate of the BDS simulation pump matched the flow rate of the actual BDS pump. However, some variability in the flow rate of the BDS simulation pump occurred during this testing as measured using tracer gas. On several occasions, the flow rate of the BDS simulation pump at the end of a five minute test run would be slightly higher or slightly lower than where it was set at the start of the run. The variability experienced was not expected to have a major impact on the capture efficiency results in this report. However, future testing should be conducted with a BDS simulation pump that is the identical model number as the actual BDS pump.

Conclusions and Recommendations

The following conclusions and recommendations are provided to further improve the protection of postal workers from potential hazards contained in mail pieces.

- Under the evaluated test conditions, capture efficiencies measured from both the BDS and VFS were statistically significantly higher for the prototype AFCS 200 than for the existing AFCS. Design features on the prototype AFCS 200 such as the enclosures upstream and downstream of the BDS hood provide more protection against room air currents such as those encountered during this testing. Based on this information, it is expected that postal workers would be better protected against a biological hazard while working at a prototype AFCS 200 design than at an existing AFCS design.

- During this testing, room air currents and the flow of mail appeared to influence the capture of the enclosure adjacent to the flats extractor. At the time of this testing, all existing AFCS machines exhaust BDS air after analysis into the enclosure adjacent to the flats extractor. The USPS should consider having all AFCS machines configured to exhaust the BDS air into a port on the 14 in. duct as shown in Figure 21 instead of exhausting into the enclosure adjacent to the flats extractor. If this change is made, all BDS pumps should be calibrated to make sure that the flow remains at 200 lpm or 400 lpm with the lower pressure drop in the 14 in. duct.

- The USPS should consider having capture efficiencies of the BDS and VFS of the AFCS tested under conditions that match different plant configurations where cross drafts are expected to be high such as machine locations near dock doors or other worst case scenarios. Alternatively, a study could be conducted using fans or other means to simulate and test the effect of different cross draft velocities and directions on capture efficiencies of the BDS hood.

- On each machine, the BDS capture efficiencies were statistically significantly higher when the BDS flow rate was set to 400 lpm compared to when it was set to 200 lpm. The lowest mean BDS capture efficiency of the prototype AFCS 200 was still higher than the highest mean BDS capture efficiencies of the existing AFCS at either BDS flow rate. Based on this information, it is expected that the prototype AFCS 200 design would have improved capabilities of detecting a biological hazard compared to the existing AFCS design.

- The USPS should consider additional tracer gas, smoke, and air velocity testing if a production AFCS 200 is developed from the prototype AFCS 200.

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Appendix A

Tracer gas capture efficiency results
Existing AFCS machine

BDS 200 LPM

200 ALPM, TRACER GAS DETECTOR LOCATED AT BDS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	6%	11%	6%	8%
B	8%	8%	5%	7%
C	83%	81%	86%	83%
D	72%	78%	77%	76%
E	67%	63%	65%	65%
F	52%	49%	63%	54%
G	24%	40%	43%	36%
H	16%	22%	28%	22%
I	5%	7%	6%	6%

200 ALPM, BDS EXHAUST ROUTED TO VFS, TRACER GAS DETECTOR LOCATED AT VFS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	84%	95%	93%	91%
B	89%	64%	80%	77%
C	52%	63%	65%	60%
D	53%	66%	70%	63%
E	59%	70%	69%	66%
F	61%	65%	70%	65%
G	61%	65%	65%	64%
H	76%	75%	79%	77%
I	>98%	96%	>98%	>98%

BDS 400 LPM

400 ALPM, TRACER GAS DETECTOR LOCATED AT BDS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	11%	8%	8%	9%
B	20%	29%	16%	21%
C	85%	87%	94%	89%
D	79%	84%	92%	85%
E	84%	78%	90%	84%
F	73%	78%	83%	78%
G	40%	56%	68%	55%
H	19%	39%	44%	34%
I	5%	11%	7%	8%

400 ALPM, BDS EXHAUST ROUTED TO VFS, TRACER GAS DETECTOR LOCATED AT VFS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	73%	88%	96%	86%
B	62%	71%	84%	72%
C	63%	70%	74%	69%
D	53%	75%	73%	67%
E	58%	73%	75%	69%
F	58%	70%	69%	66%
G	58%	68%	71%	66%
H	78%	74%	87%	80%
I	91%	94%	>98%	95%

Appendix B

Tracer Gas Efficiency Measurements
Prototype AFCS 200 Machine

BDS 200 LPM

200 ALPM, TRANSPORT SPEED 2.5 M/S TRACER GAS DETECTOR LOCATED AT BDS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	17%	55%	72%	48%
B	25%	81%	76%	61%
C	>98%	87%	89%	91%
D	92%	81%	76%	83%
E	85%	69%	78%	77%
F	32%	61%	68%	54%
G	56%	40%	41%	46%
H	39%	25%	35%	33%
I	46%	38%	43%	42%

200 ALPM, TRANSPORT SPEED 2.5 M/SBDS EXHAUST ROUTED TO VFS, TRACER GAS DETECTOR LOCATED AT VFS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	90%	70%	70%	77%
B	89%	72%	80%	80%
C	90%	79%	72%	80%
D	87%	82%	67%	79%
E	86%	76%	73%	78%
F	85%	74%	68%	76%
G	69%	76%	71%	72%
H	90%	89%	88%	89%
I	84%	92%	>98%	92%

200 ALPM, TRANSPORT SPEED 3.0 M/S TRACER GAS DETECTOR LOCATED AT BDS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	27%	57%	43%	43%
B	42%	65%	88%	65%
C	88%	84%	92%	88%
D	75%	69%	86%	77%
E	72%	70%	78%	73%
F	59%	59%	63%	60%
G	55%	56%	50%	53%
H	28%	33%	34%	32%
I	44%	46%	28%	39%

200 ALPM, TRANSPORT SPEED 3.0 M/S BDS EXHAUST ROUTED TO VFS, TRACER GAS DETECTOR LOCATED AT VFS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	83%	91%	82%	85%
B	90%	>98%	83%	90%
C	87%	82%	76%	82%
D	81%	71%	73%	75%
E	76%	82%	77%	79%
F	75%	66%	74%	72%
G	75%	78%	80%	78%
H	91%	89%	88%	90%
I	93%	94%	>98%	95%

BDS 400 LPM

400 ALPM, TRANSPORT SPEED 2.5 M/S TRACER GAS DETECTOR LOCATED AT BDS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	66%	60%	73%	66%
B	89%	91%	79%	86%
C	93%	95%	96%	94%
D	96%	93%	90%	93%
E	96%	89%	87%	91%
F	93%	81%	85%	86%
G	83%	63%	64%	70%
H	53%	38%	51%	47%
I	70%	60%	54%	61%

400 ALPM, TRANSPORT SPEED 2.5 M/S BDS EXHAUST ROUTED TO VFS, TRACER GAS DETECTOR LOCATED AT VFS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	91%	64%	68%	74%
B	87%	71%	74%	77%
C	85%	68%	73%	75%
D	92%	67%	69%	76%
E	90%	68%	70%	76%
F	86%	66%	65%	72%
G	77%	72%	72%	74%
H	93%	83%	81%	86%
I	>98%	75%	88%	87%

400 ALPM, TRANSPORT SPEED 3.0 M/S TRACER GAS DETECTOR LOCATED AT BDS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	23%	61%	50%	45%
B	77%	94%	95%	89%
C	84%	>98%	>98%	94%
D	93%	92%	96%	94%
E	91%	92%	>98%	93%
F	71%	88%	91%	83%
G	75%	77%	80%	77%
H	52%	54%	50%	52%
I	65%	45%	68%	59%

400 ALPM, TRANSPORT SPEED 3.0 M/S BDS EXHAUST ROUTED TO VFS, TRACER GAS DETECTOR LOCATED AT VFS EXHAUST				
Location	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Average**
A	71%	71%	80%	74%
B	72%	75%	84%	77%
C	72%	72%	73%	72%
D	74%	73%	73%	73%
E	71%	71%	75%	72%
F	63%	69%	67%	66%
G	77%	76%	68%	74%
H	89%	96%	83%	89%
I	90%	93%	90%	91%

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