Microbial Reduction Efficiencies of Filtration, Electrostatic Polarization, and UV Components of a Germicidal Air Cleaning System

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ABSTRACT: This study determined the effectiveness of components of a germicidal air-cleaning system involving filtration, electrostatic polarization, and UV light on the reduction of airborne bacteria and molds. The filter alone, filter and electrostatic polarization combined, and the filter, electrostatic polarization, and UV light were found to be effective ($P < 0.05$) in reducing a given concentration of *M. luteus* and *S. marcescens* by 90 to 92%. The same components were also found to be effective ($P < 0.05$) in reducing indigenous airborne bacteria and molds from ambient air in processing plant production conditions by 62 to 77% after only 1 pass through the filtration system. A germicidal air-filtration system utilizing electrostatic polarization and ultraviolet light can be used to reduce the chance of contaminating surfaces with airborne bacteria and molds.

Keywords: airborne microorganisms, electrostatic polarization, filtration, UV light

Introduction

AIR CONTAINS MANY MICROSCOPIC PARTICLES. BACTERIA AND molds that can contaminate meat and cause spoilage or foodborne microbial hazard to consumers are attached to these particles (Carpenter and Fryer 1990). Several pathogenic and spoilage organisms, including *Listeria monocytogenes*, have been implicated as potential airborne contaminates in the meat industry (Ryser and Marth 1991; Franco and others 1995). Kotula and Emswiler-Rose (1988) studied airborne microorganisms in pork-processing establishments at different locations during processing and found average log aerobic bacteria of 64.28 cfu/m^3 and 60.39 cfu/m^3 in the cooler and carcass fabrication area respectively. In the same study, they found mean log mold levels of 11.30 cfu/m^3 and 37.43 cfu/m^3 in the cooler and carcass fabrication area respectively (Kotula and Emswiler-Rose 1988). They also determined that contamination levels in pork-processing facilities were 10 times higher than in dairy facilities (Kotula and Emswiler-Rose 1988). Microbial contamination can occur in each step of processing including exsanguination, hide removal, evisceration, fabrication, grinding, and further processing (Kotula and Emswiler-Rose 1988; Rahkio and Korkeala 1997). Extensive research has been done to control microbial contamination on carcasses and on meat contact surfaces. Along with good manufacturing practices and sanitation standard operating procedures, several treatments are available to reduce microbial populations on carcasses including organic acid washes, alkaline washes, hot water washes, and trimming (Castillo and others 1998; Cabedo and others 1996; Dorsa and others 1998). However, little or no research has been done on how to reduce microbial populations in the air.

Filtration and electrostatic precipitation are known to be effective in the capture of airborne particles (Hillman and others 1992; St. Georges and Feddes 1995). It has been reported that filtration combined with electrostatic precipitation can commonly reach capture efficiencies of 99.5% (White 1984). Since bacteria and molds are attached to airborne particles, it can be hypothesized that filtration and electrostatic polarization should be effective in reducing airborne bacteria and molds. However, little research has been conducted on the effectiveness of filtration and electrostatic polarization on the reduction of airborne bacteria and molds in a meat processing facility.

Ultraviolet (UV) light is very effective in deactivating bacteria and molds (Hagstad and Hubbert 1986; Gardner and Shama, 2000). Fiksdal and Tryland, (1999) reported greater than 99.99% reductions in bacterial populations when exposed to UV light. Trapping bacteria and molds with filtration and electrostatic polarization then treating with UV light should result in reduction and inactivation of bacteria and molds. The objective of this study was to determine the effectiveness of filtration, electrostatic polarization, and UV light of a germicidal air cleaning system on the capture and deactivation of airborne bacteria and molds.

Materials and Methods

Filtration and air sampling

Germicidal air-purification console units (Environmental Dynamics Group (EDG), Model #G375, Princeton, N.J., U.S.A.) were tested for their effectiveness in removing and killing airborne bacteria and molds. These units use a combination of UV light and electrostatically polarized, low-density media filters (Figure 1). This technology differs from electrostatic precipitation in which the ionizing section of the precipitator positively charges airborne particles, which are then attracted to oppositely charged collection cells. Precipitator efficiency declines with loading and can be at a fraction of initial levels in as little as a week. The system used in the present study utilizes a high-voltage, low-current DC charge that is continuously applied to the conductive center screen of the disposable media pad. This creates an electrostatic field between the center screen of the disposable media pad and the filter frame. This force field polarizes the surface charge of both the fibers of the media pad as well as

the particles that are drawn into the filter. The polarized particles are then attracted, attach themselves to the polarized fibers, and are removed from the air stream. In this way, the low-density media is able to achieve high efficiencies with low static pressure.

These wall mount units are 58-cm wide, 31-cm deep, and 52-cm in height and weigh 22 kg. These units have an electrical input of 115 V AC/60 Hz which is converted to an electrical output of 6600 V DC/67 0‡:mA for the electrostatic polarization. They use an UV G25T8 germicidal bulb and circulate 10.61 cubic meters of air per min. The intensity of the UV bulb is 100000 mW/cm^2. Because of their console design, the filtration units may recirculate air a number of times depending on the size of room in which they are placed.

Air was sampled using an Anderson N-6 stage Microbiological Air Samplers® (Anderson Instruments, Inc., Model #10-890, Smyrna, Ga., U.S.A.). The air samplers were calibrated to sample 0.0283 cubic meters of air per min (CMM). The air samplers were sterilized prior to sampling and after sampling with 70% ethyl alcohol. Media used for microbiological analysis was plate count agar (PCA; Difco #247940, Sparks, Md., U.S.A.) for enumeration of bacterial colony forming units (cfu) and malt agar (BBL #11401, Baltimore, Md., U.S.A.) for the enumeration of mold spores. After the air samples were collected, PCA plates were incubated at 37 °C for 48 h and malt agar plates were incubated at 25 °C for 5 d (Vanderzant and Splittstoesser 1992). Colony forming units were counted and reported as cfu/m^3 of air sampled.

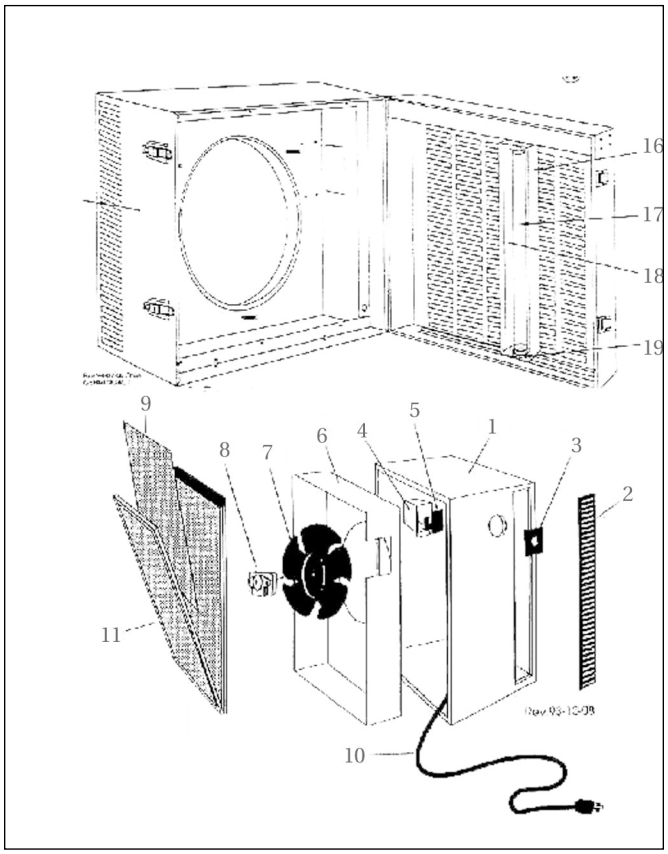

Figure 1—Germicidal air filtration unit with electrostatically-polarized, low-density media filter and scanning ultraviolet light. (1) Cabinet, (2) Exhaust grill—2, (3) Switch plate, (4) Transformer cover, (5) Transformer—24v, (6) Motor mount plate, (7) Fan, (8) Motor, (9) Replacement filter cell, (10) Power cord, (11) Filter enclosure complete with miniaturized electronic powerhead, (16) Light guard, (17) UV light bulb, (18) Parabolic light reflector, (19) Motorized track

Cultures and dilutions

Because potential bacterial pathogens may be either Gram-positive or Gram-negative, *Micrococcus luteus* ATCC 9341 (Microbiologics #688501, St. Cloud, Minn., U.S.A.) and *Serratia marcescens* ATCC 8100 (BBL #237047, Cockeysville, Md., U.S.A.) were chosen to provide a representation of Gram-positive and Gram-negative bacteria. Nutrient broth (Difco #234000) was prepared, autoclaved, and inoculated with either *S. marcescens* or *M. luteus* and cultured in a static water bath at 35 °C for 2 d before being used in the studies. Cultures were transferred every 5 d to fresh, sterile nutrient broth and vortexed prior to plating to disperse clumps of cells.

Five mL of broth containing a known concentration of bacteria (outlined in the following section) was placed in an aerosol spray bottle (Nalgene #2430-0200, Rochester, N.Y., U.S.A.). This was used to introduce a known concentration of bacteria into the air. The number of pumps to pressurize the aerosol bottle and spray time was standardized to 25 pumps and 15 sec of spray. The result was that 5 mL of inoculated dilution water with the given number of bacteria was aerosolized. Bacteria were aerosolized in a completely enclosed room with no external ventilation and personnel wore protective clothing, gloves, ventilation masks, and goggles. All surfaces were sterilized with 70% ethanol and at least 2 changes of air were filtered through the germicidal air filter after completion of a test.

Controlled component testing

Controlled testing of the filtration components of the EDG wall mount unit was conducted in a cold storage room (5 °C). Cardboard boxes were lined with plastic to allow for easy sanitation and attached to the front or intake of the filtration unit (inoculation box) and back or exhaust of the filtration unit (cleaned air collection box; see Figure 1). Air-intake valves of the air samplers were inserted through a sealed hole in bottom of each of the boxes. A hole was cut in the inoculation box to allow for introduction of the aerosol into the system. Aerosolized bacteria were sprayed into the inoculation box for each replication of the study. Air samples were collected from the inoculation box to determine the cfu/m^3 of air. The console unit was activated during inoculation. After the inoculation process, air samples were collected in the cleaned-air collection box to determine cfu/m^3 of air. Air samples were collected for each part of the study using either *M. luteus* or *S. marcescens*. Samples were collected on PCA and incubated for 48 h at 37 °C. The inoculation and sampling method was repeated in the same manner for each part of the study and for each bacteria used. After each sample collection, air samplers, the inoculation box, and collection box were cleaned using 70% ethyl alcohol.

The percent loss of bacteria caused by contact with the unit shell with no filter, electrostatic polarization, or UV light was determined and served as the control. The aerosol was sprayed into the inoculation box and the unit was activated. The volume of air sampled in the inoculation box and collection box was 0.028 m^3. Procedures then were repeated using the filter media only (FO); filter media and electrostatic polarization (FE); and filter media, electrostatic polarization, and UV light (FEUV). Air samples were taken in the inoculation box (0.007 m^3) and in the collection box (0.014 m^3) to determine initial and final concentration. Eight replications per bacteria per treatment were conducted for this study.

Table 1—Means, percent reduction, and SEM of aerosolized *M. luteus* and *S. marcescens* using various components of a console wall-mount germicidal air-cleaning system in a controlled air environment

	M. luteus, mean cfu/m³			*S. marscens*, mean cfu/m³		
Treatment[a]	Initial	Filtered	% Reduction	Initial	Filtered	% Reduction
Control	5880	4820.6[c]	17.1[d]	7213	6573.2[b]	10.1[e]
FO	56505	6776.3[b]	84.0[c]	42379	6758.6[b]	84.1[d]
FE	56505	5129.7[c]	90.9[b]	42379	5394.5[c]	87.3[c]
FEUV	56505	4352.7[c]	92.3[b]	42379	4158.5[d]	90.2[b]
SEM		239.89	1.14		190.79	0.69
P > F		0.001	0.001		0.001	0.001

[a]FO = filter only, FE = filter and electricity, FEUV = filter, electricity, and ultraviolet light.
[b,c,d,e]Means in the same column with common or no superscripts are not different ($P > 0.05$)

Table 2—Means, percent reduction, and SEM of airborne bacteria and molds in ambient air in the processing room using various components of a console wall-mount germicidal air cleaning system.

	Bacteria, mean cfu/m³			Mold, mean cfu/m³		
Treatment[a]	Initial	Filtered	% Reduction	Initial	Filtered	% Reduction
Control	75.7	61.5	18.7[c]	319.6	278.9[b]	12.7[d]
FO	149.7	74.5	50.2[b]	681.3	420.6[b]	38.3[c]
FE	102.8	41.3	59.8[b]	298.1	68.5[c]	77.0[b]
FEUV	165.6	62.5	62.3[b]	155.4	47.3[c]	69.6[b]
SEM		0.59	5.62		2.08	5.11
P > f		0.73	0.001		0.002	0.001

[a]FO = filter only, FE = filter and electricity, FEUV = filter, electricity, and ultraviolet light.
[b,c,d]Means in the same column having common or no superscripts do not differ (P > 0.05)

Ambient air component testing

EDG console wall-mounted units were tested under plant production conditions in the Processing Room of the Auburn Univ. Lambert Meats Laboratory. The filter medium was removed and the electrostatic polarization and UV light were deactivated (control). The console unit fan was activated and air samples were taken. Samples were collected in the same manner for each part of the study. Next, the effectiveness of the FO, FE, and FEUV were tested individually on reducing bacteria and mold cfu/m³ from ambient air.

A trash bag was sanitized using 70% ethyl alcohol and attached to the clean-air outputs of the console unit. Air samples were taken directly in front of the console unit to test ambient air for bacteria and mold cfu/m³. Air samples then were taken from the clean-air collection bag. An air sampler intake was inserted in the bottom of the collection bag and connected with electrical tape to the bag. Two air samples were taken; 1 of ambient air and 1 of cleaned air. Air volumes tested were 0.23 m³ for PCA plates and 0.20 m³ for malt agar plates. Initial means of bacterial numbers for this experiment were 75.7, 149.7, 102.8, and 165.6 cfu/m³ for control, FO, FE, and FEUV, respectively. Initial means for mold populations for control, FO, FE, and FEUV treatments were 319.6, 681.3, 298.1, and 155.4 cfu/m³, respectively. Fourteen samples each were taken of ambient air and cleaned air for bacteria and molds for each part of the study. Airborne bacteria and mold populations were determined for ambient air and for clean air for each part of the study. Reduction in microbial populations was reported as percent reductions.

Statistical analysis

Data for each experiment were analyzed for a completely randomized design using the General Linear Models (GLM) procedure of SAS® (SAS Institute, Inc. 1988). The main effects in the UV-light deactivation study were number of passes and bacteria. The main effects in the controlled air and ambient air component test were treatment (control, FO, FE, and FEUV). Means for significant ($P < 0.05$) main effects were separated with Fisher's protected LSD using the PDIFF option (a pairwise t-test) of the LSMEANS (least squares means) statement of SAS.

Results

BECAUSE A HIGH INITIAL LOAD OF BACTERIA IN THE CONTROL (NO FILtration treatment, Table 1) would have produced plates that were difficult to read, only 5880 cfu/m³ of *M. luteus* and 7213 cfu/m³ of *S. marscens* were put into the sealed chamber. Mean cfu/m³ after filtration for *M. luteus* for the FO treatment was higher ($P < 0.05$.) than the means for all other treatments. The percent reductions of *M. luteus* from the initial bacterial load for all treatments were higher ($P < 0.05$) than the control cleaning unit. Filter and electrostatic polarization and FEUV did not differ ($P > 0.05$) from each other but were 6.8 to 8.3 percentage points higher ($P < 0.05$) than the FO treatment. The FEUV treatment successfully removed 92% of the *Micrococcus* bacteria from the enclosure.

Mean cfu/m³ for *S. marcescens* for control did not differ ($P > 0.05$) from FO treatment, but counts after filtration from both control and FO treatments were higher ($P < 0.05$) than the either the FE or FEUV treatments. Treating the air with FEUV resulted in the lowest ($P < 0.05$) cfu/m³ compared to all other treatments. Adding FO, FE, and then FEUV each resulted in an increased ($P < 0.05$) percent reduction of *S. marcescens* with the FEUV treatment trapping more than 90% of the *S. marscens* bacteria.

Mean and percent reduction of bacteria and mold resulting from components in an uncontrolled environment are shown in Table 2. Filter component treatments did not affect ($P = 0.73$) mean cfu/m³ of bacteria present after filtration treatment. Filter only, FE, and FEUV treatments resulted in a 31.5% to 43.6% ($P <$

0.05) reduction in bacteria from the control unit.

Filtration treatments affected ($P = 0.001$) mean cfu/m^3 for molds. The control cleaning unit and FO treatment did not differ ($P > 0.05$) but had higher ($P < 0.05$) cfu/m^3 than FE and FEUV treatments. Mold loads after treatment with FE and FEUV treatments did not differ ($P > 0.05$) from each other. All treatments increased the percent reduction ($P < 0.05$) from the control unit. The FE and FEUV treatments did not differ ($P > 0.05$) from each other but both treatments had higher ($P < 0.05$) percent reduction than FO treatment. Use of the filtration system successfully removed at least 70% of the airborne molds from the air that passed through the console unit.

Discussion

THE USE OF UV RADIATION TO REDUCE BACTERIAL COUNTS ON SURfaces has been well documented (Gardner and Shama 2000; Kaess and Weidemann 1973; Sumner and others 1996). Data from the present study indicate that filtration and scanning UV light can successfully be used to remove mircoorganisms from the air. The use of filtration to capture airborne particles was studied by Hillman and others (1992). The present study found reductions in airborne bacteria, using only filtration, of 84.0 to 84.1% using a high concentration of bacteria in a closed system after 1 air pass. These reductions were greater than those reported by Hillman and others (1992), however, the initial particle concentration in the present study was lower than the concentration used by Hillman and others. In the present study, 62 to 77% of airborne bacteria and molds from ambient air were removed when passing through the filtration system. The bacterial concentration in ambient air for this study was low as compared to the concentration used by Hillman and others. At high concentrations, filtration was more effective at removing a higher percentage of particles from the air; which can be expected because a higher number of particles come in contact with filter surfaces.

The use of electrostatic precipitation and filtration for the capture of airborne particles has been well documented (White 1984; St. George and Feddes 1995; Hillman and others 1992). The results of this study, using electrostatic polarization, were comparable to those reported by St. George and Feddes 1995, but did not reach the 99.5% efficiency that White (1984) reported as commonly achieved. Using a worst-case scenario where greater than 4.2 x 10^5 cfu/m^3 were introduced to a closed system, an 87.3 to 90.9% reduction was achieved using FE in only 1 air pass. The present study also examined the effect of FE on airborne bacteria and molds from ambient air. The concentrations were much lower in ambient air than in the controlled study, but reductions of 59.8 to 77.0% were achieved in 1 pass. These reductions are comparable to results found by St. George and Feddes (1995).

Using the combination of FEUV resulted in reductions of 90.2 to 92.3% in the controlled study and 62.3 to 69.9% for the ambient air study. These results again are similar to results found by St. George and Feddes (1995) where they used only FE. We can conclude from these data that FE and FEUV treatments reduced high concentrations of airborne bacteria under controlled conditions and also reduced lower concentrations of bacteria and molds from ambient air as compared to using no filtration. Furthermore, the effectiveness of this filtration was accomplished after only 1 pass. Because the filters are designed to continue recirculating the air, it is hypothesized that further reductions in airborne bacteria and molds are possible with this system.

Conclusion

A GROWING PORTION OF MEAT PRODUCTS TODAY ARE SOLD AS "ready-to-eat" and do not undergo any further treatments that may reduce bacterial contamination. Therefore removing airborne contaminants prior to packaging is extremely critical. This research has shown that an air-filtration system that utilizes electrostatic polarization and scanning ultraviolet light is effective in trapping airborne bacteria and molds. Because of the threat of airborne pathogenic organisms, this system may be used as a part of a comprehensive system to reduce the risk of contaminating meat and meat products.

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MS 20010141 Submitted 3/21/01, Accepted 6/7/01, Received 6/13/01

Funding for this project was provided by the Alabama Cattleman's Assn. Filtration equipment for testing was provided by Environmental Dynamics Group Princeton, N.J., U.S.A.

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