Air-cleaning System Effectiveness for Control of Airborne Microbes in a Meat-processing Plant

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ABSTRACT: The effectiveness of duct-mounted and console wall-mounted germicidal air cleaning units on the reduction of airborne microbes was determined. Preliminary air samples were collected and airborne bacteria and molds were monitored over time in the retail sales room, processing room, aging cooler and chill cooler of the Auburn Univ. Meat Laboratory. Log_{10} cfu/m^3 bacteria and molds were not reduced by filtration of fresh air in the air duct of the sales room ($P > 0.05$). After at least 18 h of filtration, 3 or 4 console filtration units operated simultaneously were effective ($P \leq 0.05$) at reducing airborne bacteria and molds under controlled conditions in the processing room, aging cooler, and chill cooler. Three console filtration units reduced ($P \leq 0.05$) airborne molds under production conditions in the processing room. These data suggest that an electrostatically polarized filter medium combined with scanning UV light is effective in reducing airborne microorganisms in a small processing plant.

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

Introduction

CONTAMINATION OF MEAT PRODUCTS BY microorganisms is a major economic problem in the meat industry. There are several pathways in which pathogenic and spoilage organisms can be introduced to products. Sofas and others (1999) reported that contamination can occur at various points during the slaughter process, cold storage, and processing of meat animals. One potential source of contamination that is often overlooked is air. Air is a potential source of contamination by pathogenic and spoilage organisms in meat processing plants and should be considered a processing critical control point (Kang and Frank 1989; Franco and others 1995). A potential airborne pathogenic contaminant in meat processing plants is *Listeria monocytogenes* (Nesbakken and others 1996). Emphasis should be placed on air quality because of the possibility of contamination of food products with pathogenic and spoilage organisms. There has been considerable research conducted on the incidence of airborne contamination in meat processing plants and how to monitor microbial levels in the air (Knudston and Hartman 1993; Kotula and Emswiler-Rose 1988). However, little research has been done to reduce the incidence of airborne contamination in meat processing plants.

Several studies have been conducted to control contamination on carcasses and contact surfaces. Along with good manufacturing practices (GMPs) and sanitation standard operating procedures (SSOPs), there are several strategies available to reduce microorganisms on carcasses. These include carcass trimming (Delmore and others 1997; Castillo and others 1998), carcass washing (Cabedo and others 1996; Anderson and others 1987; Prasai and others 1995), organic acid treatments (Dorsa and others 1998; Cutter and Siragusa 1994; Goodard and others 1996), and combinations of these treatments (Castillo and others 1998). However, air contamination of meats can still occur during storage and processing. Steps should be taken to not only monitor microbial levels in the air, but also to reduce the microbial loads in the air.

Technology is available to capture and to deactivate microorganisms in the air. The use of filtration along with electrostatic precipitation is widely used to capture airborne particles (Hillman and others 1992; St. Georges and Feddes 1995). Airborne particles can harbor bacteria and molds (Carpenter and Fryer 1990), and UV light is a widely used strategy to deactivate airborne bacteria and molds (Kaess and Weidemann 1973; Gardner and Shama 2000). Because food safety is a major concern to the consumers, intervention strategies to control all sources of microbial contamination of meats, including airborne contaminants, should be pursued.

The first objective of this study was to determine the effectiveness of a duct-mounted air-cleaning unit, which uses a combination filtration and electrostatic polarization, in reducing airborne bacteria and molds. The second objective was to determine the effectiveness of a germicidal air cleaning console unit, which uses a combination of filtration, electrostatic polarization, and UV light, in reducing airborne bacteria and molds in a meat processing plant environment.

Materials and Methods

Air cleaning system

Duct-mounted air cleaners (EDG, Model nr 1000L/R, Princeton, N.J., U.S.A.), 5 cm thick, were customized to fit heating, ventilation, and air conditioner (HVAC) unit intakes. The duct-mounted units use an electrical supply of 120V AC / 60 Hz, onboard voltage of 24 V AC, which is converted at the powerhead output to 6500 V DC / 70 mA for electrostatic polarization (Figure 1). Duct-mounted units were installed in the ventilating HVAC units of the sales room in the Auburn Univ. Lambert Meats Laboratory.

Germicidal air purification console units (EDG, Model nr G375, Princeton, N.J., U.S.A.) use a combination of UV light and electrostatically polarized, low-density media filters (Figure 2). The EDG console units are 58 cm wide, 31 cm deep, 52 cm high, and weigh 22 kg. The console units have electrical input of 115 V AC / 60 Hz which is converted to an electrical output of 6600 V DC / 67 mA for electrostatic polarization. Console units use an UV G25T8 germicidal bulb and circulate 10.61 m^3 of air per minute. The intensity of the UV bulb is 100 mW/cm^2. Each console unit was placed on a cart and placed in each of 3 separate areas of the Lambert Meats Laboratory: the chill cooler, the aging cooler and the processing room.

Room specifications

Specifications for each room, including temperature, airflow speed, air volume, and production use, were determined. The sales room has a volume of 214.0 m^3, has an airspeed of 1.5 m/min at the outlet of the air duct, maintains a temperature of 14.4 to 15.6 °C, and is used for retail sales of meat and poultry products. The chill cooler, aging cooler, and processing room have self-contained refrigeration and therefore use 100% re-circulated air. Air speed is reported as maximum air velocity at product level from the refrigeration fans in each room. The chill cooler is used for chilling of hot carcasses immediately following the slaughter process. It maintains a temperature between 0 to 2 °C, has maximum airflow of 21.3 m/min, and occupies a volume of 128.3 m^3. The aging cooler occupies a volume of 364.1 m^3 and is used for the storage and aging of carcasses and meat products. It maintains a temperature of 0 to 2°C with a maximum airflow of 7.9 m/min. The processing room is used for carcass fabrication, processing, and product manufacture, maintains a temperature of 10 °C, and has maximum airflow of 3.1 m/min and a volume of 109.6 m^3.

Air sampling and media

Air was sampled using an Anderson N-6 stage Microbiological Air Samplers® (Anderson Instruments, Inc., Model nr 10-890, Smyrna, Ga., U.S.A.). The samplers were calibrated to sample 0.0283 m^3/min of air. The samplers were sanitized prior to air sampling and after sampling with 70% ethyl alcohol. Culture media used for microbiological analysis of air was Plate Count Agar (PCA; Difco nr 247940, Sparks, Md., U.S.A.) for the enumeration of total aerobic and facultative anaerobic bacteria and Malt Agar (BBL nr 11401, Baltimore, Md., U.S.A.) for the enumeration of mold spores. Media were prepared, autoclaved for 15 min at 121 °C and 15 psi, allowed to cool in a water bath held at 47 °C, and poured into 100 x 15 mm sterile disposable plastic petri dishes (Fisherbrand nr 08-757-13, North Glenn, Colo., U.S.A.). Fifteen mL of agar were poured into each plate. After samples were collected, PCA plates were incubated aerobically at 37 °C for 48 h and malt agar plates were incubated aerobically at 25 °C for 5 d (Vanderzant and Splittstoesser 1992). Colony forming units were counted and microbial concentrations were expressed as cfu/m^3 of air sampled.

Duct mount units

Prior to testing the air cleaning systems, preliminary data were collected in each area to determine the concentration of bacteria and mold (cfu/m^3 of air). Preliminary data were collected over 2 mo at various times of the d, d of the wk, and activity in the rooms. The air volume sampled was 0.28 m^3 of air per PCA plate and 0.20 m^3 of air per Malt Agar plate. The different air sampling volumes were determined prior to the study because of different concentrations of bacteria and molds in the air. The room was divided into 4 sample areas. A set of initial air samples was taken prior to activating the duct units. Air samples were taken at 3, 6, 9, 12, and 24 h after filter activation (filter put in place and electrostatic polarization apparatus turned on) to monitor airborne bacteria and molds.

Console units

Each room was isolated to minimize traffic in and out of the room during sampling and was divided into 5 areas. Air changes per h (ACH) were calculated for each room. With 1 console unit, the chill cooler had 5.2 ACH, the aging cooler had 1.8 ACH, and the processing room had 5.8 ACH. The study was conducted in the same manner for each of the 3 rooms. Using 1 console unit per room, 2 air samples were taken per area: one using PCA and the other using Malt Agar. A set of initial air samples was taken before the console unit was activated. Air samples were taken at 12, 18, 24, 36, and 48 h after filter activation. Each room was sampled 3 times.

The experiment was repeated using 2, 3, or 4 console units. Sampling, incubation and data recording were conducted in the same manner as for testing 1 filter. Air changes per h for the chill cooler were 10.4, 15.6, and 20.8; for the aging cooler ACH were 3.6, 5.4, and 6.9; for the processing room ACH were 11.6, 17.4, and 23.3, with 2, 3, or 4 air cleaners, respectively.

Production conditions

The effectiveness of the console units to reduce airborne microbial contaminants during production conditions was determined in the processing room. Samples were taken 10 times over a period beginning Monday afternoon during processing and ending Thursday afternoon during processing. These days were selected for sampling because Rahkio and Korkeala (1997) found airborne bacteria concentrations increase as the week progresses in all areas. Data were collected 3 times each d for 4 d. Air was first sampled with no console units in the room. Air

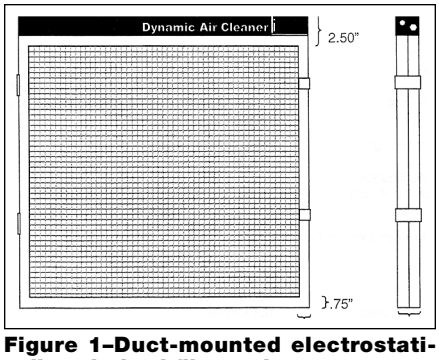

Figure 1–Duct-mounted electrostatically polarized filter unit.

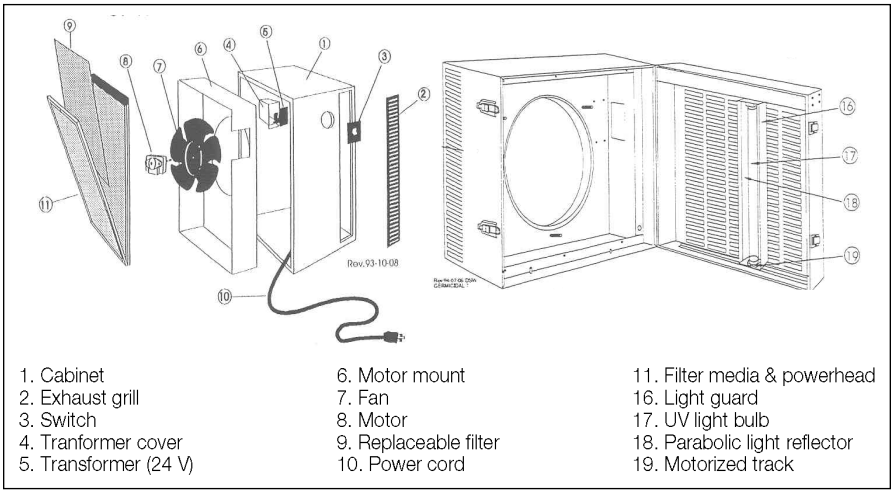

Figure 2–Console electrostatically polarized filter unit with scanning ultraviolet light.

Table 1—Means and standard error of the mean (SEM) of airborne bacteria and molds using germicidal air cleaners in an air duct system in the sales room

		Log_{10} cfu/m³	
Time, h	n	Bacteria	Mold
0	4	1.27	1.93
3	4	0.98	1.68
6	4	1.18	1.72
9	4	1.14	1.48
24	4	1.13	1.47
SEM		0.08	0.13
P > F		0.24	0.12

volumes tested per PCA plate were 0.23 m^3 and 0.20 m^3 for Malt Agar plates. The room was divided into 4 areas and 2 samples were collected in each area: one on PCA and the other on Malt Agar. The plates were incubated in the same manner as previously discussed. The study was repeated using either 3 or 4 console units. The number of units used in this study was determined from results of the previous studies. Testing of 3, or 4 filters began with an initial set of samples taken during processing of the first d.

Statistical analysis

All data were transformed (log_{10} cfu/m^3) and analyzed using the General Linear Model procedure of SAS® (SAS 1985). Data for the duct-mounted units were analyzed for a completely randomized design. Data for the console units were analyzed for a 4 (1, 2, 3, or 4 filters) by 6 (0, 12, 18, 24, 36, or 48 h after filtration) factorial arrangement of a completely randomized design. Data for the console units under production conditions were analyzed for a 3 (0, 3, or 4 filters) by 4 (d) factorial arrangement of a completely randomized design. Means reported are composed of triplicate observations. All significant ($P \leq .05$) main effect and interaction means were separated using Fisher's Protected LSD.

Results and Discussion

LOG_{10} CFU/M^3 BACTERIA AND MOLDS were not reduced (P = 0.24 and 0.12, respectively) by filtration of fresh air in the air duct of the sales room (Table 1). However, a trend did exist for less mold cfu/m^3 after 24 h of filtration. The effectiveness of air filtration (console units) on reducing airborne bacteria in 3 different rooms is shown in Table 2. While the level of bacteria in the processing room was initially higher (0 h, $P \leq 0.05$) when 3 or 4 console units were tested compared to 1 or 2 units, the concentration of bacteria was reduced to the same (3 units) or lower (4 units) as tests with 1 or 2 units ($P \leq 0.05$).

Table 2—Means and standard error of the mean (SEM) for console filtration unit number and time of filtration effects on airborne bacteria

		Log_{10} cfu/m³ Bacteria		
Filter Hour	n	Processing room	Aging cooler	Chill cooler
1 filter unit				
0	30	1.03^{efg}	0.86^{bcd}	1.01^{abc}
12	30	1.06^{def}	0.79^{cdefg}	0.85^{cdef}
18	30	1.05^{def}	0.76^{defgh}	0.61^{ghi}
24	30	1.04^{efg}	$0.71^{defghij}$	0.74^{defgh}
36	30	1.27^{cd}	0.73^{defghi}	0.80^{cdefgh}
48	30	1.03^{efg}	0.76^{defgh}	0.69^{efgh}
2 filter units				
0	30	1.16^{cde}	0.99^{bc}	0.91^{bcd}
12	30	1.11^{de}	0.82^{bcdef}	0.40^{ij}
18	30	0.82^{gh}	0.55^{hijklm}	0.68^{efgh}
24	30	1.16^{cde}	0.81^{bcdef}	0.59^{hi}
36	30	0.85^{fgh}	0.58^{ghijkl}	0.88^{bcde}
48	30	1.21^{cde}	0.61^{fghijk}	0.67^{efgh}
3 filter units				
0	30	1.77^{a}	1.03^{b}	1.18^{a}
12	30	1.37^{bc}	$0.62^{efghijk}$	0.82^{cdefg}
18	30	1.13^{de}	0.52^{ijklm}	0.65^{fgh}
24	30	0.86^{fgh}	0.38^{klm}	0.70^{defgh}
36	30	0.76^{hi}	0.47^{jklm}	0.80^{cdefgh}
48	30	1.14^{de}	0.49^{jklm}	0.60^{hi}
4 filter units				
0	30	1.57^{ab}	1.40^{a}	1.09^{ab}
12	30	1.11^{de}	0.84^{bcde}	0.67^{efgh}
18	30	0.85^{fgh}	0.40^{klm}	0.59^{hi}
24	30	1.01^{efg}	0.53^{ijklm}	0.68^{efgh}
36	30	0.59^{i}	0.33^{m}	0.69^{efgh}
48	30	0.65^{hi}	0.44^{klm}	0.31^{j}
SEM		0.080	0.082	0.078
P > F		0.001	0.001	0.002

^{a,b,c,d,e,f,g,h,i,j,k,l,m}Interaction means in a column having a common or no superscript do not differ ($P \leq 0.05$).

In the aging cooler, use of 1 console filtration unit did not reduce airborne bacteria ($P \leq 0.05$). Using 2 units reduced airborne bacteria at 18, 36, and 48 h after activation, 3 units reduced airborne bacteria after at least 18 h of filtration and 4 units reduced bacteria by about 1 log after at least 12 h compared to the control (0 h, $P \leq 0.05$). In the chill cooler, the use of 1 console filtration unit reduced airborne bacteria after 18, 24, and 48 h and 2 units reduced airborne bacteria after 12, 24, 36, and 48 h ($P \leq 0.05$). In addition, filtration reduced ($P \leq 0.05$) airborne bacteria after at least 12 h of filtration when 3 or more filtration units were used.

The effectiveness of console filtration units at reducing airborne molds in 3 different rooms is shown in Table 3. Using 1 console filtration unit in the processing room did not reduce ($P \leq 0.05$) airborne molds at any time after filter activation. Using 2, 3, or 4 console filtration units reduced ($P \leq 0.05$) airborne molds after 12 or more h of filtration compared to the 0 h control. This resulted in a maximum of a 0.9, 1.2, and 1.3 log_{10} reduction in airborne molds using 2, 3, or 4 console units, respectively.

Airborne molds in the chill cooler were not affected by filtration using 1 console unit ($P \leq 0.05$). The use of 2, 3, or 4 console filtration units reduced ($P \leq 0.05$) airborne molds after at least 12 h of filtration. In addition, the use of 4 console units reduced molds by more that 1 log_{10} after 48 h.

Number of console filtration units, d after activation, and their interaction did not affect ($P \leq 0.05$, Table 4) airborne bacteria in the processing during normal production. Without filtration mean log_{10} cfu/m^3 molds tended ($P \leq 0.05$) to increase as the week progressed. Three filtration units decreased ($P \leq 0.05$) airborne molds by at least 0.34 log_{10} on d 2, 3, and 4 compared to d 1. Using 4 filtration units did not reduce airborne molds ($P \leq 0.05$) which may have been confounded, since the testing of 4 filters followed testing 3 filters which did reduce molds.

Bacterial and mold populations were not significantly reduced using duct

Table 3–Means and standard error of the mean (SEM) for console filtration unit number and time of filtration effects on airborne molds

		Log_{10} cfu/m^3 Molds		
Filter nr/h	n	Processing room	Aging cooler	Chill cooler
1 filter				
0	30	1.53^{defg}	1.31^{ab}	1.11^{cdef}
12	30	1.50^{defg}	1.33^{ab}	0.98^{cdefg}
18	30	1.48^{efg}	1.20^{bc}	0.90^{cdefg}
24	30	1.63^{def}	1.39^{ab}	1.09^{cdef}
36	30	1.71^{cde}	1.19^{bc}	1.15^{cde}
48	30	1.48^{efg}	1.42^{ab}	0.92^{defg}
2 filters				
0	30	2.52^{a}	1.20^{bc}	1.71^{a}
12	30	2.03^{b}	0.98^{cd}	0.74^{gh}
18	30	1.70^{cde}	0.68^{efgh}	0.85^{efg}
24	30	1.75^{bcde}	0.79^{def}	1.22^{cd}
36	30	1.63^{def}	0.71^{defg}	1.09^{cdef}
48	30	2.00^{bc}	0.94^{cde}	0.83^{efg}
3 filters				
0	30	2.58^{a}	1.49^{a}	1.73^{a}
12	30	1.97^{bc}	0.63^{fgh}	1.21^{cd}
18	30	1.73^{bcde}	0.43^{h}	0.96^{cdefg}
24	30	1.83^{bcd}	0.82^{def}	1.13^{cdef}
36	30	1.43^{efg}	0.43^{h}	1.25^{bc}
48	30	1.75^{bcde}	0.50^{gh}	0.81^{fg}
4 filters				
0	30	2.60^{a}	1.51^{a}	1.55^{ab}
12	30	1.81^{bcd}	0.94^{cde}	1.07^{cdef}
18	30	1.33^{fg}	0.48^{gh}	1.01^{cdefg}
24	30	1.23^{g}	0.71^{defg}	0.96^{cdefg}
36	30	1.18^{g}	0.50^{gh}	1.03^{cdefg}
48	30	1.31^{fg}	0.51^{gh}	0.49^{h}
SEM		0.12	0.10	0.12
P > F		0.001	0.001	0.005

^{a,b,c,d,e,f,g,h}Interaction means in a column having a common or no superscript do not differ ($P \leq 0.05$).

Table 4–Means and standard error of the mean (SEM) for console filtration unit number and d of week effects on airborne bacteria and molds during production

		Log_{10} (cfu/m^3)+1	
Filter nr/d	n	Bacteria	Molds
0 filters			
Day 1	3	1.06	1.78^{ab}
Day 2	3	0.97	1.96^{a}
Day 3	3	1.03	2.05^{a}
Day 4	3	1.00	2.09^{a}
3 filters			
Day 1	3	1.00	1.87^{a}
Day 2	3	0.99	1.54^{bc}
Day 3	3	0.65	1.43^{c}
Day 4	3	0.74	1.53^{bc}
4 filters			
Day 1	3	1.04	1.46^{c}
Day 2	3	1.01	1.47^{c}
Day 3	3	1.00	1.48^{c}
Day 4	3	1.08	1.33^{c}
Day			
SEM		0.07	0.05
P > F		0.86	0.89
Filter			
SEM		0.08	0.05
P > F		0.07	0.001
Filter X Day			
SEM		0.13	0.09
P > F		0.42	0.02

^{a,b,c}Interaction means in a column having a common or no superscript do not differ ($P \leq 0.05$).

mount cleaning units. The duct-mounted filters differed from the console filters in that they use only electrostatic polarization to trap contaminants. In addition, these filters treat only the air being routed into the room and do not treat any of the air already present in the room. While a trend did exist for mold counts to decrease over time, it appears that HVAC ducts were not a significant source of airborne bacteria and molds in the sales room, and therefore the filtration units were not able to lower airborne concentrations below 1.0 (bacteria) to 1.5 (molds) $\log_{10}$.

The present study showed that console air filtration units produced a 1 to 1.5 $\log_{10}$ reduction in airborne bacteria and molds regardless of the room in which they were tested. These reductions are comparable to the reduction of particles using filtration and electrostatic precipitation studied by St. George and Feddes (1995). It was also shown that the console filtration units are not able to reduce airborne bacteria or molds below about 0.5 $\log_{10}$ cfu/m^3. This suggests that either their efficiency is limited at some point, or more likely, that bacteria and molds are harbored in niches and continually become aerosolized. Perhaps more extensive surface sanitation would further reduce the amount of airborne contaminants.

With no cleaning units used in the processing room there tended to be an increase in airborne molds from Monday through Thursday during production. This finding was similar to trends discovered by Rahkio and Korkeala (1997). By Thursday of the sample period a 0.31 $\log_{10}$ increase in molds was observed. With 3 and 4 console units activated during processing, airborne molds did not increase after the initial sample time and airborne molds were reduced when 3 console filtration units were used. Under production conditions, the console filtration units were not able to remove more than 1.5 $\log_{10}$ cfu/m^3 molds. Previous research has shown that airborne or aerosolized microbes in commercial processing facilities are found in higher concentrations than those reported in the present study. Microbes were found to be present at 2.0 to 2.3 $\log_{10}$ cfu/100 L of air in slaughter houses (Rahkio and Korkeala 1997), 0.3 to 2.5 $\log_{10}$ cfu/0.028 m^3 in a pork slaughter and further processing plant (Kotula and Emswiler-Rose 1988), and 1.8 to 3.0 cfu/100 L in a dairy processing plant (Ren and Frank 1991). We hypothesize that if the console filtration units are able to reduce airborne microbes (down to a background level) when concentrations are very low, they should be effective at reducing airborne contamination at higher concentrations. Indeed more research is needed to determine if this is the case.

Conclusion

A GERMICIDAL AIR CLEANING SYSTEM HAS application for controlling airborne contamination in meat processing facilities. The use of germicidal air cleaning units has merit to substantially reduce the risk of microbial contamination of meat products in a small meat processing plant.

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