

EVALUATION AND CONTROL OF WORKER EXPOSURE TO FUNGI IN A BEET SUGAR REFINERY

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*A study of worker exposure to airborne fungi was undertaken in a sugar beet refinery to evaluate the level of exposure and to determine if controls could be implemented that would lower these exposures. A previous study at this refinery identified one worker who reacted on challenge testing to the moldy but not the fresh sugar beet pulp, had specific Immunoglobulin G to *Aspergillus niger*, and specific Immunoglobulin E to *Aspergillus*. Also, two employees were diagnosed with occupational asthma. In the study reported here, two field surveys were conducted, the first during the sugar production campaign (January) and the second during postproduction cleanup and maintenance (June). Approximately 65 personal and area air samples were collected on polycarbonate filters and the culturable fungal spores were identified and enumerated. This study showed high exposure of pellet loaders and pellet silo workers to various species of *Aspergillus*. Other fungal species that might pose a health hazard were detected. Exposures to fungi during the postproduction cleanup and maintenance phase were much higher than those measured during the production campaign. Engineering controls that would reduce employee exposure are discussed.*

In 1989, the Michigan Department of Public Health (MDPH) investigated employee complaints of asthma-like symptoms related to their employment at a sugar beet refinery. The work force was seasonal, ranging from a high of approximately 300 workers during the production campaign to a low of less than 100 workers during the postproduction cleanup and maintenance phase. In the

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MDPH investigation, questionnaires were given to the approximately 300 workers at the subject plant. Questionnaires from 73 workers were returned.⁽¹⁻³⁾ Health effects reported were daily nasal stuffiness, runny nose, tearing and burning of the eyes, redness of the eyes, sore throat, cough, wheezing, and shortness of breath. Only one worker consented to sensitization testing (provided by Michigan State University). That worker had been symptomatic during the postproduction cleanup and maintenance phase. He reacted to moldy sugar beet pulp (skin test and specific serum IgE), had specific IgG to *Aspergillus niger*, specific IgE to *Aspergillus*, and reacted on challenge testing to the moldy but not the fresh sugar beet pulp. Occupational asthma was diagnosed in this worker.⁽²⁾ Two other workers with asthma-like symptoms were tested by their private physicians but did not have specific IgE to moldy sugar beet pulp. It was postulated that these workers might be reacting to possible antigens in the sugar beet extract. The pulp silo was suspected to be the source of exposure because of the large amount of visible fungal growth in the silage. While workers emptied the silo, gross biological growth was observed by MDPH personnel during a study in June 1990. The potential exposure of maintenance and production workers to microorganisms also existed in the milling area, where large quantities of dust had settled.

Previous studies of hypersensitivity pneumonitis in sugar beet workers have focused on nickel sulfates produced during welding operations.⁽³⁻⁸⁾ In those studies, no evaluations were made to test those affected for sensitivity to fungal spores or other biological material. No welding operations were performed during either of the current studies. An investigation of a sugar beet plant in England identified mesophilic bacteria, actinomycetes, gram-negative bacteria, and fungi as potential causes of respiratory problems in workers.⁽⁹⁾ That investigation centered on the beet-slicing

machines and the cossette (slender strip of beet produced by the slicing machines) conveyor. In addition, spoilage in stored farm crops, caused by the growth of some species of *Penicillium* and *Aspergillus*, has been well documented.⁽¹⁰⁾

The current study was conducted to assist the MDPH in the investigation of the occupational asthma case mentioned above. The request was made as part of the Michigan involvement in the National Institute for Occupational Safety and Health (NIOSH) Sentinel Event Notification System for Occupational Risks (SENSOR).⁽¹¹⁾ SENSOR was created as a cooperative state-federal effort designed to develop local capability for the recognition, reporting, follow-up, and prevention of selected occupational disorders, including occupational asthma. As a SENSOR participant, MDPH requested that NIOSH investigators evaluate the exposure of sugar beet refinery workers to fungal spores, especially workers in contact with sugar beet pulp. Furthermore, MDPH requested recommendations for engineering controls to minimize worker exposure.

The objective of this study was to identify and quantify exposures to airborne fungi and to determine what engineering controls could be used to minimize these exposures. It is hoped that this information can be used by industrial hygienists and industrial engineers to reduce worker exposures in similar operations.

PLANT DESCRIPTION

In Michigan, sugar beets were harvested from September to mid-October and transported by truck to the plant or remote storage location, where they were placed in 6-m high piles. These storage piles had a base of approximately 40 m and a top of approximately 25 m in width. As needed, beets were trucked from either a remote storage location or the on-site storage piles to the refinery yard. Front-end loaders transferred the beets into a wet hopper in which the beets were transported by a water flume to the plant.

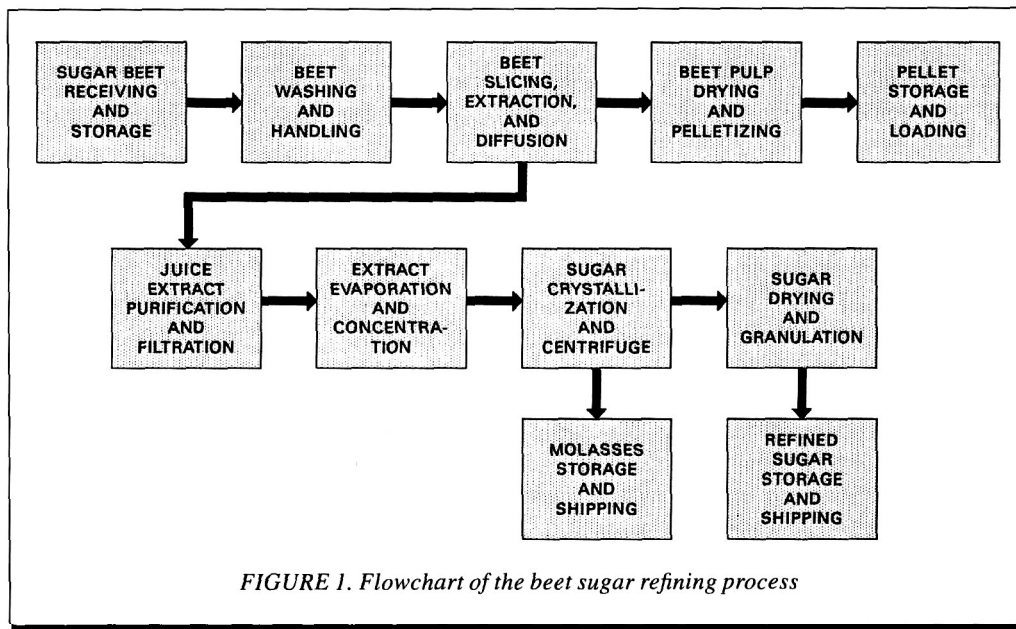


FIGURE 1. Flowchart of the beet sugar refining process

A schematic of the refining process is shown in Figure 1. First the sugar beets were washed and rinsed. The next step was to slice the beets into cossettes. These cossettes were charged into the diffuser, where the sugar was leached countercurrently with water to form "raw juice." After the cossettes were processed in the diffuser, the pulp residue was pressed to reduce the moisture content, then kiln-dried to a moisture content of about 10%. The hot pulp was transported to one of several pelletizers. Pulp pellets were screened to remove fragmented pellets, then transported to a silo and sold to animal-feed producers. The storage silo, shown in Figure 2, was 30 m in diameter, with an outer wall height of 9

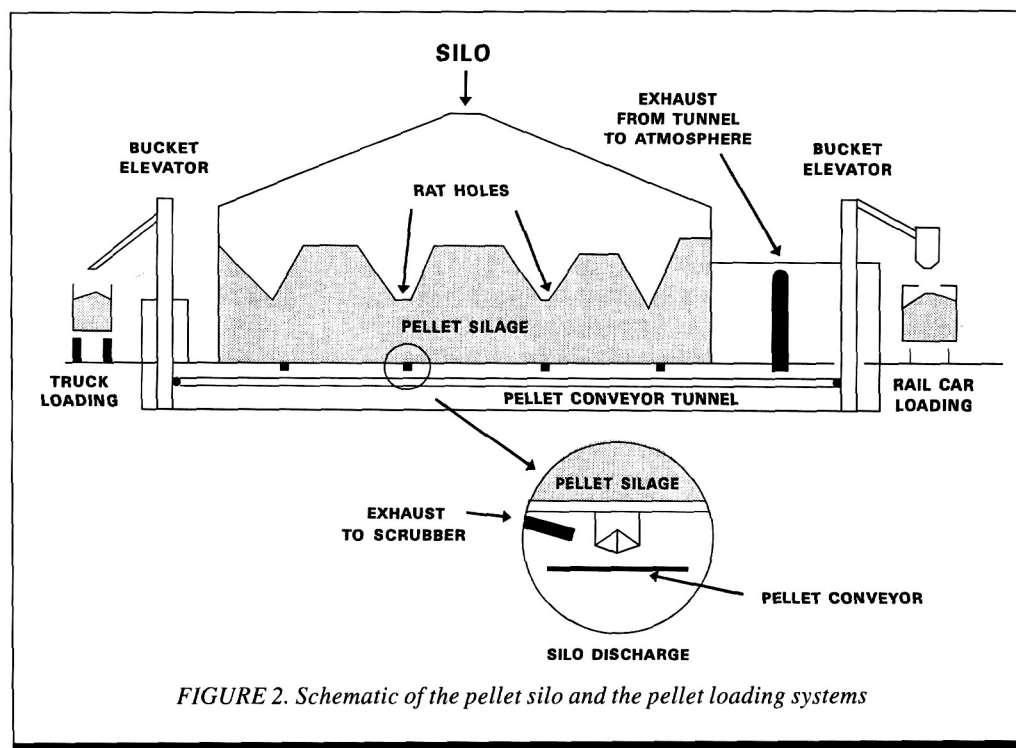


FIGURE 2. Schematic of the pellet silo and the pellet loading systems

m that tapers an additional 10 m to an apex, where pellets entered the silo.

The raw juice purification began in the precarbonation step with the addition of milk of lime ($\text{Ca}(\text{OH})_2$) to begin precipitation of impurities. This was followed by two stages of carbonation using carbon dioxide (CO_2) generated in the lime kiln to complete the crystallization of CaCO_3 with its entrapped nonsugars. The calcium carbonate and impurities were then filtered from the raw juice. Sulfur dioxide may have been added to the raw juice after the second carbonation to control pH. The purified juice was concentrated in multiple effect evaporators to raise the percent of dissolved solids from 10 to 15% to 50 to 60%. The resulting thick juice was seeded with crystalline sugar, then heated and filtered in "juice presses" to obtain the "standard liquor." Sugar was crystallized from the standard liquor by boiling in vacuum pans. The crystals were washed with pure hot water, centrifuged, dried, cooled, and stored. The white sugar was transferred to trucks for bulk shipment or packaged on site for retail sale.

METHODOLOGY

Personal exposure air samples were collected on persons working in different job categories in the plant and in selected plant areas. Sampling was performed in two phases of plant operation: (1) during the sugar production campaign and (2) during the postproduction cleanup and maintenance phase. The purpose was to determine where the workers had the highest exposure to microorganisms, so that engineering controls could be developed to contain fungal spores in the most problematic process(es). During the production campaign study, personal sampling was focused on pellet loaders, beet loaders, beet washer operators, pellet mill operators, and maintenance workers in the plant. Area samples were collected in the plant office, the plant roof, the vacuum pan area, the trash catcher area, the pulp dryer area, and the pellet conveyor area. Special attention was given to employees who loaded trucks and railroad cars with pulp pellets from the pellet silo. Two cassette samples per day per worker were collected. Most jobs and areas were sampled for three days. Forty-four air samples were collected, both area and personal.

During the postproduction cleanup and maintenance phase, the study focused on the pellet loaders removing pulp pellets from the silo to trucks and railroad cars, silo unloaders operating front-end loaders in the silo, and pellet mill operators working in the pellet mill area. Twenty-one personal air samples were obtained.

Sampling and Analytical Methods

Personal and area air samples were collected on sterile 37-mm polycarbonate membrane filters with a 0.8- μm pore size (Nuclepore® 110809, Costar Nuclepore, Cambridge, Mass.). Air was drawn through the filter at a flow rate of 2.0 L/min using battery-powered sampling pumps (SKC® Air Check Sampler, Model 224-PCXR7, SKC Inc., Eighty-Four, Penn.). The samples were immediately refrigerated to inhibit

TABLE I. Culturable Fungi Identified in Airborne Samples

<i>Genera most frequently observed</i>	
<i>Penicillium</i>	<i>Cladosporium</i>
<i>Aspergillus glaucus</i> ^A	<i>Aspergillus vericolor</i> ^A
<i>Aspergillus flavus group</i> ^A	<i>Aspergillus fumigatus</i> ^A
<i>Monilia</i> ^B	<i>Trichoderma</i> ^B
<i>Rhizopus</i> ^B	
<i>Genera present but reported as "Other (nonyeast)" in Tables II–IV</i>	
<i>Alternaria</i>	<i>Aureobasidium</i>
<i>Ascospores</i>	<i>Aspergillus flavus columbiae</i>
<i>Basidiospores</i>	<i>Beauveria-like</i>
<i>Botrytis</i>	<i>Drechslera</i>
<i>Fusarium</i>	<i>Mucorales</i>
<i>Paecilomyces</i>	<i>Pithomyces</i>
<i>Wallemia</i>	

^AReported as *Aspergillus*

^BFrequently overgrew the culture plate

it growth of fungi. Within 72 hours of sampling, the filters and cassettes were delivered to the Allergy Research Laboratory of The University of Michigan, Ann Arbor, Michigan, for analysis.

Each membrane filter was washed with a 0.02% Tween 20 (J.T. Baker Chemical Co., Phillipsburg, N.J.) in water solution (three 2-mL washes), with agitation.⁽¹²⁾ A portion of the recovered wash volume was serially diluted from full strength (1:10, 1:100, 1:1000), and 0.1 mL of each was inoculated onto duplicate 100-mm × 15-mm petri dishes containing only malt extract agar (MEA). This serial dilution method allowed flexibility in dealing with a large range of spore densities on the sample filters. Residual colony forming units (CFUs) on the filter were counted by placing the filter on an MEA petri dish to allow growth of residual spores. The MEA petri dishes were incubated under fluorescent lights rich in blue and red wavelengths (Gro and Sho lights, General Electric, Fairfield, Conn.) for up to seven days before colony identifications were made. Personnel trained in the identification of fungi classified the culturable fungi by spore and colonial morphology. Fungi that were not identified to the genus level were classified as "Other (nonyeast)."

RESULTS

Several genera of fungi were identified in the air samples collected in this plant during the first and second surveys, including *Alternaria*, *Aspergillus*, *Beauveria*, *Botrytis*, *Cladosporium*, *Drechslera*, *Monilia*, *Mucorales*, *Penicillium*, *Rhizopus*, and *Trichoderma*. All Fungi identified during the two study periods are listed in Table I. They were found in varying numbers at different times and locations in the plant, but certain genera were frequently present in significant concentrations. Of the 18 genera identified in Table I, *Penicillium*, *Cladosporium*, *Aspergillus*, *Monilia*, *Trichoderma*, and *Rhizopus* were predominant.

TABLE II. Average Concentration of Culturable Fungi Spores in Air (CFU/m³) Collected at Six Locations in the Plant During the Production Campaign (January)

Fungi	Plant Roof	Plant Office	Pellet Conveyor	Pulp Dryer	Trash Catcher	Vacuum Pan
<i>Penicillium</i>	1000	90	340	460	330	130
<i>Cladosporium</i>	430	15	20	56	25	20
<i>Aspergillus</i>	1300	14	25000	85	300	9
<i>Monilia</i>	5	9	450	37	0	9
<i>Trichoderma</i>	0	0	0	0	7	0
<i>Rhizopus</i>	5	0	9300	20	0	9
Other (nonyeast)	1700	20	34000	30	58	53
Total fungi	4400	150	69000	690	720	230
No. of samples	3	3	3	3	2	3

TABLE III. Average Personal Exposure to Culturable Fungi Spores in Air (CFU/m³) in Six Job Categories in the Plant During the Production Campaign (January)

Fungi	Pellet Mill Operator	Pellet Loader	Maintenance Worker	Beet Loader	Pellet Mill Foreman	Beet Washer
<i>Penicillium</i>	480	16 000	2000	1600	2300	670
<i>Cladosporium</i>	310	130	730	100	450	20
<i>Aspergillus</i>	250	9200	380	40	300	40
<i>Monilia</i>	500	12	0	160	600	10
<i>Trichoderma</i>	510	0	0	0	0	0
<i>Rhizopus</i>	5	6	0	0	10	0
Other (nonyeast)	310	4800	270	260	5	210
Total fungi	2400	30 000	3400	2200	3700	950
No. of samples	3	6	6	6	3	3

TABLE IV. Average Personal Exposure to Culturable Fungi Spores in Air (CFU/m³) in Three Job Categories in the Plant During Postproduction Cleanup and Maintenance (June)

Fungi	Pellet Mill Operator	Pellet Loader	Silo Unloader
<i>Penicillium</i>	43 000	800 000	400 000
<i>Cladosporium</i>	12 000	20 000	0
<i>Aspergillus</i>	27 000	490 000	300 000
<i>Monilia</i>	0	42 000	64 000
<i>Trichoderma</i>	2000	42 000	39 000
<i>Rhizopus</i>	0	53 000	67 000
Other (nonyeast)	12 000	77 000	410 000
Total fungi	96 000	1 500 000	1 300 000
No. of samples	4	10	7

Results of the area air sampling in six plant areas during the production campaign are presented in Table II. Results of the personal air sampling by job category for the production campaign and the postproduction cleanup and maintenance

phase are presented in Tables III and IV, respectively.

Of the six areas sampled, the pellet conveyor area was the most contaminated area of the plant, with a spore concentration of 69 000 CFU/m³, more than 10 times the next highest area (plant roof). Periodically, pellet loaders were required to enter the pellet conveyor area.

During the production campaign, the pellet loaders had the highest average personal exposures to fungal spores, 30 000 CFU/m³. Exposure was principally to *Penicillium* (16 000 CFU/m³) and *Aspergillus* (9200 CFU/m³). The pellet mill operators, maintenance workers, beet loaders, and pellet mill foremen had intermediate fungal spore exposures (2200 to 3700 CFU/m³). Of all the job categories sampled, beet washers had the lowest average exposure (950 CFU/m³). Workers were exposed primarily to *Penicillium* and to lower concentrations of *Cladosporium* and *Aspergillus*.

Comparison of the production campaign and postproduction cleanup and maintenance

phase results show a great increase of exposure levels during the postproduction cleanup and maintenance phase for each job tested. The pellet silo, predominantly closed during the campaign, was opened in June so that the pellet loaders could enter with a front-end loader to remove residual pellets from the silo floor. Residual pellets were visibly infested with fungal growth and high spore levels were encountered. The pellet loaders also loaded railroad cars and trucks. The average exposure to fungi of the pellet loaders (1 500 000 CFU/m³) during postproduction cleanup and maintenance was 50 times greater than their average exposure during the production campaign. Exposure levels of the pellet loaders during both the production campaign and the postproduction cleanup and maintenance phase are shown in Figure 3. Also, a further breakdown of the production campaign exposure levels of the pellet loaders is shown in Figure 3.

The pellet mill operators ran the pellet mills during the production campaign; during the postproduction cleanup and maintenance phase, they did maintenance work and were exposed to moldy pulp dust. Their average exposure to fungi (96 000 CFU/m³) increased about 40 times over their exposure during the production campaign study. The exposure levels of the pellet mill operators during both the production

PRODUCTION CAMPAIGN AND POSTPRODUCTION CLEANUP & MAINTENANCE PHASE EXPOSURE DATA

PRODUCTION CAMPAIGN EXPOSURE DATA

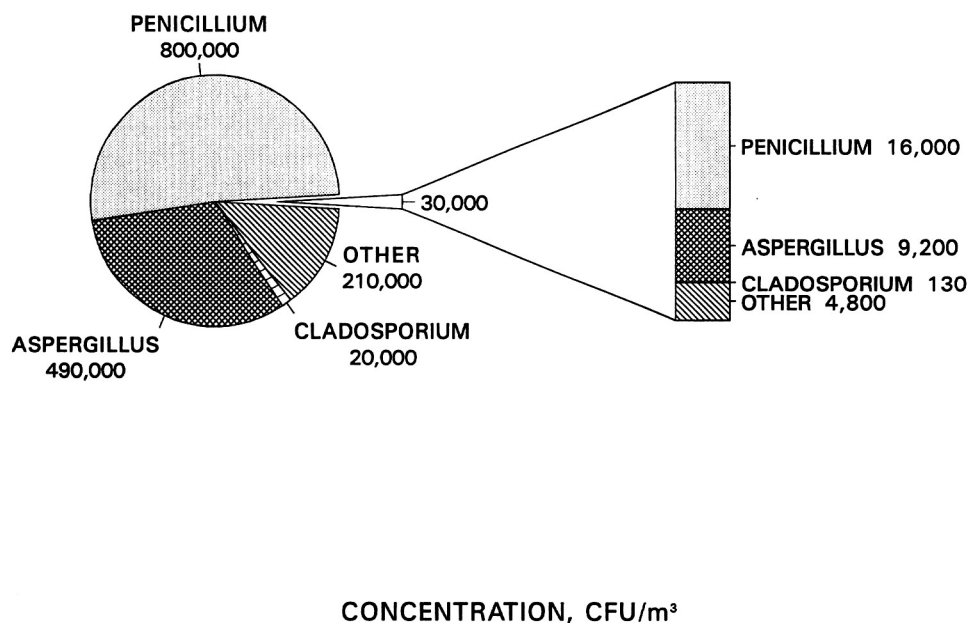


FIGURE 3. The fungi exposure levels (CFU/m³) of the pellet loaders during the production campaign (January) and the postproduction cleanup and maintenance phase (June)

campaign and the postproduction cleanup and maintenance phase are shown in Figure 4. Also, a further breakdown of the production campaign exposure levels of the pellet mill operators is shown in Figure 4.

DISCUSSION

This study showed high exposure of pellet loaders and pellet silo workers to *Aspergillus*, *Penicillium*, and *Cladosporium*. Several species of *Aspergillus* have been reported to cause allergic health problems, as well as the opportunistic infection aspergillosis.⁽¹³⁻¹⁴⁾ In addition, exposures to species of *Penicillium*, *Aspergillus*, and *Cladosporium* have been associated with occupational asthma and hypersensitivity pneumonitis.⁽¹⁵⁻²⁰⁾ Of the lesser predominant fungi, *Alternaria* is noted to cause hypersensitivity pneumonitis, conjunctivitis, and skin and nail infections.⁽¹³⁾ Members of the genera *Botrytis*, *Drechslera*, *Monilia*, and *Trichoderma* are identified as allergens.⁽²¹⁾

The exposures to fungi during the postproduction cleanup and maintenance phase were much higher than those measured during the production campaign. This was expected since the original workers' complaints occurred in June

when the silo was opened for removal of the residual pellets. The comparison of the exposure of pellet loaders in the two sampling periods shows that the general spectrum of taxa is similar, but the concentration of fungal spores during postproduction cleanup and maintenance was 50 times greater. This may be attributed to the higher temperature (June) and the long time for fungal growth while some pellets had been trapped near the bottom and walls of the silo.

In the work areas sampled, *Penicillium* was the predominant genus except at the pellet conveyor, where *Aspergillus* predominated. During the production campaign, the *Penicillium* concentration in the pellet conveyor area was approximately 340 CFU/m³, which is surprising since the average exposure of the pellet loaders to *Penicillium* was 16 000 CFU/m³. The pellets were presumably the same in both cases. One possible explanation for the difference could be that there is an inherent weak-

ness in the enumeration procedure. High analytical dilutions can statistically exclude taxa present in the air sample at low concentrations. This dilution technique favors the predominant fungi populations at the expense of minor populations.

Engineering Controls

The design of the pellet silo was a factor in spore exposure during and after the campaign due to fungal growth in the immobile pellets on or near the flat floor of the silo. There were four pellet discharge ports in line with the pellet conveyor beneath the silo; thus, a large area of the silo floor did not feed pellets into the ports. These four in-line discharge ports were located along the diameter of the silo, above the pellet conveyor. When open, pellets directly above the port were drawn out of the silo, creating channels, called rat holes, in the pellet silage. This situation is depicted in Figure 2. With continuous operation, the incoming pellets periodically collapsed to fill these rat holes and tended to pass directly through the silo. Pellets beyond the rat holes had a longer residence time in the silo. The pellets near the bottom and by the walls remained stationary until the silo was emptied during postproduction, contributing to

PRODUCTION CAMPAIGN AND POSTPRODUCTION CLEANUP & MAINTENANCE PHASE EXPOSURE DATA

PRODUCTION CAMPAIGN EXPOSURE DATA

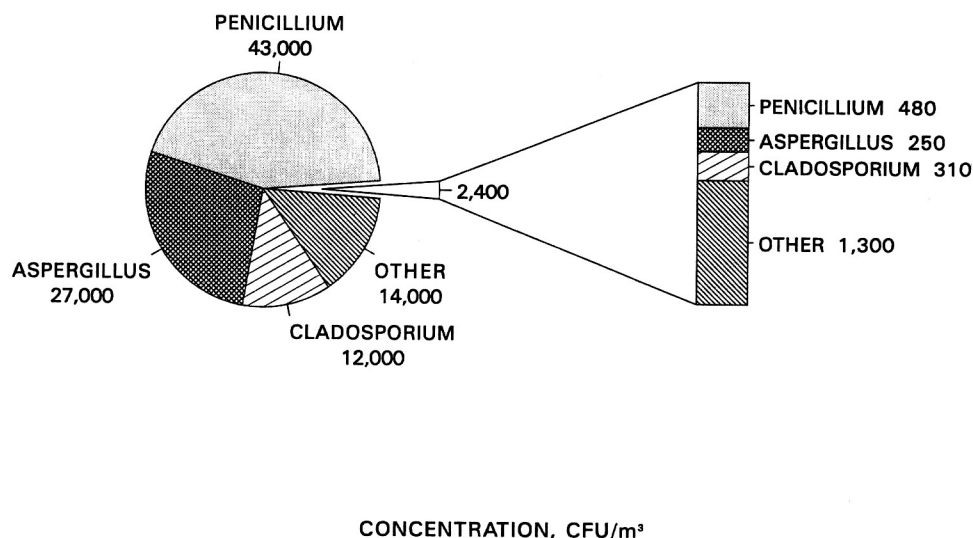


FIGURE 4. The fungi exposure levels (CFU/m³) of the pellet mill operators during the production campaign (January) and the postproduction cleanup and maintenance phase (June)

fungal growth and subsequent exposure of workers of spores.

Improving the silo design may be the most important element in the reduction of exposure to the fungal spores. By preventing the accumulation and subsequent biodegradation of pellets, production of fungal spores would be minimized and exposures in subsequent transport and loading would be reduced. The flat-floored design of the silo was responsible for the stagnation and subsequent deterioration of the pellets through microbial growth. Two alternatives exist for improved pellet flow. The first would be to install a sloped metal floor in the existing silo. The geometry of the existing silo would limit the slope to a maximum of 30 degrees, so stagnant spots would still exist along the line of the discharge ports. Installation of a screw conveyor(s) in the "vee" formed by the sloped floor could eliminate all stagnant spots. A second alternative would be to replace the existing silo with a series of smaller diameter silos, eliminating dead zones (i.e., mass-flow silos). Principal characteristics and design criteria of mass-flow and funnel-flow silos are well defined.⁽²²⁻²³⁾

High levels of airborne microorganisms were found in the pellet conveyor area. This airborne contamination was due to the fungal growth in the silo described above. The discharge openings were clogged with decaying clumps of pellets that required manual removal. Spillage from the conveyor belt and inadequate ventilation of the pellet

conveyor area contributed to the high exposures in this area. An exhaust duct was present at each point where the silo discharges onto the conveyor belt. However, the ducts were located too far from the point of dust generation to capture dust effectively. To improve ventilation in the pellet conveyor area the existing exhaust ducts should be connected to sheet metal (or other rigid material) enclosures built around the discharge openings. Rubber (or other flexible material) skirts should be placed directly above the conveyor belt.⁽²⁴⁾

Some mechanisms for the existing clamshell discharge doors were inoperable, requiring the operator to wedge the doors open with a stick. This resulted in poor control of pellet flow and subsequent spillage. The need for workers to enter the pellet conveyor area could be minimized by repairing and motorizing the doors. The pellet feed rate

could then be controlled from outside the conveyor area. Installation of sideboards along the conveyor could be considered to reduce the spillage of pellets onto the floor of the conveyor tunnel. A vacuum cleaner (preferably one with HEPA filters) for use in the pellet conveyor area would prevent aerosolization of fungal spores when cleaning up spilled pellets and dust.

Pellet loaders were exposed to high levels of pellet dust during the loading of trucks and railroad cars. The pellets dropped a considerable distance (2 to 3 m) through chutes and into the trucks or railroad cars. During this fall, the pellets induced a flow of air that became contaminated by pellet debris.⁽²⁵⁾ When the pellets were spoiled, the pellet debris contained fungal spores. Dust exposure during the loading of trucks and railroad cars can be reduced by the installation of ventilated loading spouts. These systems were originally developed for grain loading operations and are available from several sources.⁽²⁶⁾ They typically consist of two concentric tubes. Product material is discharged through the inner tube. Dust and displaced air from the container being filled are exhausted through the outer tube, countercurrent to the flow of solids.

CONCLUSIONS

The exposure of the pellet loaders and pellet silo workers to pellet dust can be reduced by implementing the following:

(1) redesign the silo to provide for product turnover, with conditions unfavorable for microbial growth; (2) modify the pellet conveyor area to prevent pellet spillage and to ventilate the pellet dust more effectively; and (3) use ventilated loading spouts when filling trucks and railroad cars with silage.

The design ideas discussed above would help to lower potential exposures to fungal spores. This reduction, in turn, will reduce the number of workers who become sensitized to fungi. As others have reported, it is important to note that no control, short of using a supplied-air breathing apparatus or removing the worker from the job site, would prevent a worker predisposed to occupational asthma or hypersensitivity from having adverse reactions to low concentrations of fungi spores in air.⁽²⁷⁾ Besides reducing the potential exposure to fungal spores, the recommended controls will reduce exposure to other biological contaminants in the pellet dust such as bacteria and mites.

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