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Coliforms in Aerosols Generated by a Municipal Solid Waste Recovery System

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Airborne total and fecal coliform concentrations averaged 2.1×10^3 and $9.9 \times 10^2/m^3$, respectively, inside an operating solid waste recovery system. Installation of dust control equipment reduced these levels by 50%. Frequency of recovery of coliforms also dropped by 15%.

Energy conservation efforts have resulted in the development of considerable interest in municipal solid waste recovery systems (SWRS). In these systems, ferrous, nonferrous, and glass materials are recycled. The lightweight fraction, composed of paper, plastic, and other combustible materials, is salvaged for use as a fuel in electricity-generating power plants. Municipal solid waste is composed of many types of substances, including decaying animal and vegetable matter, disposable diapers, pet feces, and soiled facial tissue. Thus, municipal solid waste contains a diverse and variable microbial flora, and aerosols with a high microbial content can be generated when the wastes are processed.

In 1974, the City of Ames, Iowa, completed construction of an SWRS. The Ames SWRS consists of a refuse-processing plant where solid waste is dumped onto a "tipping" floor and subsequently shredded. The metals are then separated and the shredded refuse is conveyed to an air classifier, where the lightweight (combustible) fraction is separated from the heavyweight (noncombustible) fraction. The lightweight material is conveyed to an Atlas storage bin which acts as a buffer between the output of the processing plant and the demand of the power plant. The material from the bin is conveyed to the power plant for combustion as needed.

Shortly after the Ames SWRS began routine operation, we observed that aerosols and dust concentrations reached high levels. Studies were initiated to assess the potential microbial hazards involved in the operation of a municipal SWRS. During this study, dust control equipment was installed at the Ames SWRS; thus, data were gathered both before and after dust control was implemented. Other environs were examined for comparative purposes.

Total coliforms (TC) are the standard indicators of pollution in drinking water, and fecal coliforms (FC) are the standard indicators of fecal pollution in wastewater. Since a study by Goldberg and Leif (12) revealed that 70% of the retained fraction of a test aerosol was found in the gastrointestinal tract of the exposed experimental animal, we decided to monitor coliform concentrations as an indicator of microbial air quality in the Ames SWRS.

MATERIALS AND METHODS

Samples for coliform analyses were obtained by using all-glass impingers (AGI-30) (4, 21) containing 20 ml of lactose broth (Difco Laboratories). The impingers were positioned approximately 1 m above the walking surface of the sampling site. A vacuum pump (9.5 liters/min) was placed on the walking surface so as not to disrupt the airflow around the impinger. After a 20-min sampling period, the impingers were placed in an ice chest to keep the samples at $3 \pm 2°C$ until they could be processed. All samples were processed within 6 h.

Violet red bile agar (VRB; Difco) was used to determine coliform counts (13). Two sets of VRB plates were made from each sample; one set was incubated for 48 h at $35 \pm 0.5°C$ (13), and the other set was incubated at $44.5 \pm 0.5°C$ (16). Dark red colonies greater than 0.5 mm in diameter were considered positive for both TC and FC.

Samples for total counts were collected on 5% sheep blood agar plates by using an Andersen 2000 sampler (4, 21).

Locations. Representative locations often occupied by Ames SWRS personnel were sampled as follows: (location 1) ambient locations, including an enclosed shopping mall (Ames), a municipal park (Des Moines), and a horticulture garden (Ames); (2) tipping floor of solid waste-processing plant (SWPP), plant operating; (3) tipping floor of SWPP, plant not operating; (4) entryway of SWPP, plant operating; (5) entryway of SWPP, plant not operating; (6) inside processing area of SWPP before dust collectors were installed, plant operating; (7) inside processing area of SWPP before dust collectors were installed, plant not operating; (8) inside processing area of SWPP after dust collectors were installed, plant operating; (9) inside processing area of SWPP after dust collectors were installed, plant not operating; (10) Atlas bin control room; (11) 100 and 300 m upwind from municipal SWRS; (12) 100 and 300 m downwind from municipal SWRS; (13) wastewater treatment plant pump station; (14) poultry house, inside, next to cages; (15)

Iowa State University hog farm, outside, locations 2 m from pig pens; (16) Des Moines landfill, within 10 m of dumping site and at a height of 1.5 m.

The Ames plant is entirely enclosed and has two large doors opening to the outside to permit access to the tipping floor. These doors were usually open when the facility was operating and occasionally open when the facility was not operating. Samples were taken in the Ames SWRS both before and after the installation of dust collectors.

The Atlas storage bin control room (location 10) is located below ground underneath the storage bin. The bin stores the processed solid waste until it is needed as fuel. Ames SWRS personnel were infrequently stationed there.

For comparative purposes, other locations which might be expected to have higher than normal microbial activity were also monitored (locations 13 through 16, respectively).

Except for the poultry house, all air samples at these latter locations were taken outside. The poultry house air samples were taken in a hallway immediately outside two rooms containing approximately 100 caged birds. At the hog farm, impingers were run adjacent to a pen containing 10 or fewer hogs. The landfill samples were taken within 10 m of the working face where landfill personnel directed traffic. The wastewater treatment plant air samples were taken at a pump house 15 to 30 m from the trickling filters.

RESULTS

The coliform results from the various locations are summarized in Table 1. Average total colony-forming units (CFU) for some of the locations (CFU per cubic meter) were: inside processing plant, 10^5; Des Moines landfill, 10^4; wastewater treatment plant, 10^3 to 10^4; and ambient locations, 10^2 to 10^3.

Using the ambient locations (location 1), as a base line, relative comparisons of the various sampling sites can be made. This type of control was used because no standard methods exist for microbial aerosol sampling and sample processing, and no standards exist for microbial numbers or types that might be considered safe or unsafe.

All locations in the operating plant (locations 2, 4, 6, and 8) showed higher than base-line levels of TC and FC. The highest levels and the highest

TABLE 1. *TC and FC data obtained on the 16 sampling locations listed in Materials and Methods*

Location	Sample	No. of samples	No. of times found	% of times found	Avg when found (CFU/m^3)	Avg of all samples (CFU/m^3)	Highest no. found (CFU/m^3)
1	TC	51	1	2	68	1.3	68
	FC	51	1	2	98	1.9	68
2	TC	32	10	31	410	130	1,500
	FC	32	8	25	280	69	1,200
3	TC	14	1	7	6,300	450	6,300
	FC	14	1	7	4,800	340	4,800
4	TC	23	7	30	170	53	290
	FC	23	5	22	70	15	110
5	TC	6	0	0	0	0	0
	FC	6	0	0	0	0	0
6	TC	35	32	91	2,300	2,100	8,000
	FC	35	31	89	1,100	990	5,100
7	TC	11	3	27	210	56	380
	FC	11	1	9	110	10	110
8	TC	18	14	78	1,100	820	2,600
	FC	18	13	72	490	360	1,800
9	TC	9	1	11	110	12	110
	FC	9	0	0	0	0	0
10	TC	31	7	23	110	24	250
	FC	30	4	13	88	12	110
11	TC	47	1	2	50	1.1	50
	FC	47	1	2	100	2.1	100
12	TC	53	2	4	150	5.6	250
	FC	53	1	2	150	2.8	150
13	TC	21	4	19	110	21	290
	FC	20	0	0	0	0	0
14	TC	10	1	10	48	4.8	48
	FC	10	1	10	48	4.8	48
15	TC	23	0	0	0	0	0
	FC	23	0	0	0	0	0
16	TC	34	4	12	71	8.3	100
	FC	34	2	6	42	2.4	50

frequencies of coliform recoveries were obtained inside the plant (location 6) before the dust collectors were installed. Levels in the operating plant (location 8) decreased after the dust collectors were installed but still remained an average of 820 CFU/m^3 higher for TC and 360 CFU/m^3 higher for FC than ambient locations. The frequency of recovery also remained 75% above base-line conditions. In general, data obtained at locations 6 and 8 showed that the dust collectors resulted in a 15% reduction in frequency of recovery and a 50% reduction in coliform levels in the operating plant.

When the plant was not operating, no coliforms were found in the entryway (location 5), but the coliform levels on the tipping floor remained elevated. In some instances, however, solid waste was received and moved on the tipping floor even though the processing circuit was not operating. Generally, the doors to the tipping floor were closed when no solid waste was being received.

Samples taken at upwind and downwind sites from the municipal SWRS (locations 11 and 12) yielded coliform levels comparable to those measured at ambient locations. This suggests that coliforms are released at minimal levels from the municipal SWRS or that air currents, dilution of aerosols, and loss of bacterial viability result in low recoveries.

Inside the Atlas storage bin control room (location 10), the coliform levels were higher than background levels and were similar to the levels of the processing plant entryway (location 4).

No FC were recovered from air samples obtained at the wastewater treatment plant. This result was unusual considering the high level of FC present in sewage. However, the samples were taken at the pump station where an operator would be stationed and not necessarily downwind from the trickling filters. Locations 13 through 16 all revealed much lower frequencies of occurrence and overall lower levels of coliforms than the operating municipal SWRS.

DISCUSSION

Few data are available on the microbial content of air samples obtained from the variety of environments that we studied. A complex interaction of variables must be accommodated when comparing coliform recoveries between locations and between researchers. An example is outdoor air sampling at a sanitary landfill and at the tipping floor in a municipal SWRS. Both receive and manipulate solid waste. However, microbial levels are subject to (i) dilution by atmospheric diffusion (18), (ii) solar radiation (2, 8, 11), (iii) weather conditions (2, 11), and (iv) open-air factors (6). All these factors influence coliform counts less in a municipal SWRS than at a landfill and probably explain the differences in recoveries.

In a similar study at a solid waste-handling facility in St. Louis (9), lower numbers of coliforms were observed than at the Ames plant. These researchers used a Hi-Vol (filter) sampler and most-probable-number analytical technique. In a later publication (10), the same authors recommended that Hi-Vol (filter) air samplers not be used to sample for airborne microorganisms beeause of the deleterious effects of desiccation on microbial viability. The variables between studies included microbiological analysis techniques, air sampling devices, and sample-handling procedures. To better standardize the techniques used, air sampling devices and analytical procedures should be compared. Researchers (3, 19) have compared the Andersen impactor with the LEAP high-volume air sampler for total bacteria and coliform recoveries. No consistent difference in recovery efficiency was encountered. Additional comparisons between the LEAP, the impinger, and the impactor would be beneficial.

As mentioned earlier, VRB agar was selected for this work. This technique is advantageous because of the ease of processing samples and should be compared with *Standard Methods* (1) most-probable-number tests. Other investigators have increased the sensitivity of the VRB method (14, 17), and coliform counts on these media probably would be higher than the counts that we obtained. Confirmation of their results would better enable environmental scientists to monitor waste-handling facilities.

Tests of aerosol emissions, including coliform concentrations, have been conducted at various wastewater treatment processes. Goff et al. (11) recovered 10^1 to 10^3 coliforms/m^3 downwind from trickling filters. Low airborne coliform recoveries of 10^1 CFU/m^3 were detected at an activated sludge plant (5); upwind and downwind total coliforms were approximately 1 CFU/m^3. At another facility (15), downwind TC and FC concentrations ranged from 1.2 CFU/m^3 for TC and 0.3 CFU/m^3 for FC at 107 m to 2×10^2 and 8.9 CFU/m^3, respectively, at 1 m downwind. Other trials at similar distances detected lower concentrations. Coliform aerosols 8 cm above the surface of dewatered sewage applied to a forest clear-cutting (7) ranged from 0 to 10^4 CFU/m^3.

If one relates the TC and FC levels at the Ames SWRS (location 13) with the results of wastewater treatment facilities, the upwind and downwind levels (locations 11 and 12) are comparable. Studies on the health effects of emissions from such facilities (5, 15) have yielded no evidence of significant public health risks. However, the much higher levels of TC and FC in the municipal SWRS, even with dust collectors installed, suggests that plant personnel are subject to a greater exposure to any pathogens that might be present in the solid waste. Coliforms indicate the presence of intestinal pathogens; plant personnel could ingest coliforms if good hygienic habits are not followed. The possible inhalation of *Klebsiella pneumoniae*, a potential respiratory tract pathogen, suggests that an epidemiological study of solid waste recovery systems is needed. However, a recent publication by Sprenkel (20) indicates that the health of the employees at the Ames SWRS has not been affected to date by these factors.

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