APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Dec. 1978, p. 972-974
0099-2240/78/0036-0972$02.00/0

Vol. 36, No. 6
Printed in U.S.A.

Coliform Aerosols Generated from the Surface of Dewatered Sewage Applied to a Forest Clearcut

ROBERT L. EDMONDS* AND WILLIS LITTKE
College of Forest Resources, University of Washington, Seattle, Washington 98195

Received for publication 13 September 1978

Concentrations of airborne coliform bacteria as high as 1.5×10^4 m^{-3} were observed 8 cm above anaerobically digested sewage sludge applied to a forest clearcut. Dry conditions and high wind speeds tended to favor aerosol generation.

Potential pathogens occur in the air near sewage treatment plants (1, 5, 10, 11) and wastewater irrigation areas (8). They could also occur above sludge-treated forest land since total and fecal coliform bacteria are known to survive for months in sludge applied to forest clearcuts (4). This study was initiated to determine whether coliform bacterial aerosols are generated from sludge surfaces in a forest clearcut and, if so, to determine what meteorological conditions favor such generation.

Anaerobically digested, dewatered (20 to 40% solids) sewage sludge was transported from the City of Seattle's West Point Treatment Plant 120 km south to the Charles Lathrop Experimental Forest of the University of Washington. Approximately 41 m^3 of dewatered sludge (15 cm deep) was applied on 29 and 30 December 1976 to a 0.1-hectare circular area in a 21-hectare clearcut. An adjacent area received sludge on 25 August 1977.

Aerosol samples were taken with an All Glass Impinger (9), sampling 8 liters min^{-1} in the middle of the treated areas. The low sampling rate prevented excessive foaming. The orifice of the sampler was located 8 cm above the sludge surface and was pointed into the wind. Samples were taken for 1 h, generally in the early afternoon when bacterial concentrations were expected to be near the maximum (6), at approximately monthly intervals for 6 months, starting on 2 January 1977, for the winter treatment and at weekly intervals, from 1 September to 6 October, 1977 for the summer treatment. Air samples were also taken on a control plot approximately 1 km upwind from the sludge-treated site. The collection solution was 30 ml of 0.1% peptone (Difco Laboratories). Total coliform bacteria counts were determined by using lactose fermentation and the most-probable-number technique (2). Three replicates and a threefold dilution series were used. Samples were processed within 0.5 h after collection. Total coliforms in sludge at the initiation and end of the study were also determined by the most-probable-number technique (2). Sludge moisture was determined gravimetrically in the summer treatment.

Wind speed, air temperature, relative humidity, solar radiation, and rainfall data (at 10 m) were obtained from the meteorological station at Pack Forest, located about 1 km from the sludge-treated areas. Such meteorological data were generally representative of the study site. On-site instruments should be used in future studies, however.

Coliform bacteria were generated from the surface of sludge which had been applied in December 1976 (Table 1). No coliform bacteria were detected in the control samples. The highest concentration was found on 5 April 1977. At this time, air temperature, solar radiation, and wind speed were high (21.7°C, 0.88 cal [ca. 3.69 J] cm^{-2} min^{-1}, and 1.15 m s^{-1}, respectively). A dry period preceded the sampling time. Interestingly, on 27 June, although similar meteorological conditions prevailed, no airborne coliforms were detected. This could have been due to a dieoff of coliform bacteria in the sludge. Initial sampling revealed 3.5×10^7 coliform bacteria per g of sludge, whereas numbers were only 5.0×10^5 per g of sludge on 27 June. No precipitation was recorded during either sampling period.

When low airborne concentrations of coliform bacteria occurred, air temperatures were cooler, the sampling periods were preceded by wet periods, and wind speeds were low. For example, during the 17 May sampling, when low concentrations of coliform bacteria occurred, the air temperature was 8.9°C, the wind speed was 0.13 m s^{-1} (Table 1), and rain fell before the sampling period.

Results of the initial study led to the second study examining a summer sludge application. Again similar results were found (Table 2), in that generally the highest bacterial aerosolization occurred after a dry period and when air temperature, solar radiation, and wind speed

TABLE 1. *Airborne coliform bacteria concentrations (most probable number) above dewatered sludge applied to a forest clearcut on 29 and 30 December 1976 and a control area,[a] wind speed, air temperature, solar radiation, relative humidity, and precipitation[b] during the sampling period*

Sampling date (1977)	Sampling time (h)	Airborne coliform bacteria (no. m^{-3})	Wind speed (m s^{-1})	Air temp (°C)	Solar radiation (cal cm^{-2} min^{-1})	Relative humidity (%)
21 Jan.	1310-1410	—[c]	0.75	4.8	0.07 (0.29)[d]	90
24 Feb.	1337-1447	1.1×10^2	0.70	7.5	0.40 (1.67)	55
24 Mar.	1112-1232	1.0×10^2	1.73	7.5	0.73 (3.06)	56
7 Apr.	1308-1408	1.2×10^3	1.15	21.7	0.88 (3.69)	53
17 May	1124-1234	55	0.13	8.9	0.17 (0.71)	87
27 June	1320-1420	0	1.27	18.6	0.84 (3.52)	54

[a] No coliform bacteria were detected in the control samples.
[b] No precipitation occurred during the sampling periods.
[c] Coliforms were observed, but concentrations were not determined.
[d] Numbers in parentheses are joule equivalents.

TABLE 2. *Airborne coliform bacteria concentrations (most probable number) above dewatered sludge applied to a forest clearcut on 25 August 1977 and a control area,[a] percent moisture of the sludge, wind speed, air temperature, solar radiation, precipitation,[b] and relative humidity during the sampling period*

Sampling date (1977)	Sampling time (h)	Airborne coliform bacteria (no. m^{-3})	% moisture (fresh wt basis)	Wind speed (m s^{-1})	Air temp (°C)	Solar radiation (cal cm^{-2} min^{-1})	Relative humidity (%)
1 Sept.	1153-1243	1.5×10^4	72	1.00	20.1	0.95 (3.98)[c]	54
8 Sept.	1120-1205	2.3×10^2	25	1.22	16.8	0.94 (3.93)	55
14 Sept.	1230-1315	1.1×10^2	50	1.58	18.8	0.83 (3.48)	50
22 Sept.	1215-1302	0	60	0.62	14.0	0.76 (3.18)	66
29 Sept.	1241-1322	0.9×10^2	74	0.18	11.4	0.16 (0.67)	85
6 Oct.	1153-1247	1.0×10^2	47	0.95	12.2	0.47 (1.98)	90

[a] No coliform bacteria were detected in the control samples.
[b] No precipitation occurred during sampling periods except for a trace on 6 October.
[c] Numbers in parentheses are joule equivalents.

were high during the sampling period (Table 2). Although sludge moisture was high (72%) on the initial sampling date of 1 September 1977, surface drying had occurred. The highest airborne concentrations were also observed at this time (Table 2). High concentrations also occurred during the second sampling period when the sludge moisture content was lowest (25%) (Table 2). Coliform bacteria numbers in the sludge changed little during the sampling period and averaged 1.4×10^6/g.

A trace of rain fell during the 6 October sampling, and rain splash may have entered the sampler. This represents a second mechanism for aerosol generation other than wind blowing of drying particles (3).

Coliform bacteria, which are universal indications of fecal pollution, are apparently capable of being aerosolized from the surface of dewatered sludge applied as a land treatment. It might have been better to use fecal coliforms rather than total coliforms in this study since the former are better indicators. However, one advantage of using total coliforms was that aerosolization mechanisms could be better examined because of their longer survival in the sludge. The highest concentrations generally resulted during warm, dry periods when particles were picked up in the wind. Rain splash may be another mechanism for aerosolization. It would also appear that the highest numbers are likely to be generated in the first few months after application, when both total and fecal coliform counts are high. Airborne coliforms were detected during both the summer and the winter above the sludge and could be detected months after sludge application.

This research was supported by a grant from the Municipality of Metropolitan Seattle.

LITERATURE CITED

1. **Adams, S. P., and J. C. Spendlove.** 1970. Coliform aerosols emitted by sewage treatment plants. Science **169**:1218–1220.
2. **American Public Health Association.** 1965. Standard methods for examination of water and wastewater, 12th ed. American Public Health Association, Inc., New York.
3. **Blanchard, D. C., and L. Syzdek.** 1970. Mechanism for water to air transfer and concentration of bacteria. Science **170**:626–628.
4. **Edmonds, R. L.** 1976. Survival of coliform bacteria in sewage sludge applied to a forest clearcut and potential movement into groundwater. Appl. Environ. Microbiol. **31**:537–546.
5. **Fannin, K. F., J. C. Spendlove, K. W. Cochran, and**

J. J. Gannon. 1976. Airborne coliphages from wastewater treatment facilities. Appl. Environ. Microbiol. 31: 705-710.

6. **Gregory, P. H.** 1973. The microbiology of the atmosphere. John Wiley and Sons, New York.
7. **Gregory, P. H., and J. L. Monteith (ed.).** 1967. Airborne microbes. Proceedings of the 17th Symposium, Society for General Microbiology. Cambridge University Press, Cambridge.
8. **Kerr, R. S.** 1974. Land application of sewage effluents and sludges: selected abstracts. U.S. Environmental Protection Agency, Corvallis, Oreg.
9. **May, K. R., and G. H. Harper.** 1957. The efficiency of various liquid impinger samplers in bacterial aerosols. Br. J. Ind. Med. 14:287-297.
10. **Pereira, M. R., and M. A. Benjaminson.** 1975. Broadcast of microbial aerosols by stacks of sewage treatment plants and effects of ozonation on bacteria in the gaseous effluent. Public Health Rep. 90:208-212.
11. **Randall, C. W., and J. O. Ledbetter.** 1966. Bacterial air pollution from activated sludge units. Am. Ind. Hyg. Assoc. J. 27:506-519.