Effect of Lagoon Aeration on Odor Emissions from a Swine Grow-Finish Facility(1)

Final Report(2)

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Abstract

Odor emission from a 6,000 head swine grow-finish facility was measured in May, 1998. Lagoon odor emission with simulated wind speeds of 2.5 mph (1.1 m/s) in a new buoyant convective flux chamber ranged from 89 to 123 OU/min-m^2 and averaged 100 OU/min-m^2. The total odor emission from the 2.4-acre (9,720 m^2) surface-aerated first-stage lagoon would be 16,163 OU/s at this rate. The aerated lagoon emitted 82% less odor than similar unaerated lagoons with only half the volumetric loading rate. Odor emissions from the grow-finish buildings with recirculation flush pits was18 OU/min-AU. Estimated total farm odor emission of 43 OU/s-AU was similar to average odor emissions from deep-pit buildings of 36 OU/s-AU measured in another study.

Introduction and Objectives

Anaerobic lagoons have been used for many years to provide practical treatment and storage for swine manure, because of their simplicity in operation and maintenance, and relatively low cost compared to other treatment methods (Zhang et al., 1996). Lagoons become more odorous when they are overloaded due to sludge buildups, additional inputs, and cold weather. Aeration is a well-known method of upgrading existing lagoons to significantly reduce odor problems, but field data is lacking.

Submerged static tube aerators (RAMCO Sales, Inc., Cushing, OK) consist of 4, 8, or 12 inch (10, 20 or 31 cm) diameter vertical tubes containing 2 or 3 free-turning counter-rotating turbines that shear a coarse bubble stream of air into fine bubbles. The aerators are submerged with weights and the air lift action of rising bubbles keeps the aerator tubes vertical. Coarse air is delivered by air headers and valved air laterals with a blower providing air at 3 to 7 psi (750 to 1750 Pa) pressure. A short section of flexible hose is connected from the laterals to the air diffusers which contains several 0.25 or 0.38 inch (0.7 to 1.0 cm) holes. As this coarse air and water mixture rises, it is deflected by Venturi rings into the turbines. Because of the large hole sizes in coarse air diffusers, static tube aeration systems are maintenance-free (Boss and Aberg, 1987).

A modified static tube aeration system (RAMCO, 1997) was designed to aerate surface water only. A system was installed in the 2.4 acre (9,655 m^2) first-stage lagoon at a 6,000-head, swine finishing site in Oklahoma. It began operating on August 8, 1997. The blower provided 33 cfm (56 m^3/h) to each of 21 aerators.

The swine finishing site consisted of six, 31x246 ft (9.45x75m) grow-finish buildings each with four, 10'x125' (3.1x38.1m) recirculation flush pits (MWPS, 1985). On a weekly basis, the pits were drained into a first-stage lagoon located about 150 ft (45.7m) east of the buildings, and recharged with second-stage lagoon water. Slurry from the second-stage lagoon was used to recharge each pit with about 20 inches (51 cm) of water after flushing the drained pit for 20 minutes. Each building had a 4 ft (1.2m) thermostatically-controlled curtain on each sidewall. Sidewall openings were created by lowering these curtains. There was no ceiling and the ridge had no ventilation openings. The 3 ft (0.3m) deep flush pits were ventilated via two central underfloor plenums with 3 in (7.5 cm) diameter holes spaced 10 ft (3.05 m) on center along the building length on each side. Three, 12" (30 cm) diameter fans exhausted air from each plenum through a concrete annex located outside each endwall.

The objective of this project was to evaluate odor emissions from the aerated 2.4 acre (9,655 m^2) first-stage lagoon and six grow-finish buildings with recirculation flush pits. Another objective was to test the effect of flushing frequency on air quality in the buildings.

Procedure

Ammonia and carbon dioxide concentrations were measured using a hand-held gas sampling pump and gas absorption tubes. Replicated samples of CO_2 and NH_3 were taken at two locations in each building to assess air quality and gas emissions.

Gas samples from the lagoon and the buildings were collected in 10 L chemically-inert bags and sent overnight to Purdue University for analysis by a human panel with dynamic dilution olfactometry. Dilution thresholds were evaluated by eight panelists.

The heat balance method (Heber et al., 1998b) was used to estimate airflow rates from each building. Temperatures in two buildings and the outside temperature were recorded every 20 s using battery-operated temperature recorders. To study effects of flushing frequency, building 3 was flushed on May 2 and building 4 was flushed on May 6. Building emissions measured in buildings 3 and 4 on May 6 and 7 provided a comparison of gas concentrations and emissions before and after flushing the pit, and after 1, 4, 5 and 7 days since last flush.

A buoyant convective flux chamber was designed and constructed for measuring odor emissions from the lagoon surface under controlled conditions. The chamber covered 8.1 ft^2 (0.76 m^2) of lagoon surface. Inside chamber walls and ceiling were lined with stainless steel and surrounded by rigid waterproof insulation to cause enough buoyance to keep 6 inches (15 cm) of the chamber above the surface. A buoyant variable air supply unit floating adjacent to the emission chamber forced air through a gas absorption and dust filtering system and into the emission chamber through a Teflon hose. Air followed a hairpin path through the chamber. A surface air velocity of 219 fpm (1.1 m/s) was established by adjusting the variable-speed exhaust fan and measuring air velocity with a hot-wire anemometer. Samples of air going into and out of the emission chamber were collected in 2.0-3.0 minutes at an airflow rate of 0.08 to 0.12 cfm (2.5 to 3.3 Lpm). Odor emission was determined by multiplying airflow rate through the chamber by the difference between inlet and outlet odor concentrations.

Lagoon emission was measured on May 4 at five surface air speeds: 20, 41, 176, 268 and 333 fpm (0.10, 0.21, 0.89, 1.36 and 1.69 m/s). The chamber was placed in the lagoon from the west berm about 170 ft (51.8m) from the northwest corner of the lagoon. Inlet and outlet odor concentrations were evaluated at each air speed. On May 5, odor emission was measured twice with inlet and outlet samples taken both times. On May 6, odor emission was measured with one inlet sample and three outlet samples. The chamber was placed in the water from the west berm about 100 ft (30m) from the south end of the lagoon. The same procedure was used on May 7, but the chamber was placed in the water from the south berm.

Results and Discussion

Based on a lagoon volume of 575,000 ft^3 (16,300 m^3) and a surface area of 2.4 acre (9,655 m^2), the lagoon was overloaded at the time of testing by 1.5 and 1.8 times based on volume and surface, respectively. The volumetric volatile solids loading of the first cell was 8.9 lb/1000 ft^3 compared to the recommended loading rate of 6 lb/1000 ft^3. The surface loading rate of the lagoon was estimated at 2,131 lb/acre-day as compared to the 1,200 lb/acre-day maximum recommended by ASAE (1997). The lagoon had been loaded uniformly for two weeks prior to May 4.

Lagoon slurry temperature was 68F (20C) as measured by a battery-operated temperature sensor along the edge of the lagoon. Chemical oxygen demand, biodegradable oxygen demand, total suspended solids, volatile solids, and dissolved oxygen of samples taken near the surface of the lagoon were 7,105, 1,646, 1,450, 0.04, and 1,040 mg/L, respectively. Slurry pH was 8.1.

Lagoon Odor Emission

A regression equation was developed from the May 4 test to determine an odor emission rate of 93 OU/min-m^2 at 2.5 mph (1.1 m/s). Odor emission rates on May 5 were 89 and 90 OU/min-m^2 for the first and second runs, respectively. Odor emission rates on May 6 and 7 were 123 and 111 OU/min-m^2, respectively. Overall, they ranged from 89 to 123 OU/s and averaged 100 OU/min-m^2. The odor emission rate from the 2.4 acre (9,655 m^2) lagoon with a 2.5 mph (1.1 m/s) wind was therefore estimated at 16,163 OU/s.

Odor emissions from unaerated lagoons at two other swine grow-finish sites were measured in other projects. Lagoons #1 and #2 had volume loading rates of 5.0 and 3.2 lb VS/1000 ft^3-d and surface loading rates of 988 and 1,926 lb VS/acre-d, respectively. Odor emissions from lagoons #1 and #2 were 705 and 473 OU/s, respectively, and averaged 577 OU/s. The aerated lagoon, with twice the volumetric loading rate, emitted 82% less odor than the unaerated lagoons. This preliminary data suggested that static tube aeration was very effective in reducing odor emissions and confirms the findings in the literature concerning the effectiveness of aeration on odor control.

Odor and Ammonia Emissions from Buildings

Buildings 3 and 4 had 1,024 and 925 pigs weighing 120 and 130 lb (55 and 59 kg), respectively. Airflow from each pit fan was 1,500 cfm (2,550 m^3/h) based on a velocity traverse of the fan air outlets. The three west fans of buildings 3 and 4 were shut off and covered with plastic on May 7 so total pit fan airflow was reduced from 9,000 to 4,500 cfm (15,300 to 7,650 m^3/h). However, this represented only a small fraction of total ventilation airflow since curtains were wide open most of the time,. The pit fan plenum was essentially used as an air sampling duct for evaluating indoor air quality.

The pit fan exhaust air had much higher ammonia concentration than air exhausted through the curtains. Pit odor concentration can therefore be assumed to be higher than that of air blowing crossways through the top part of the building. It was therefore assumed that average gas concentration of all fan exhaust air was 10% of gas concentration in the pit fan exhaust air. Since odor intensity is related to the log of gas concentration, it was assumed that the average gas concentration (dilution to threshold) of the overall exhaust stream was 50% of that measured at the pit fan exhaust. Therefore, total odor emission from the building was estimated by multiplying odor concentrations at the pit fans by heat balance airflow and dividing by two. Average odor concentration of air at the pit fans ranged from 34 to 56 OU. Calculated odor emission rates were affected by airflow which was much higher on May 7. The airflow rates of the buildings on May 6 ranged from 58,197 to 69,019 cfm (98,935 to 117,332 m^3/h) whereas on May 7, airflow ranged from 327,789 to 377,717 cfm (557,241 to 642,119 m^3/h). Odor emissions from buildings 3 and 4 were 595 and 772 OU/s on May 6 and 4,048 and 2,658 OU/s on May 7. The average building odor emission measurement was 2,018 OU/s or 18.3 OU/s-AU. With these assumptions and measurements, total odor emission from the six grow-finish houses was 12,153 OU/s, as compared to 16,163 OU/s from the lagoon.

Heber et al. (1998a) reported an average odor emission rate of 36 OU/s-AU from deep-pit swine grow-finish buildings based on 80 simultaneous measurements of odor concentration and fan airflow. The average building odor emission measured in this test with recirculation flush pits was 18.3 OU/s-AU. The average total farm odor emission was 43 OU/s-AU which was similar to odor emission from deep-pit buildings.

The total odor emission from the farm was estimated at 28,316 OU/s based on this preliminary set of data. If the same lagoon was unaerated, it would have generated five times and the total farm emissions would have been 92,924 OU/s. Using an emission-based setback model (Williams and Thompson, 1985), it can be calculated that the aeration system reduced the setback distance for the farm from 0.96 to 0.47 miles (1.54 to 0.75 km).

Uncertainty in odor emission measurements is due to the following reasons:

- Lagoon odor emissions vary significantly with time of loading, wind speed, slurry temperature and air temperature. The number of lagoon surface odor measurements was relatively small (n=5), especially for the unaerated lagoons (n=3 and 1). However, the variability of odor emission measurements with the convective flux chamber was low.
- Building airflow was calculated from a building heat balance which was based on inside temperature measured at only one point. A uniform temperature throughout the building was assumed. Relatively small temperature differences in warm weather contribute to higher airflow estimate errors.
- There was a large difference between gas concentrations of pit fan exhaust air and curtain exhaust air. A 10:1 factor for ammonia and a 2:1 factor for odor were assumed in calculating average concentrations of total exhaust.

Ammonia generation ranged from 1.3 to 6.3 mg/h-kg and averaged 3.6 mg/h-kg. Ni et al. (1998b) measured a mean ammonia emission rate of 10.2 mg/h-kg in buildings with deep pits.

Gas measurements showed a slight trend toward improved air quality in buildings with higher frequency flushing. There was a large building airflow difference between May 6 and 7 during odor sampling times. However, odor concentration in the pit exhaust air was directly proportional to the number of days since last flush. Odor concentrations were 34, 37, 46 and 56 OU and ammonia concentrations were 7, 8, 9 and 9 ppm for days 1, 4, 5 and 7, respectively. Paired emission measurements on May 6 representing days 1 and 5 since last flush and May 7 measurements representing days 4 and 7 were compared with each other since airflows were similar. Odor concentration, odor emission rate and ammonia concentration of day 5 since last flush were 34, 52, and 34% greater than on day 1, respectively. Odor concentration, odor emission rate and ammonia concentration of day 7 were 54, 30 and 10% higher than day 4, respectively.

Conclusions

- Five lagoon emission measurements with simulated wind speeds of 2.5 mph (1.1 m/s) ranged from 89 to 123 OU/min-m^2 and averaged 100 OU/min-m^2. The total odor emission from a 2.4-acre, surface-aerated lagoon would be 16,163 OU/s at this rate.
- Based on measurements at similar unaerated lagoons, the aeration lagoon emitted 82% less odor while having twice the volumetric loading rate. With an 82% odor reduction, aeration reduced the odor impact distance from 0.96 to 0.47 miles according to an empirical setback model.

- The mean odor emission from grow-finish buildings with recirculation flush pits was 18 OU/min-AU or 50% of that measured in deep-pit buildings by Heber et al. (1998a). At this rate, the total odor emission from the six grow-finish buildings would be 12,109 OU/s.
- Total farm odor emission was 43 OU/s-AU was similar to 36 OU/s-AU measured in deep-pit buildings (Heber et al., 1998a).
- Odor and ammonia concentrations in the pit exhaust was directly proportional to number of days since last flush.
- Pit exhaust ammonia concentrations were about 10 times higher than in the room.
- Odor emission measurements with the buoyant convective flux chamber exhibited repeatability.
- Ammonia generation rates averaged 3.6 mg/h-kg as compared to 10.2 mg/h-kg measured recently in grow-finish buildings with deep pits.

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