Detecting and Reducing Ammonia Emissions from Cattle Feedlots and Dairies: A Review

John M. Sweeten, Professor and Resident Director[1/], N. Andy Cole, Animal Scientist[2/], David B. Parker, Assistant Professor[3/], and Brent W. Auvermann, Assistant Professor[4/]

ABSTRACT

Ammonia is one of 170 compounds detected in livestock manure odor. Approaches to ammonia monitoring include acidic solution traps, chemoluminescence, and GC-MS. A review of prior research indicated that ammonia is emitted from surfaces of open, unpaved cattle feedlots and dairy corrals at concentrations of 360-980 $\mu g/m^3$ as compared to background levels of 1-4 $\mu g/m^3$. Ammonia volatilization losses are reportedly 50% or more of total N excreted from open lot surfaces and 23-70% following field spreading. Approaches to ammonia and odor control include improved manure collection and treatment processes, capture and treatment of odorous gases, and improved dispersion through site selection.

KEY WORDS: Ammonia, Odor, Beef Cattle, Dairy Cattle, Olfactometer, Livestock

INTRODUCTION

Dairies and cattle feedlots sometimes produce odor that is an annoyance to and affects the well being of nearby residents. Odorous gases arise from feed materials, fresh manure, and stored or decomposing manure (Sweeten, 1992). Eaton (1996) listed 170 different compounds present in swine manure odor. Odorous gases emitted from animal waste include ammonia and amines, sulfides, volatile fatty acids, alcohols, aldehydes, mercaptans, esters, and carbonyls (National Research Council, 1979; Miner, 1975B; Barth et al., 1984; ASAE, 1987). Olfactory threshold values detected by human panelists may span a range as great as 5 or 6 orders of magnitude for a single compound and range from as low as 7.5×10^{-8} ppm for skatole to as high as 12,000 ppm for formaldehyde (Eaton, 1996). Ammonia has reported odor threshold values ranging from 0.0317 ppm to 37.8 ppm. Concentrations of odor compounds at downwind locations are very low; however, some may exceed olfactory threshold values and create nuisance conditions but are not considered toxic at concentrations found downwind of livestock feeding facilities.

[1/]Texas Agricultural Experiment Station, Texas A&M University Agricultural Research & Extension Center, 6500 Amarillo Boulevard West, Amarillo, Texas 79106.
[2/]USDA-Agricultural Research Service, P. O. Drawer 10, Bushland, Texas 79012.
[3/]West Texas A&M University, Division of Agriculture, Box 60998, Canyon, Texas 79016.
[4/]Texas Agricultural Extension Service, Texas A&M University Agricultural Research & Extension Center, 6500 Amarillo Boulevard West, Amarillo, Texas 79106.

Beef cattle feedlots utilize open lot construction with animal spacings (stocking densities) ranging from 9-12 m^2/hd (100-125 ft^2/head) in arid (< 380 mm/yr; <15 inch) rainfall areas to an average of about 14-16 m^2/hd (150-175 ft^2/head) in the Southern Great Plains which receives rainfall of 380-625 mm/yr (15 to 25 inches/year). Approximately one ton of manure (at 40% moisture wet basis (w.b.) per head fed is typically collected after each pen of cattle has been sold (Sweeten, 1990 and 1992).

Most of the new or expanded dairies in low to moderate rainfall areas (< 600 mm/yr), of the southwestern U.S. utilize an open lot design, with 56-140m^2 (600-1,500 ft^2) corral area per cow. Free-stall designs are favored in moderate to high rainfall areas (above 600 mm/yr). Manure is typically collected very frequently; i.e. at intervals of once per week for open lot dairies; once or twice daily for free stall barns; and two or more times per day for milking centers. The type and design of open lot dairy operations, milking facilities and associated wastewater characteristics and management practices in central Texas are discussed in other reports (Sweeten and Wolfe, 1994). Manure-covered surfaces (e.g., building floors and animals), manure storage tanks and anaerobic lagoons often used for manure storage and treatment may be important sources of ammonia and other odorants (National Research Council, 1979).

When open feedlot or dairy corral surfaces become wet, particularly in warm weather, they may support anaerobic decomposition with an associated large surface area for the evolution of odorous gases, including ammonia. Feedlot odor emissions are greatest in warm, humid areas and in feedlots constructed in areas with inadequate drainage or poor drying conditions (Sweeten, 1992). Losses of N as ammonia or other odorous compounds not only contributes to potential air quality problems but also decrease the fertilizer value of collected manure.

Odor characteristics that contribute to nuisance conditions are as follows: (a) the intensity, concentration or strength of the odor; (b) the odor frequency or number of times detected during a time period; (c) the duration of the period in which the odor remains detectable; (d) the perceived offensiveness and character or quality of the odor (Jones, 1992). These factors interrelate in causing nuisance conditions. Odor frequency and duration are partly dictated by climatic conditions, including wind-direction frequency, atmospheric stability, and moisture conditions.

ODOR MEASUREMENT APPROACHES

Odor measurement methods applicable to animal waste management systems were reviewed previously (Bulley and Phillips, 1980; Barth, et al., 1984; Watts, 1991; Sweeten, 1995; McFarland and Sweeten, 1995). General approaches to estimate the strength or intensity of livestock manure odors include:

1. Measurement of concentrations of specific odorous gases (directly or indirectly).
2. Sensory methods that involve presenting odor samples to human panelists (diluted or undiluted).

Reference will be made to specific methods within each of these two approaches in reporting research results on ammonia emissions and associated projects in the U.S. for dairies and feedlots.

Gas Chromatography/Mass Spectrometry (GC/MS)

Considerable effort has been devoted to identification and measurement of specific gases within the atmosphere of livestock and poultry confinement buildings (Burnett, 1969; Elliot et al., 1978; Hammond and Smith, 1981). A large number of odorous compounds are present in very low concentrations (Miner and Licht, 1981). Miner (1974) reported that the measured concentration of each gaseous compound identified in animal waste odor was below the reported minimum olfactory threshold.

Instruments available to identify and measure the concentrations of specific odorous gases (odorants) emitted from animal manures include gas chromatography and mass spectrometry (White et al., 1971; Hammond et al., 1974). These methods are very sensitive in detecting compounds in very low concentrations. As a result of the low concentrations of many odorants in feedlot air, in many cases the compounds must be concentrated before analysis by use of methods such as solvent desorption, thermal adsorption (Wright, 1994: Zahn, et al., 1997) or solid-phase microextraction (Zhang et al., 1994).

Peters and Blackwood (1977) listed 31 odorants identified at cattle feedlots, together with their threshold limit value (TLV) in ppm and odor threshold (ppm), where known. Peters and Blackwood (1977) reported difficulty in positively identifying compounds present in feedlot air samples using GC-FID (gas chromatography-flame ionization detector) technology. Low peak values precluded the use of GC-MS for amines.

Measurement of Ammonia Emissions

Ammonia is one of the fixed gases of both aerobic and anaerobic decomposition of organic wastes. Much of the nitrogen excreted by cattle is in the form of urea, which rapidly hydrolyzes to NH_3. Additional NH_3 as well as amine are produced during microbial breakdown of fecal material in confinement buildings, on feedlot surfaces, in stockpiles, and in lagoons or runoff retention ponds. Ammonia evolution rates are a function of time, temperature, pH of the manure surface, and level of biological activity. Ammonia (NH_3) volatilization is probably the most important pathway for on-site loss of nitrogen in animal manure to air and water resources.

Ammonia concentrations can be measured by packed bed chemical-specific syringe tubes that are primarily used in occupational safety and health applications (Sweeten et al., 1991). A second approach is GC/MS as mentioned previously. The third approach -- generally favored by researchers -- is an ammonia absorption trap in which a known volume of air is passed through a weak acid solution (e.g. 0.01N sulfuric acid) inside a beaker (Luebs et al., 1974). Other researchers favor a weak boric acid solution (Moore et al., 1995; O'Halloran, 1995). The absorption of ammonia occurs cumulatively over a sampling period and permits measurement of ammonia concentration which is related to mass emissions and/or concentrations (mass per unit volume of air sample). The dairy or feedlot air may be drawn into a sampling hood or flux chamber. The ammonia-absorption technique allows for comparisons of ammonia concentrations and emission rates between various times and locations (White et al., 1974). A fourth approach, discussed by Oosthoek and Kroodsma (1990) and Phillips et al. (1995), involves use of an ammonia monitor based on the principle of chemoluminescence, in which ammonia and NO_2 are converted to NO at 750°C. In a split airstream at 350°C, the NO_2 is converted to NO. Ammonia concentration is calculated as the difference in NO concentration between the 350° and 750°C airstream.

Electronic Sensors

Mackay-Sim (1992) listed four approaches to electronic volatile gas (odor) detection: metal oxide semi-conductor capacitors; chemically modified field-effect transistors; optical devices; and piezo-electronic quartz crystal devices. These approaches raise the possibility of remote odor monitoring/surveillance networks for individual compounds or odorant mixtures. The piezo-electric crystals are sensitive to changes in surface mass caused by interaction with gaseous molecules. As mass is added to the surface, the resonant frequency decreases. The sensor surface can be designed to respond to single chemicals or groups of chemicals. Research involves testing the response to different types of crystals and coatings to 8 odorants over a 200-second test period. Ammonia requires a single crystal, but pyridine, a more complex odorant, requires multiple sensors with overlapping sensitivity.

Watts (1992) discussed the use of a Cosmos Model XP-329 Portable Odor Level Indicator (New Cosmos Electric Co., 1988), a hand-held instrument that consists of a sampling pump, an odor detection transducer, electronic circuitry, and a digital LCD display. This electronic odor level indicator detects odor molecules using a high sensitivity metal oxide (SnO_2, ZnO) thermal semiconductor sensor maintained at a temperature of 300 to 450°C by a current flowing in a coil of platinum wire. As odor molecules in a pumped air stream are deposited on the surface of the metal oxide, the thermal conductivity of the semiconductor increases and the resistance decreases. These changes are interpreted electronically in reference to a base value set from an "odor free" environment. Matthewson (1992) and Watts (1992) reported that two Cosmos electronic odor meters responded consistently to pure 1-butanol and to ammonia, but responded erratically to feedlot odor in Australia.

Berckmans et al. (1992) in Belgium developed a thick film semiconducting metal oxide sensor for monitoring ammonia concentrations within, and emissions from, livestock confinement buildings. Using conventional screen printing technology, a patterned multi-layer structure consisting of a heater element, a contact layer, a dielectric layer and a gas sensitive semiconductive metal oxide layer was placed on a 96% alumina substrate. The ammonia sensor was placed in the exhaust chimney of a swine confinement building equipped with a mechanical ventilation system (Berckmans et al., 1992). The output signal of the ammonia sensor was recorded in the form of voltage. The sensor covered the range of 0 to 150 ppm ammonia in dry air at a sensor surface temperature of 450°C. In field tests, the output of the ammonia sensor responded to ammonia concentrations but there were also interferences from relative humidity and perhaps other gases.

MEASURED AMMONIA EMISSIONS FROM CATTLE FEEDLOTS AND DAIRIES

Measurements of the amount of nitrogen in feedlot manure and dairies lost as gaseous ammonia and amines have been limited in the U.S. Estimates of nitrogen load due to ammonia volatilization have been as high as 50-75% from open lots (Cole and Parker, 1999). Ammonia losses from feedlot surfaces have been estimated to be as high as 50 % of feed N content (Bierman, 1995). Reportedly volatilized ammonia can react with nitrogen oxides from combustion sources and contribute to atmospheric particulates (Seinfeld, 1975). Ammonia emissions are also important both for their contribution to odor and as a potential water pollutant since atmospheric ammonia can be absorbed in rainfall or in nearby surface waters (Peters and Blackwood, 1977).

Ammonia is considered a precursor to $PM_{2.5}$ (Meng et al., 1997) where gaseous nitrate compounds (HNO_3) is also present to form a solid-phase ammonium nitrate particulate (NH_4NO_3). Factors affecting this reaction include temperature, humidity, ozone, and other gases.

Ammonia from Cattle Feedlots

Hutchinson et al. (1982) measured feedlot ammonia and amine emissions at a cattle feedlot near Greeley, Colorado with a capacity of 120,000 head. Stocking density was 12 m^2/hd (128 ft^2/hd). Vertical ammonia and amine flux densities were measured at 8 sampling heights of 1.5 to 8.8 m (5 to 29 feet) above the cattle feedlot surface. This approach imposed no artificial conditions upon the area under study, and it provided a flux value that was integrated over a large feedlot area with a wind fetch of over 1,000 m (0.62 miles) without obstruction except for cattle and fences.

Ammonia and aliphatic amine concentrations in the atmosphere above the feedlot were sampled at each of the sampling heights by drawing air at 1 L/min through bubblers containing 15 mL of 0.01 N sulfuric acid (Hutchinson et al., 1982). The bubblers removed more than 99% of the nitrogen compounds in feedlot air samples. Sampling was done during mid-afternoon in most cases. Micrometeorological conditions of the feedlot were also measured. The identities and concentrations of ammonia and amines were confirmed by GC analysis.

Hutchinson et al. (1982) found that atmospheric ammonia emissions at the fence rail (5 feet height) were 2 or 3 orders of magnitude higher than normal ambient ammonia level in that part of Colorado (1-4 μg NH_3-N/m^3). Ammonia levels on 13 sampling dates averaged 520 $\pm$ 309 $\mu g/m^3$. However, on 10 relatively dry days with normal dispersion conditions, concentrations were 361 $\pm$ 46 μg NH_3-N/m^3. The two highest ammonia concentrations (980 and 1,200 $\mu g/m^3$) occurred on days when the feedlot was drying out after significant precipitation, and the third highest concentration (970 $\mu g/m^3$) occurred under atmospheric inversion conditions.

Concentrations of methylamine (MA) and trimethylamine (TMA) in feedlot air (1.5 m) on 9 sampling dates averaged 0.64 $\pm$ 0.92 μg N/m^3 and 5.5 $\pm$ 5.0 μg N/m^3, respectively (Hutchinson et al., 1982). MA and TMA were the only amines that occurred in measurable quantities on all sampling days. However, dimethyl, iso-propyl, n-butyl, and pentyl-amines were also detected on at least two days, in maximum concentrations of 0.91, 2.3, 0.02 and 2.8 μgN/m^3, respectively. Compared to odor thresholds reported by Leonardos et al. (1969), only TMA (threshold of 0.13 μgN/m^3) should have been detectable to humans at the monitoring site.

Hutchinson et al. (1982) found that the vertical flux density of NH_3-N during daytime hours ranged from 0.64 to 2.37 kg N/ha/hr and averaged 1.4 $\pm$ 0.7 kg N/ha/hour on 5 sampling dates. Lower ammonia fluxes were found when the feedlot surface was wet but were increased as the surface dried. Hutchinson et al. (1982) speculated that a relatively constant rate of NH_3-N evolution occurs from the urea -N fraction being deposited by cattle which is almost immediately hydrolyzed to ammonia. Precipitation decreases urea-derived ammonia emissions but stimulates additional ammonia production from fecal protein catabolism, building up a reservoir of ammonia that is released as the surface dries. The mean vertical flux density for ammonia was half the calculated rate of N deposition in urine, or about one fourth the rate of total N deposition on the feedlot surface.

The flux density of all amine compounds was less than 1 percent of the ammonia-N flux density (Hutchinson et al., 1982). The flux density of TMA exceeded the sum of all other amines averaging 6 g N/ha/hr (maximum value of 7.3 g N/ha/hr).

Another study of feedlot ammonia emissions was conducted near Blackfoot, Idaho at a cattle feedlot of 24,000 head capacity (Miner and Stroh, 1976). The objectives of this study were: to determine the level of ammonia evolution from an untreated feedlot surface; to study the effect on odor and ammonia evolution from various feedlot surface treatments consisting of odor control chemicals; to determine the dilution of ammonia at positions downwind from the feedlot; and to determine the effectiveness of water spray curtains in scrubbing out ammonia odor.

Ammonia evolution rate, odor intensity, absorption rate, hydrogen sulfide concentration, particulate matter concentration, and ammonia concentration were measured to evaluate odor and determine the effectiveness of alternate abatement treatments. A sampling box placed in areas representative of the overall lot surface was used to quantify the rate of ammonia release (Miner, 1975A). Replicated measurements were made. Measurements were made on both the experimental lot and an adjacent control lot on the same day. Also, Scentometer (Barnebey-Cheney, 1987) readings of various pen surfaces on representative sampling days were taken to determine odor concentration. Various chemicals were applied to the feedlot surface to reduce the odor.

Miner (1975A) observed that odor concentrations as determined with the Scentometer and ammonia concentrations diminished rapidly with distance downwind of the feedlot. Effective measurements of ammonia concentrations were possible only up to 200 m downwind from the feedlot, because of the low levels of ammonia evolved at the source and dilution from the wind. Ammonia concentrations were reduced by 82 to 96% within 120 m (400 feet) from the corrals.

Of the various chemicals used in this study (Miner and Stroh, 1976), a product identified as AGCO increased the ammonia evolution slightly, and Sanzyme treatment appeared to decrease ammonia evolution after three days. DSS40 which was fed to cattle as a solidifying and odor preventing chemical had negligible effects after 10 days, and negative effects occurred after 14 days, based on ammonia evolution measurements. LSS10 slightly decreased ammonia evolution for two days after treatment. Sodium bentonite was the most effective when spread on pen surfaces, decreasing the ammonia evolution rate approximately 2-3 fold after application.

The data indicated that ammonia evolution from a feedlot surface was closely associated with the temperature of the surface, humidity and moisture conditions (Miner, 1975A). Following a rainy day, the evolution from an initially dry surface nearly tripled. Odors were mostly of low intensity.

Peters and Blackwood (1977) sampled feedlot air within two Texas High Plains cattle feedlots. Ammonia levels were determined using an ammonia trap consisting of fiberglass filters impregnated with sulfuric acid. Feedlot air samples were passed through the sampler for 10 minutes to entrap ammonia. Ammonia was extracted from the filters with sodium hydroxide into an aqueous solution that was analyzed. The results showed that 2.6 and 3.0 μg of ammonia were collected, and the ambient concentration averaged 104 and 120 $\mu g/m^3$ at Feedlots A and B, respectively. Simultaneously, stainless steel sampling tubes with polymer packings were used to sample other gaseous compounds for analysis on the gas chromatograph-flame ionization detector (GS-FID) or gas chromatograph-mass spectrometer (GS-MS) analyzers. This resulted in 5 amine compounds being identified at Feedlot B and one amine compound at Feedlot A. Carboxylic acids were not detected at the lower detection limit of 4 $\mu g/m^3$. Total sulfides measured 5 $\mu g/m^3$ at Feedlot B and 27.5 $\mu g/m^3$ at Feedlot A, together with an identification of n-propyl mercaptan at the latter feedyard. No other sulfide compounds were identified because of low concentrations. Peters and Blackwood (1977) estimated the annual emissions of ammonia, amine compounds and sulfur compounds from beef cattle feedlots in the U.S. (based on 1972 fed cattle marketing figures) at 3,480, 139 and 522 metric tons per year, respectively.

Phillips et al. (1995) reported ammonia emissions of 10 mg/hr per 500 kg liveweight from housed beef cattle with straw bedding in winter and 180-260 mg/hr per 500 kg liveweight from dairy housing conditions. Results were obtained using a chemoluminescent NOx analyzer preceded by a thermal oxidation chamber.

Cole and Parker (1999) used sulfuric acid traps to capture ammonia from air flow chambers (0.25 x 0.30 x 0.15 m) placed on simulated feedlot surfaces to quantify ammonia losses from feedlot surfaces over a 42-day period as a function of chemical additives. Additions of alum (4 to 8 ton/acre), calcium chloride (4 to 8 ton/acre), and a urease inhibitor (N-(n-butyl) thiophosphoric triamide:NBPT) decreased ammonia emissions by 50 to 99% over a 21-day sampling period. Similar procedures have been used to determine ammonia volatilization from poultry litter (Moore et al., 1995) and liquid swine manure (O'Halloran, 1993).

Ammonia from Dairies

Luebs et al. (1974) measured ammonia concentrations at 1.2 m height upwind and downwind of open-lot dairy operations near Chino, California, in which 145,000 dairy cows were concentrated in several farms within a 60 square mile area near Los Angeles. Concentrations of ammonia (distillable nitrogen) were below the odor threshold concentrations reported for ammonia. An ammonia concentration of 540 $\mu g/m^3$ was measured at the downwind corral fence of a 600-cow dairy. This concentration was reduced to 18 $\mu g/m^3$ at a downwind distance of 0.5 miles (0.8 km). By comparison, ammonia concentrations were 92 ± 89 $\mu g/m^3$ at Chino airport near the center of the dairy area and 4 ± 2 $\mu g/m^3$ at a non-agricultural reference site. Diurnal fluctuations were observed in ammonia concentration at the Chino airport with highest concentrations between 1800 and 2200 hours (184 μg/m^3) and 0600 to 1000 hours (128 μg/m^3). Much lower ammonia concentrations occurred in afternoons 1400 to 1800 hours (6 μg/m^3). Fenceline observations at an individual dairy did not coincide with the diurnal pattern at the center of the dairy area.

Pain et al. (1988) used a small wind tunnel (2 m x 0.5 m x 0.45 m) to collect samples of odorous air and to measure ammonia emissions following the surface spreading of liquid dairy cattle manure (1 to 2 day storage time), before and after mechanical separation with a roller press, onto grassland in the United Kingdom. Odor samples were collected beneath the flexible plastic sheet canopy into 50 L Tedlar bags inflated within 4 to 5 minutes time. Odor concentration was measured by 4 to 8 panelists using dynamic olfactometry with 4 to 6 dilutions of each sample presented for determination of the odor threshold (ED_{50}) value. The odor emission rate was calculated as the product of odor units (OU) and the volumetric airflow rate (odor units/m^2/hr). The odor emission rates measured by Pain et al. (1988) for liquid dairy manure spread on pastures were reported by Smith and Watts (1994) at 22 OUm/s and 11 OUm/s at time intervals of 3 and 48 hours, respectively, after spreading. In essence, the odor emission rate was reduced by 50% two days after spreading liquid manure. Similar values were obtained for swine manure slurry. Total odor emissions were similar for whole dairy cattle manure slurry and separated slurry (Pain et al., 1988).

Ammonia volatilized from the slurry was measured (Pain et al., 1988) by drawing air samples from the tunnel inflow and outflow sections through absorption flasks containing orthophosphoric acid (0.005 M). Ammonia losses following application were 23 to 70 percent within 10 to 14 days after application, although 80 percent of these losses occurred within 2 days of application. There was a strong correlation ($r^2 = 0.94$) between odor emissions and ammonia emissions following application of dairy cattle slurry to the grassland pasture. A similar relationship was obtained for swine manure slurry. A greater proportion of ammonia was lost from dairy cattle slurry than from swine slurry.

Keck (1997) determined the influences of manure removal frequency, climatic conditions, and exposed surface area on ammonia emissions from cattle exercise yards and from wind tunnel simulations of 7 m^2 manured surfaces where airflow volume could be determined. Ammonia concentration was determined using HCl absorption. Urine caused more than 8 times greater ammonia emission per unit area than feces (205 mg/m^{2}h vs. 25 mg/m^2/h). Daily removal of manure (feces and urine) produced a small decrease in ammonia emission compared to removal at three-day intervals. Ammonia emissions were greater in warm season than in cold weather. Reducing the surface area of manure decreased the ammonia emission.

Schmidt et al. (1997) conducted field measurements at 5 dairies in Southern California during winter and summer seasons to determine surface emission rates of ammonia and other compounds implicated in contributing to PM 10 emissions. Sampling was conducted using a surface isolation flux chamber (EPA, 1986). Of the compounds studied, ammonia had the highest flux rate. Manure stockpiles that were disturbed produced the highest ammonia flux rate. Amine compounds were not detected above the detection threshold. The average ammonia emissions for 4 dairies was 11.2 ± 4.3 kg/cow/year projected from the late summer/early fall testing period, and was 4.8 ± 1.1 kg/cow/yr projected from the winter testing period.

Oosthoek and Kroodsma (1990) reported monthly ammonia concentrations of 3.0-4.8 mg/m^3 from a 40-cow dairy free-stall housing unit. Monthly ammonia emission rates ranged from 39 to 60 kg/month, or 1 to 1.5 kg/head/month, where cattle were housed at night. A scraped concrete floor had three times the ammonia emission rate of a flushed concrete floor (600 mg/m^2/hr vs. 200 mg/m^2/hr).

CONTROLLING ODOR: DESIGN AND MANAGEMENT APPROACHES

Specific measures have been devised to reduce odor from livestock facilities (Miner, 1974 and 1975B; Barth et al., 1984; ASAE, 1987; Sweeten, 1992). These odor control methods generally fall under three broad approaches (Sweeten et al., 1991): manure treatment, capture and treatment of odorous gases, and enhanced dispersion.

Manure Treatment Approaches to Odor Control

Manure treatment methods for odor control include maintaining aerobic conditions during storage, aerobic treatment (aerated lagoons or composting), anaerobic digestion or biochemical treatment. Oosthoek and Kroodsma (1990) noted a three-fold reduction in ammonia emission rate by flushing the concrete floor in a free stall dairy barn, with minimal ammonia reduction from scraping the concrete floor.

For open lot surfaces, rapid drying is the key to odor control. The same should be true for reducing ammonia emissions on a mass basis. Frequent, uniform removal of surface manure and excellent drainage in which manure is regularly harvested leaving a smooth, uniformly sloped pen surface with interfacial layer intact to maintain surface-sealing are also beneficial.

Wet manure on a feedlot or dairy lot surface can be responsible for the generation of significant odor, in terms of both odor concentration and offensiveness. Watts et al. (1994) determined a 60-fold difference in measured odor concentration (in terms of odor units measured with a dynamic forced-choice triangle olfactometer) between dry and wet feedlot surfaces. Odor generation peaked at 2-3 days after rainfall and at a surface moisture content of 60-67% (w.b.). Therefore, feedlots with wet anaerobic manure accumulation will create odor of greater concentration, offensiveness and duration than a well-drained and well-maintained feedlot. Ration had less effect on odor concentration than moisture content. Odors were highest at mid-day.

A feedlot should be designed and managed to shed water. Pen slope of 3 to 5% away from feedbunks or feeding alleys is needed, with discrete drainage provided for each feed pen into a drainage channel that accelerates runoff away from the feedlot surfaces with minimal solids deposition. Potholes should be backfilled as soon as they develop, and overflows or leaks from cattle watering facilities onto the feedlot surface should be avoided. Proper stocking density in pens can ensure that moisture excretion by cattle plus rainfall does not exceed average evaporation in winter as well as summer months.

Several studies have investigated the use of chemical amendments to decrease ammonia emissions from animal manures. Alum additions have been shown to decrease ammonia emissions from poultry litter (Moore, et al., 1995) and beef cattle manure (Cole and Parker, 1999). Similarly, urease inhibitors have been shown to decrease ammonia emissions from beef cattle manures (Varel, et al., 1999; Cole and Parker, 1999). However, the effects of these compounds on emissions of other potentially odorous compounds have not been thoroughly studied.

A laboratory study was conducted to evaluate soil amendments for reducing ammonia emissions from open-lot beef cattle feedyards (Shi et al., 1999). A mixture of 1,550 g of soil, 133 g of manure, and 267 g of urine was placed into plastic containers (20 cm X 20 cm X 12 cm depth). Treatments with four replicates consisted of a blank (soil with no manure), control (mixture with no amendment), 4,500 kg/ha $Al_2(SO_4)_3$ (alum), 9,000 kg/ha alum, 375 kg/ha commercial product (CP), 750 kg/ha CP, 4,500 kg/ha $CaCl_2$, 9,000 kg/ha $CaCl_2$, 9,000 kg/ha brown humates, 9,000 kg/ha black humates, 1 kg/ha of the urease inhibitor N- (n-butyl) thiophosphoric triamide (NBPT), and 2 kg/ha NBPT. Ammonia emissions in air passed over the soil treatments were monitored daily using a hydrochloric acid trap following application of the amendments. Cumulative ammonia emissions after 21 days, expressed as a percentage of the control were: 0.4% for the blank, 8.5% for 4,500 kg/ha alum, 1.7% for 9,000 kg/ha alum, 73.6% for 400 kg/ha CP, 68.2% for 750 kg/ha CP, 28.8% for 4,500 kg/ha $CaCl_2$, 22.5% for 9,000 kg/ha $CaCl_2$, 32.4% for 9,000 kg/ha brown humates, 39.8% for 9,000 kg/ha black humates, 35.9% for 1 kg/ha NBPT, and 34.4% for 2 kg/ha NBPT. Results of these experiments suggest that ammonia emissions from open feedlots can be reduced using chemical additives. Cost-effectiveness and environmental impacts from the amendments will need to be evaluated before use in a commercial feedyard setting.

Capture and treatment of odorous gases

This approach includes the use of covered storage pits or lagoons; soil incorporation of applied liquid or solid manure; and dry scrubbers for building exhaust gases, including soil absorption beds, bio-filter fields, or packed beds. Kelly (1995) listed 10 technologies for controlling odor from mechanically ventilated confinement buildings (cattle, swine, or poultry) or composting facilities.

Soils and organic materials such as peat or wood chips readily absorb odorous gases and provide for aerobic decomposition of captured odorants. Sweeten et al. (1991) found that ammonia concentrations in exhaust air at 65-192 ppm NH_3 from a poultry manure composting operation were reduced by 97-99% in air at 76 mm above a 230-250 mm deep fine gravel/sand biofilter field. Soil injection or disking manure into the soil after application reduced odor concentrations by 90 to 99% as compared to surface spreading (Lindvall et al., 1974). Safley and Westerman (1990) demonstrated the use of a floating flexible membrane cover to capture and collect biogas (including odorants) produced from a primary treatment lagoon for a 150 cow free-stall dairy to fuel an internal combustion engine and electric generator.

Enhanced Dispersion of Odor

Sound site selection with adequate separation distance and, if necessary, elevated sources or mechanical turbulence will help achieve odor dispersion and avoid nuisance conditions. Odorants may be transformed between the source and the receptor, and this includes interactions with other odorous gases or particulates (Peters and Blackwood, 1977). Ammonia and hydrogen sulfide are highly reactive, have relatively high odor thresholds and low molecular weights and disperse rapidly (i.e. low persistence factor) (Summer, 1971).

Sound site selection is the simplest and cheapest odor control strategy (Kelly, 1995) that protects investments in new concentrated animal feeding operations and surrounding real estate and avoids exorbitant expense of legal actions involving odor nuisance. To achieve good dispersion, operators should choose a remote site relative to neighbors; gently sloped topography without confining valley walls; and low probability of wind direction toward nearby neighbors, coupled with stable atmospheric conditions that retard dispersion.

Development and use of emerging technology for modeling of odor dispersion requires knowledge of emission rates (i.e., concentration times airflow rate) as a surrogate for mass emission rate (Smith and Watts, 1994; McFarland, 1995). For instance, Smith and Watts (1994) used dynamic forced-choice triangle olfactometer measurement to calculate odor emission rates ranging from 5 OUm/s for a dry feedlot pad to over 500 OUm/s for a wet feedlot pad, and these data were used to model dispersion. Modeling will be used in the future to predict odor impacts on surrounding land users more accurately in advance, before projects (agricultural or non-agricultural) are actually built. However, much more research is needed before accurate odor models are developed, calibrated, and utilized with accuracy. The non-linear/non-additive nature of odor emissions from contributing sources makes it difficult to predict odor emission rates from complex sources, such as feedlots and dairies (Kelly, 1995).

REFERENCES

1. ASAE. 1987. Control of Manure Odors. ASAE EP-379. Agricultural Engineers Yearbook of Standards. American Society of Agricultural Engineers. St. Joseph, MI. pp. 405-406.
2. Barnebey-Cheney. 1987. Scentometer: An Instrument for Field Odor Measurement. Bulletin T-748, Barnebey-Cheney Activated Carbon and Air Purification Equipment Co., Columbus, Ohio. January. 3p.
3. Barth, C.L., L.F. Elliot, and S.W. Melvin. 1984. Using Odor Control Technology to Support Animal Agriculture. Transactions of the ASAE, 27 (3): 859-864.
4. Berckmans, D., J.Q. Ni, J. Roggen, G. Huyberechts. 1992. Testing an Ammonia Sensor for Livestock Buildings. Paper No. 92-4522, Presented at the International Winter Meeting of the American Society of Agricultural Engineers, Nashville, Tennessee. December 15-17. 21 p.
5. Bierman, S.J. 1995. Nutritional Effects on Waste Management. M. S. Thesis, University of Nebraska, Lincoln, Nebraska.
6. Bilbrey, D., G. Boggs, and D. Krupnick. 1997. Cattle Feeding Capital of the World: 1997 Fed Cattle Survey. Southwestern Public Service Company, Amarillo, Texas. 6p.
7. Bulley, N.R. and D. Phillips. 1980. Sensory Evaluation of Agricultural Odors: A Critical Review. Canadian Agricultural Engineering, 22(2):107-112.

8. Burnett, W.E. 1969. Qualitative Determination of the Odor Quality of Chicken Manure. In: Odors, Gases and Particulate Matter from High Density Poultry Management Systems as They Relate to Air Pollution Final Report, Department of Agricultural Engineering, Cornell University. Contract No. C-1101. pp. 2-17.
9. Cole, N.A. and D.B. Parker. 1999. Personal Communication. USDA-Agricultural Research Service, Bushland, Texas and West Texas A&M University, Canyon, Texas.
10. Eaton, D.L. 1996. Swine Waste Odor Compounds. Pioneer Hi-Bred International, Livestock Environmental Systems, Des Moines, Iowa. 14p.
11. Elliot, L.F., J.W. Doran, and T.A. Travis. 1978. A Review of Analytical Methods for Detecting and Measuring Malodors from Animal Wastes. Transactions of the ASAE, 21(1):130-135.
12. EPA. 1986. Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber, Users Guide. U. S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.
13. Hammond, E.G. and R.J. Smith. 1981. Survey of Some Molecularly Dispersed Odorous Constituents in Swine-House Air. Iowa State Journal of Research, 55(4): 393-346.
14. Hammond, E.G., P. Kuczala, G.A. Junk, and J. Kozel. 1974. Constituents of Swine House Odors. In: Livestock Environment, Proceedings of the International Livestock Environment Symposium, American Society of Agricultural Engineers, St. Joseph, MI. April 17-19. P. 364-372.
15. Hutchinson, G.L., A.R. Mosier, and C.E. Andre. 1982. Ammonia and Amine Emissions from a Large Cattle Feedlot. Journal of Environmental Quality, 11(2): 288-293.
16. Jones, M. 1992. Odour Measurement Using Dynamic Olfactometry. In: Odour Update 92: Proceedings of a Workshop on Agricultural Odors. MRC Report No. DAQ 64/24, Department of Primary Industries, Toowoomba, QLD. April. pp. 17-32.
17. Keck, M. 1997. Ammonia Emission and Odour Thresholds of Cattle Houses with Exercise Yards. In: Proceeding, Ammonia and Odour Control from Animal Production Facilities, International Symposium, Vinkelord, The Netherlands, 6-10 October.
18. Leonardos, G., D. Kendall, and N. Barnard. 1969. Odor Threshold Determinations of 53 Odorant Chemicals, Journal of Air Pollution Control Association. 19(2):91-95.
19. Lindvall, T., O. Noren, and L. Thyrelius. 1974. Odor Reduction for Liquid Manure Systems. Transactions of the ASAE. 17(3):508-512.
20. Luebs, R.E., K.R. Davis, and A.E. Laag. 1974. Diurnal Fluctuation and Movement of Atmospheric Ammonia and Related Gases from Dairies. Journal of Environmental Quality, 3(3): 265-269.
21. Mackay-Sim, A. 1992. Electronic Odour Detection-Problems and Possibilities. In: Odour Update '92: Proceedings of a Workshop on Agricultural Odours. MRC Report No. DAQ 64/24, Department of Primary Industries, Toowoomba, QLD. April. pp. 57-61.

22. Matthewson, M.D. 1992. Odour Time Series. Thesis, School of Engineering, University of Southern Queensland, Toowoomba, Queensland, Australia. November. 81 p.
23. McFarland, A.M.S. 1995. Dispersion Modeling of Odor Transport from Open Lot Dairies. In: Proceedings, Odors: Indoor and Environmental Air, Air Waste Management Association Conference, Bloomington, MN. 13p.
24. McFarland, A.M.S. and J.M. Sweeten. 1995. Odor Measurement: Applications to Livestock Feeding Facilities. In: Innovations and New Horizons in Livestock and Poultry Manure Management. Texas A&M University System. pp 149-159.
25. Meng, Z., D. Dabdub and J.H. Seinfeld. 1997. Chemical Coupling Between Atmospheric Ozone and Particulate Matter. Science. 227 (July):116-119.
26. Miner, J.R. and L.A. Licht. 1981. Fabric Swatches as an Aid in Livestock Odor Evaluations. Livestock Waste: A Renewable Resource. Proceedings of the 1980 International Symposium on Animal Waste, American Society of Agricultural Engineers, St. Joseph, MI. pp 302-305.
27. Miner, J.R. 1974. Odors from Confined Livestock Production. EPA660/2-74-023. U.S. EPA, Washington, D.C., 124 p.
28. Miner, J.R. 1975A. Evaluation of Alternative Approaches to Control of Odors from Animal Feedlots. Idaho Research Foundation, Moscow, Idaho.
29. Miner, J.R. 1975B. Management of Odors Associated with Livestock Production. In: Managing Livestock Wastes, Proceedings of Third International Symposium on Livestock Wastes. American Society of Agricultural Engineers. St. Joseph, MI. pp. 378-380.
30. Miner, J.R., and R.C. Stroh. 1976. Controlling Feedlot Surface Odor Emission Rates by Application of Commercial Products. Transactions of the ASAE, 19(3):533-538.
31. Moore, P.A., T.C. Daniel, D.R. Edwards, and D.M. Miller. 1995. Effect of Chemical Amendments on Ammonia Volatilization from Poultry Litter. J. of Environmental Quality. 24:293-300.
32. National Research Council. 1979. Odors from Stationary and Mobile Sources. National Academy of Sciences, Washington, D.C. 491 p.
33. New Cosmos Electric Co. 1988. Operators Manual, Portable Odor Level Indicator XP-329. New Cosmos Electric Co., Ltd, Tokyo, Japan. 12 p.
34. O'Halloran, I.P. 1993. Ammonia volatilization from liquid hog manure: Influence of Aeration and Trapping Systems. Soil Science Society of America. 47: 1300-1303.
35. Oosthoek, J. and W. Kroodsma. 1990. Ammonia Emission Reduction from Cowsheds. In: Agricultural and Food Processing Waste (Proceedings of the 6th International Symposium on Agricultural and Food Processing Wastes). American Society of Agricultural Engineers. pp. 442-448.
36. Pain, B.F., Y.J. Rees, and D.R. Lockyer. 1988. Odour and Ammonia Emission Following the Application of Pig or Cattle Slurry to Land. In: Volatile Emissions from Livestock Farming and Sewage Operations. (V.C. Nielsen, J.H. Voorburg, and P.L. Hermite, Eds.). Elsevier Applied Science, London and New York. pp. 2-11.

37. Peters, J.A. and T.R. Blackwood. 1977. Source Assessment: Beef Cattle Feedlots. EPA-600/2-77-107, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. June. 10 p.
38. Phillips, V.R., M.R. Holden, R.P. White, R.W. Sneath, T.G.M. Demmers, and C.M. Wathes. 1995. Measuring and Reducing Gaseous and Particulate Air Emissions from U.K. Livestock Buildings. In: Proceedings, 7th International Symposium on Agricultural and Food Processing Wastes (C.C. Ross, ed.), American Society of Agricultural Engineers, St. Joseph Michigan. pp. 241-251.
39. Safley, L.M. and P.W. Westerman. 1990. Psychrophilic Anaerobic Digestion of Dairy Cattle Manure. In: Agricultural and Food Processing Wastes. Proceedings of the 6th International Symposium on Agricultural and Food Processing Wastes, American Society of Agricultural Engineers, St. Joseph, MI. pp. 250-258.
40. Schmidt, C.E., J. Lester, and E. Winegar. 1997. Assessment of PM10 Precursor Air Emissions from Dairy Industry Livestock Waste in Southern California. Journal of Air and Waste Management Association. In review.
41. Seinfeld, J.H. 1975. Air Pollution. McGraw-Hill Book Company. pp. 73-75.
42. Shi, Y., D.B. Parker, N.A. Cole, B.W. Auvermann, L.W. Greene. 1999. Soil Amendments for Minimizing Ammonia Emissions from Feedyard Surfaces. Paper No. 99-4083, presented at 1999 ASAE/CSAE Annual International Meeting, Toronto, Ontario, Canada. July 18-21. 8p.
43. Smith, R.J. and P.J. Watts. 1994. Determination of Odor Emission Rates from Cattle Feedlots: Part 1, A Review. Journal of Agricultural Engineering Research 57:145-155.
44. Summer, W. 1971. Odor Pollution of Air - Causes and Control. the Chemical Rubber Company Press, Cleveland, Ohio. 310p.
45. Sweeten, J.M. 1990. Cattle Feedlot Waste Management Practices for Water and Air Pollution control. Texas Agricultural Extension Service, Texas A&M University System. B-1671, 24pp.
46. Sweeten, J.M. 1992. Livestock Feedlots. Chapter 13 -- Food and Agricultural Industry. In: Air Pollution Engineering Manual (A.J. Buonicore and W.T. Davis, eds.). Van Nostrand Reinhold, New York. pp. 542-548.
47. Sweeten, J.M., R.C. Childers, J.S. Cochran, and R. Bowler. 1991. Odor Control from Poultry Manure Comporting Plant Using a Soil Filter. Applied Engineering in Agriculture, 7(4): 439-449.
48. Sweeten, J.M. 1995. Odor Measurement Technology and Applications: A State of the Art Review. In: Proceedings of the International Symposium on Agricultural and Food Processing Wastes, Chicago, Illinois, ASAE-The Society for Engineering in Agricultural, Food, and Biological Systems. pp 214-229.
49. Sweeten, J.M. and M.L. Wolfe. 1994. Manure and Wastewater Management Systems for Open Lot Dairy Operations. Transactions of the ASAE. 37(4):1145-1154.
50. Varel, V.H., J.A. Nienaber and H.C. Freetly. 1999. Conservation of Nitrogen in Cattle Feedlot Waste with Urease Inhibitors. J. Anim. Sci. 77:1162-1168.

51. Watts, P.J. 1991. The Measurement of Odours: A Discussion Paper for Australia. AMLRDC Report No. DAQ. 64/5. Feedlot Services Group, Queensland Department of Primary Industries, Toowoomba, QLD. 40 p.
52. Watts, P.J. 1992. Odour Measurement at a Queensland Feedlot. In: Odour Update 92: Proceedings of a Workshop on Agricultural Odours. MRC Report DAQ 64/24, Department of Primary Industries, Toowoomba, QLD. pp. 71-91.
53. Watts, P.J., M. Jones, S.C. Lott, R.W. Tucker, and R.J. Smith. 1994. Feedlot Odor Emissions Following Heavy Rainfall. Transactions of the ASAE. 37(2):629-636.
54. White, R.K., E.P. Taiganides, and C.D. Cole. 1971. Chromatographic Identification of Malodors from Dairy Animal Waste. pp. 110-113. In: Proceedings, Livestock Waste Management and Pollution Abatement. American Society of Agricultural Engineers, St. Joseph, Michigan 49085. ASAE Publication PROC-271.
55. White, R.K., C.L. Barth, D.C. Ludington, and J.R. Miner. 1974. Sampling and Analysis of Gases/Odors. Paper No. 74-4544, American Society of Agricultural Engineers, St. Joseph, Michigan. 19p.
56. Wright, G.D. 1994. Air Sampling Methods for Gaseous Pollutants. In (Wright, G.D., ed.) Fundamental of Air Sampling. Lewis Publ. Ann Arbor, MI. pp 99-110.
57. Zahn, J.A., J.L. Hatfield, Y.S. Do, A.A. DiSpirito, D.A. Laird and R.L. Pfeiffer. 1997. Characterization of Volatile Organic Emissions and Wastes from a Swine Production Facility. J. Environ. Quality. 26:1687-1696.
58. Zhang, Z., M.J. Yang and J. Pawliszyn. 1994. Solid-Phase Microextraction. Anal. Chem. 66:844A-853A.