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Abstract

Methods for measuring concentrations and emission rates of particulate matter (PM) from mechanically ventilated livestock buildings were evaluated in a laboratory facility and in a swine-finishing barn. Concentrations of PM were measured inside the room (room sampling) and at the exhaust duct (exhaust sampling). Concentrations at the exhaust duct were determined using high-volume traverse downstream of the exhaust fan, low-volume traverse downstream of the fan, and fixed sampling upstream and downstream of the fan. The traverse methods, which served as the reference, were conducted under isokinetic conditions; fixed sampling was done under both isokinetic and sub-isokinetic conditions. Compared to the traverse method, both room sampling and exhaust sampling under subisokinetic conditions overestimated PM concentrations. Fixed sampling under isokinetic conditions, on the other hand, did not differ significantly ($P>0.05$) from the high-volume traverse method. Thus, isokinetic fixed sampling can be an alternative to the more expensive and time-consuming high-volume PM traverse method to measure PM concentrations and emission rates at the exhaust.; Swine Day, Manhattan, KS, November 14, 2002

Keywords

Swine day, 2002; Kansas Agricultural Experiment Station contribution; no. 03-120-S; Report of progress (Kansas State University. Agricultural Experiment Station and Cooperative Extension Service); 897; Swine; Air quality; Dust; Emission; Measurement

MEASURING EMISSION RATES OF PARTICULATE MATTER FROM FAN VENTILATED SWINE BARNS [1]

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Summary

Methods for measuring concentrations and emission rates of particulate matter (PM) from mechanically ventilated livestock buildings were evaluated in a laboratory facility and in a swine-finishing barn. Concentrations of PM were measured inside the room (room sampling) and at the exhaust duct (exhaust sampling). Concentrations at the exhaust duct were determined using high-volume traverse downstream of the exhaust fan, low-volume traverse downstream of the fan, and fixed sampling upstream and downstream of the fan. The traverse methods, which served as the reference, were conducted under isokinetic conditions; fixed sampling was done under both isokinetic and sub-isokinetic conditions. Compared to the traverse method, both room sampling and exhaust sampling under sub-isokinetic conditions overestimated PM concentrations. Fixed sampling under isokinetic conditions, on the other hand, did not differ significantly (P>0.05) from the high-volume traverse method. Thus, isokinetic fixed sampling can be an alternative to the more expensive and time-consuming high-volume PM traverse method to measure PM concentrations and emission rates at the exhaust.

(Key Words: Air Quality, Dust, Emission, Measurement.)

Introduction

Emissions of particulate matter (PM), odors, and gases from animal production systems are rapidly becoming an important concern for livestock producers. Numerous complaints of adverse effects on the quality of life of residents in communities near large animal facilities have been reported. Measurement of emission rates of specific airborne pollutants from animal buildings is an important step towards developing a thorough understanding of the issues and in finding cost-effective solutions.

Previous studies have used different methods of determining air pollutant emission rates from livestock buildings. Most methods were based on the product of the air pollutant concentration at the exhaust and the ventilation rate. However, the sampling locations for measuring pollutant concentration varied. Some studies sampled inside the exhaust duct while others measured concentrations at a distance upstream of the duct. Still others measured outside the building in the discharge plume of the exhaust fans. Methods for measuring the ventilation rate also varied. Some studies used fan-wheel anemometers, others used tracer gases, while some relied on the performance curves of the ventilation fans. This wide variability in emission measurement

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protocols precludes meaningful comparison of results from various studies and hinders the compilation of an emission inventory, from which a reliable emission factor can be derived.

This study was conducted to develop and evaluate simple methods for measuring PM emission rates from livestock buildings. Specifically, different techniques for measuring the emission rates from mechanically ventilated swine buildings were compared. The influence of isokineticity and sampling location on the measured emission rate was investigated in an in-house laboratory facility and in an actual swine barn.

Procedures

Laboratory experiments. Three air sampling methods were investigated in a test chamber (Figure 1), which was 12 ft long, 8 ft high, and 24 ft wide. The chamber had a PM generation system that has been used in previous air quality studies. A variable speed fan (diameter = 24 in.) provided the desired airflow rate, which ranged from 3800 to 4200 ft^3/min. Outside air entered through a sidewall inlet (11 × 47-in. opening) with a baffle at an angle of 45°. The fan had a fiberglass housing typical of ventilation exhaust fans in swine buildings. A 74-in.-long round extension duct (25-in. diameter) was added at the exhaust side of the fan. The downstream sampling plane for the fixed samplers was 48 in. from the fan while the PM traverse was at a plane 56 in. from the fan. The upstream sampling plane was located 22 in. before the fan, which was approximately 3.5 in. upstream of the wall plane.

Particulate matter sampling methods. Three air sampling methods were considered: low-volume PM traverse under isokinetic conditions, fixed sampling at specific locations within the duct cross-section, and high-volume PM traverse under isokinetic conditions. The low-volume PM traverse used a sampling head with 0.55-in. probe inlet diameter and a 1.46-in. filter assembly. The sampling head was attached to a flowmeter with a flow control mechanism and a vacuum pump. During sampling, the sampling head was positioned at selected locations (Fig. 1) within the sampling plane, facing the airstream. At each location, the sampling flow rate was adjusted to achieve isokinetic condition and the sampler was operated for 4.0 min before moving to the next location. Isokinetic condition was achieved by varying the air sampling flow rate to match the air velocity at the inlet plane of the sampler with the airstream velocity outside the sampler. The required sampling flow rates for isokinetic sampling were determined by conducting an air velocity traverse at the sampling plane prior to PM sampling.

The fixed sampling method used 0.55-in. samplers and IOM samplers. The 0.55-in. sampler was similar to that in the low-volume traverse method while the IOM sampler was an inhalable PM sampler operated under either isokinetic condition or at the recommended flow rate of 0.071 ft^3/min (sub-isokinetic sampling for this study). An air velocity traverse was also conducted prior to sampling to determine the required isokinetic sampling flow rate.

The high-volume sampler, which was considered as the reference sampler for this study, was assembled based on specifications in test methods for high-volume sampling for low concentrations of PM from stationary sources (ASTM D4536-95 and US EPA CTM-003). The sampling train consisted of a 2-in. diameter probe, an 8 × 10-in. filter holder, a flow nozzle, and a variable-speed vacuum motor. Similar to the low-volume PM traverse, PM was also extracted isokinetically at specified sampling locations within the sampling plane.

After sampling, the probe and the front part of the filter holder were rinsed with acetone (about 75-100 mL) to collect the PM deposited on the probe and filter holder walls. The acetone was allowed to evaporate and the mass of the residual PM was added to that of the PM collected on the filter. The sampling duration at each traverse point (approximately 3.0 min) was determined from preliminary tests such that the total PM mass collected was at least 100 mg as specified in ASTM D4536-95.

All laboratory tests were replicated three times. For each test, one IOM sampler, operated sub-isokinetically at 0.071 ft^3/min, was installed at an additional upstream sampling location to determine the effect of anisokineticity on the measured PM concentrations.

All collection filters were type AE, binder-free glass fiber filters. Filters were conditioned in a constant humidity container (77°F, 50% relative humidity) for 24 h prior to weighing both before and after sampling. All filters were weighed in an electronic microbalance with a sensitivity of 0.01 mg.

The air velocity traverse was conducted at the sampling plane using a pitot tube and a micromanometer with an accuracy of ±0.002-in. water guage. The traverse points (Fig. 1) were selected based on the guidelines specified in US EPA Method 1. For a round duct with a diameter of 25 in., the sampling points for a 12-point velocity traverse were located along two perpendicular diametrical lines at distances of 1.1, 3.7, and 7.3 in. from the duct wall.

For each velocity traverse point, the air velocity was calculated from the velocity pressure reading obtained from the pitot tube. The isokinetic sampling flow rate for each point was calculated as the product of the velocity and the area of the inlet opening of the sampler. The ambient air conditions were monitored with a psychrometer to determine the air density. The ambient air temperature during the laboratory tests ranged from 77 to 82°F, with relative humidity between 19 and 46%.

The average air velocity at the traverse plane was calculated from the velocity pressure readings from all traverse points. The fan ventilation rate was calculated as the product of the average air velocity and the cross-sectional area of the duct.

Field test. The 0.55-in. samplers and the high-volume traverse method were used to measure the PM emission rate from a swine-finishing barn. The barn was 112 ft long, 40 ft wide, and 8 ft high, with 80 pens arranged in four rows over fully-slatted floors. Each pen (5.3 × 5.3 ft) had a feeder and drinker and held two pigs during the study. Outside air entered through 21 sidewall inlets (21-in. wide each) distributed along the two sidewalls, passed through two underfloor pits running longitudinally under the pens, and exhausted by three 24-in. exhaust fans at one end of the building. The outside air temperature ranged from 37 to 53°F during the study, and only 8 - 10 of the inlets were used with baffle vertical opening adjusted to about 3 to 4 in. The temperature inside the barn ranged from 66 to 76°F. All measurements were done on the minimum ventilation fan.

The same extension duct, downstream sampling locations and sampling procedures used in the laboratory were used in the field tests. The mean airflow rate through the fan was 3900 ft^3/min, ranging from 3600 to 4100 ft^3/min. Preliminary tests indicated that a sampling duration of 12 min at each sampling location was necessary to obtain the required target catch of at least 100 mg from the PM traverse. Two fixed samplers were operated isokinetically with a mean flow rate of 1.79 ft^3/min. Another sampler was ran anisokinetically at a mean flow rate of 0.91 ft^3/min while the required flow rate for isokinetic sampling was 1.66 ft^3/min. The fixed samplers were operated simultaneously with the PM traverse, which lasted for about 150 to 190 min. Duplicate IOM samplers were installed at the center of the barn to monitor the corresponding room PM concentrations during the emission test. These IOM samplers were operated at the recommended flow rate of 0.071 ft^3/min for 4 to 5 hours.

Data analysis. The PM concentration was calculated by dividing the PM collected by the total air volume sampled. The total air volume was obtained from the product of the sampler's average sampling flow rate and the total time that the sampler was operated. The emission rate was the product of the calculated PM concentration and the fan ventilation rate obtained from the velocity traverse. Because the ventilation rate for each test was the same for the methods being compared, only the PM concentrations were used in the analysis. The measured PM concentrations, C_a, were normalized by dividing each with the concentration from the corresponding PM traverse, C_r.

Results and Discussion

Laboratory tests. The mean normalized PM concentrations measured by the different methods in the laboratory and the mean PM concentrations from the PM traverse are summarized in Table 1. Room PM concentrations were considerably higher than the PM concentration at the exhaust (Tests 1-3). The disparity between the room average and exhaust PM concentrations can be due to the imperfect mixing within the room, which would result in spatial variability in PM concentrations. As such, to estimate PM emission rates from mechanically ventilated buildings, sampling should be conducted at the exhaust.

The IOM sampler, when operated at its rated sampling flow rate and under subisokinetic conditions, overestimated PM concentration by more than 2.4 times that of the reference sampler (Tests 1-3). This could be attributed to oversampling of the large airborne particles due to the mismatch in the velocity between the airstream that entered the sampler inlet and the airstream outside the sampler. The unequal velocities would result in the divergence of the airstream approaching the sampler inlet; consequently, large particles that should not have entered the sampler were projected into the sampler due to their momentum.

The upstream and downstream 0.55-in. fixed samplers (Test 3), when operated isokinetically, did not differ significantly ($P>0.05$) in PM concentration. While they underestimated the PM concentrations indicated by the reference method by 12% and 9%, respectively (Test 3), the differences were not significant ($P>0.05$).

Field test. The mean PM concentration at the center of the swine barn was 2.08 mg/m^3 (range of 1.26 to 2.81 mg/m^3). This concentration was significantly ($P<0.05$) higher than the mean concentration measured at the exhaust airstream (1.12 mg/m^3), reinforcing the need to measure the PM concentration at the exhaust when determining PM emission rates.

The mean PM concentrations measured with the high-volume PM traverse and the downstream isokinetic 0.55-in fixed samplers did not differ significantly ($P>0.05$), with only a 3% difference. The PM concentration measured by the anisokinetic 0.55-in. sampler downstream of the fan was significantly ($P<0.05$) higher than that obtained by the reference method.

The PM emission rates from the exhaust fan considered were calculated from the PM concentrations measured by the high-volume traverse method and the airflow rates measured by velocity traverse. The fan PM emission rate had a mean of 7.4 g/h, ranging from 6.9 to 8.3 g/h. Expressing the emission rate based on a livestock unit (500-kg liveweight), the rate ranged from 415 to 733 mg/h per 500 kg, with a mean of 526 mg/h per 500 kg. The total PM emission rate from the swine barn was approximately 1.25 - 1.33 times higher than the fan PM emission rate because of the emissions from the other two exhaust fans. The calculated PM emission rates were comparable to those obtained in similar type of swine buildings in northern Europe in which inhalable PM emission rates ranged from 418 to 895 mg/h per 500 kg with a mean of 612 mg/h per 500 kg

From the observations made in this study, it appears that isokinetic fixed sampling at the exhaust could be an alternative method for accurate measurement of PM emission rates from mechanically ventilated swine buildings. This method is less expensive and easier to implement than the high-volume PM traverse method. This information can be useful in the development of standard protocols for measurement of PM emission rates from mechanically ventilated livestock buildings.

Table 1. Normalized PM Concentrations (mean $C_a/C_r \pm$ SD) Measured Using the Different Methods. Measured PM concentrations (C_a) were normalized using concentration obtained from the reference method (C_r)

Test #	Room (IOM sampler)	Sampling Location				Reference Method Concentration, C_r (mg/m^3)[c]
		Upstream of Exhaust Fan		Downstream of Exhaust Fan		
		Isokinetic[b] (IOM or 0.55-in. sampler)	Anisokinetic (IOM sampler)	Isokinetic (0.55-in. sampler)	Anisokinetic (0.55-in.] sampler)	
Laboratory Tests (3 replicates)						
1	4.78[a] ± 0.63	0.93[a] ± 0.01	2.53[a] ± 0.24	-	-	8.30 ± 1.68
2	2.26 ± 0.87	1.00 ± 0.02	3.85[a] ± 0.45	-	-	7.11 ± 0.32
3	4.20 ± 1.55	0.88 ± 0.06	2.39[a] ± 0.22	0.91 ± 0.04	-	6.00 ± 2.05
Field Test (5 replicates)						
4	1.85[a] ± 0.45	-	-	1.03 ± 0.13	1.37[a] ± 0.30	1.12 ± 0.07

[a]Indicates significant difference ($P<0.05$) with respect to PM traverse.

[b]Tests 1 and 2 used the IOM sampler while Test 3 used the 0.55-in. sampler.

[c]The high-volume PM traverse was the reference method for Tests 1, 3, and 4; the low-volume PM traverse was the reference for Test 2.

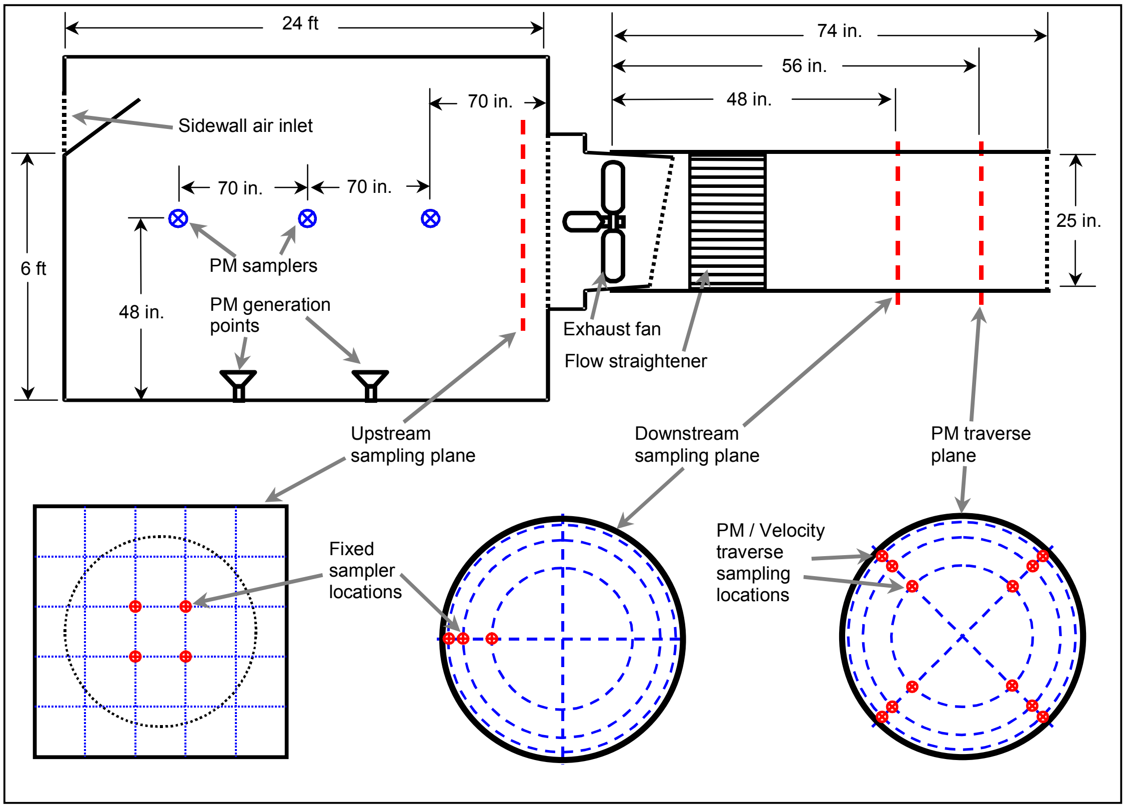

Figure 1. Schematic Diagram of the In-house Laboratory Set-Up Showing the Location of the Sampling Planes and the Sampling Locations Within Each Plane (not drawn to scale).