

Effects of aerosolized class C fly ash in weanling goats

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Objective—To determine effects of repeated aerosol exposures to fly ash dust on respiratory tracts of tent-confined goats.

Animals—12 weanling Boer-Spanish crossbred goats.

Procedure—Goats were randomly assigned to 2 groups: fly ash treatment group (principal goats, $n = 6$) or control group (control goats, 6). Aerosolized fly ash dust was provided during a 4-hour period for each of 6 applications given over 3 months and one 2-hour application prior to necropsy. Fly ash particle diameters ranged from 0.1 to 130 μm and averaged 178 μm , with 1.5% of fly ash particles in the 0.1- to 5- μm -diameter range. A mean \pm SD of 748 \pm 152 g/treatment was delivered inside a tent containing principal goats; control goats were placed inside a similar tent for 4-hour treatments without dust. Following treatment, rectal temperatures were taken at 0, 4, 6, 8, 24, and 72 hours; Hcts were recorded at 0, 24, and 72 hours.

Results—Rectal temperatures were significantly increased at 4, 6, and 8 hours and decreased at 72 hours, compared with 0 hours. Mean \pm SEM Hct values were significantly increased for principal goats (37.47 \pm 0.39%), compared with control goats (36.17 \pm 0.42%). A significant increase in the mean area of gross atelectatic lung lesions (1,410 mm^2) was found in principal goats ($n = 6$), compared with control goats (440 mm^2 ; 5).

Conclusions and Clinical Relevance—An increase in atelectatic lung lesions was observed in principal goats, compared with control goats; however, overall, fly ash dust effects were nontoxic. (*Am J Vet Res* 2005;66:991–995)

The Southern High Plains has most of the large feedyards; this location is semiarid, and rainfall is infrequent. However, when it rains, feedyards become muddy. Fly ash is an inexpensive material that has been used to make semisolid surfaces over the soil of feedyard pens in the High Plains of the United States. Concrete is frequently used as a pad behind the feed bunks and around the waters where cattle gather to eat and drink. This prevents large holes from developing at the feed bunks and waters following rains, cattle movement, and cleaning the pens. Concrete is not used on

the rest of the pens because it is too expensive, and the feet of heavy cattle are more susceptible to injury on concrete,^{1,2} compared with soil.

Fly ash is a dusty material,^{3,4} and when dump trucks and heavy equipment apply the material to the ground, wind frequently creates large plumes of fly ash dust, which can be blown into pens containing cattle and onto feedyard workers. When water is mixed with the fly ash and allowed to harden for several days, little dust comes from the semisolid material, but leaching of heavy metals contained in the hardened fly ash is possible.^{5,6} The objective of this study was to determine the effect of aerosolized class C fly ash repeatedly administered to weanling goats confined in a specially designed tent. The hypothesis was that repeated aerosolized fly ash dust exposure would cause conjunctivitis and gross and histologic lung lesions in the principal goats.

Materials and Methods

Animals—Twelve Boer-Spanish crossbred weanling goats were housed in a 3-sided barn. They were treated for internal helminth^a parasites and coccidia.^b Goats were limited to a commercial pelletized ration (44% grain concentrate, 20% alfalfa hay, 30% cottonseed hulls and meal, 5% molasses, vitamins A and E, and trace minerals) and watered free choice. Goats were acclimated for 3 weeks, then randomly allotted to control (control goats) and treatment (principal goats) groups (6 goats/group), and placed in separate pens that were each 1.9 \times 9.3 m in size. The Regional Animal Care and Use Committee approved the experimental protocol.

Dust—Class C fly ash dust was purchased^c in 22.73-kg bags. The size of the dust particles was measured and quantified by a particle analyzer^d with an optical bench (dual 466-nm blue light-emitting diode and 2-mW 633-nm helium neon laser-light source). The proportion of various sized particles was determined for the fly ash dust, and this analysis was performed in triplicate.

The following process was used to determine the percent solubility of the fly ash. Three fritted-glass vacuum filters^e were fitted with a cyclone prefilter^f and oven heated at 105°C for 24 hours. Prefilters were then each weighed and reinstalled on the fritted-glass vacuum filters. Ten grams of fly ash was added to each filter, and 50 mL of reverse-osmosis water^g was added to the fly ash on each filter. The leaching process was allowed to continue for 30 minutes, and the process was repeated 3 more times (total volume of reverse-osmosis water was 200 mL). The filters with the remaining fly ash were oven dried at 105°C for 24 hours, and each was reweighed. Percent solubility was calculated as a percent loss from initial sample weight.

Administration of aerosolized fly ash dust to goats—On each dust treatment day, goats were moved into a semi-airtight dust tent^h (183 \times 244 \times 213 cm). Briefly, a typical amount of fly ash dust (mean \pm SD, 748 \pm 152 g) was delivered for 4 hours to the inside of the tent by placing it in a hopperⁱ that had an auger in the bottom.⁷ The auger was used

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to move the dust into a funnel that led to a jet mill.^j When the dust exited the jet mill, it was lifted by air through a polyvinyl chloride pipe and out through a set of baffles located on the inside of the tent near the roof. The principal goats were dust treated for 4 hours on each of 6 treatment days spread over 3 months, with a seventh dust treatment of 2 hours duration being applied immediately prior to necropsy. When the principal goats were treated with dust, control goats were placed in a similar tent but no dust was administered.

A 5-stage cyclone device^k (aspirating 28.31 L of air/min) was placed above the goats to determine the amount of fine dust collected over the 4-hour treatment period. Particle sizes collected were as follows: stage 5, 0.32- μ m-diameter particles; stage 4, 0.65- μ m-diameter particles; stage 3, 1.4- μ m-diameter particles; stage 2, 2.1- μ m-diameter particles; and stage 1, 5.4- μ m-diameter particles. The amount of dust collected in each of the 5 chambers was weighed.

Sampling intervals—Rectal temperatures^l were recorded at 0, 4, 6, 8, 24, and 72 hours after dust treatment. At 0, 24, and 72 hours after dust treatment, total WBC counts^m were determined.

Necropsy—Goats were euthanized by an overdose of barbituratesⁿ given IV. Goats were immediately exsanguinated to help clear the blood from the lung tissue, and the esophagus was tied off to prevent spontaneous inhalation of ingesta into the lungs. A board-certified pathologist performed all necropsies. A pathologist, who was not aware of the group status of each goat, performed gross and histologic examinations of the tissues. Tissue samples from all 7 lobes of the lungs were examined from each group of goats. The areas of atelectatic lung lesions were measured with a micrometer.

Statistical analysis—Mean values for measured variables were compared by analysis of variance by use of the general linear models procedure.⁸ Mean values for rectal temperatures and total WBC counts were compared between treatment and control groups throughout the study and within collection periods for specific sample days. Significant differences between mean values for any sample day were determined by use of the Bonferroni and Dunnett adjusted paired *t* test. Values of *P* \leq 0.05 were considered significant.

Results

Fly ash dust—Fly ash particle diameters ranged from 0.1 to 130 μ m and averaged 17.8 μ m in diameter, with 1.5% of the fly ash particles in the 0.1- to 5- μ m-diameter size range, according to the analysis on 3 repeated tests. There was a mean \pm SD volume of 78.87 \pm 17.5 g of fly ash/m³ in the tent during each 4-hour dust treatment.

The cyclone device collected the following mean \pm SD amounts of fine dust per stage: stage 1, 0.4152

\pm 0.155 g; stage 2, 0.1043 \pm 0.03 g; stage 3, 0.1104 \pm 0.029 g; stage 4, 0.0344 \pm 0.009 g; and stage 5, 0.0128 \pm 0.0114 g. The cyclone device collected a mean of 0.6957 g of dust over a typical 4-hour treatment period (*n* = 5; Table 1). The range of dust particle sizes that was collected in the 5 cyclone chambers ranged from 0.32- to 5.2- μ m-diameter particles. This was based on the mean of five 4-hour collections (the sixth collection was destroyed as a result of goat curiosity). The seventh 2-hour collection prior to necropsy was not included in the calculations. The mean percent solubility for the fly ash was 0.86%.

Clinical effects and necropsy results—No signs of panic or distress were observed in the principal goats during the 4-hour dust treatments. Occasionally, some goats would cough during the dust treatment. Coughing seemed to increase for a few hours after the principal goats were removed from the tent and returned to their pen. Their hair was covered with the fine gray fly ash dust. It was expected that conjunctivitis would occur in some principal goats following fly ash treatment, but none was observed.

Rectal temperatures of the control and principal goats were compared. The rectal temperature of goats for the overall model statement was significantly increased at 4, 6, and 8 hours and significantly decreased at 72 hours, compared with 0 hours. The mean rectal temperature of the treatment group was significantly higher than the control goats at 24 and 72 hours following treatment (Figure 1). Total WBC counts of goats for the overall model statement were not significantly changed at 0, 24, and 72 hours (data not shown). However, the total WBC counts of goats for the overall model statement were significantly decreased during the fourth, fifth, and sixth dust events, compared with the first dust event (Figure 2). No significant differences in mean total WBC counts were found between the 2 groups (Figure 3). The mean \pm SEM Hct of goats for the overall model statement was significantly increased for principal goats (37.47 \pm 0.39%), compared with control goats (36.17 \pm 0.42%). The mean Hct for the treatment group was significantly different at 24 hours, compared with 0 hours (Figure 4). A significant increase in the mean area of gross atelectatic lung lesions (1,410 mm²) was found in principal goats (*n* = 6), compared with control goats (440 mm²; 5). One control goat was determined to have had a pneumonic incident prior to being purchased; it had 2,927 mm² of atelectatic lung tissue, which was 727 mm² more atelectasis than that of the 5 other control goats added together. This goat had no

Table 1—Mean amount of aerosolized fly ash dust applied during each 4-hour application period.

No. of dust application	Dust in hopper (g)	Dust in tent (g)	Dust in tent air (g/m ³)	Cyclone stages (grams of dust collected)					Filter
				Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	
1	1,500	1,006	106	0.5593	0.1513	0.1466	0.0452	0.0344	0.0028
2	1,500	852	90	0.2005	0.1024	0.0860	0.0421	0.0451	0.0091
3	1,500	799	84	0.4834	0.1034	0.1349	0.0346	0.0250	0.0011
4	1,500	553	58	0.3059	0.0678	0.0859	0.0204	0.0185	0.0009
5	1,500	659	69	0.5271	0.0968	0.0988	0.0298	0.0191	0.0011
6	1,500	633	67	*	*	*	*	*	*
Mean \pm SD	1,500	750 \pm 167	62.3 \pm 30	0.4152 \pm 0.1549	0.1043 \pm 0.0300	0.1104 \pm 0.0285	0.0344 \pm 0.001	0.0284 \pm 0.0113	0.0030 \pm 0.0035

*Goats chewed vacuum line in half, and data were lost.

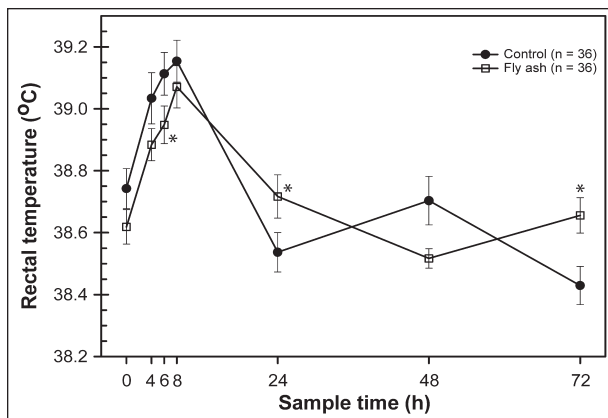


Figure 1—Mean \pm SEM rectal temperatures for aerosolized fly ash-treated goats confined to a tent were compared with non-treated (control) tent-confined goats. *Significantly ($P < 0.05$) different from the control goats.

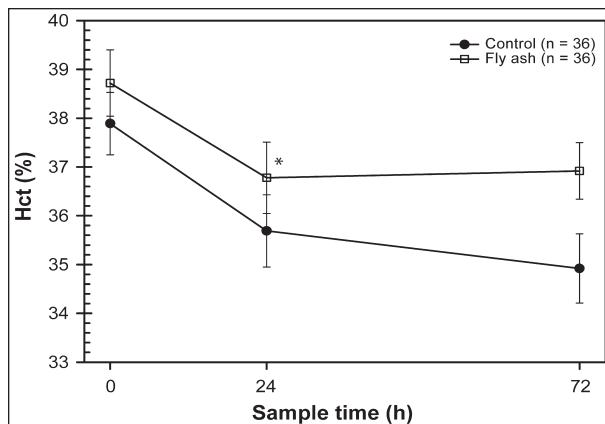


Figure 4—Mean \pm SEM Hct for aerosolized fly ash-treated goats confined to a tent were compared with tent-confined control goats. *Significantly ($P < 0.05$) different from value at 0 hours.

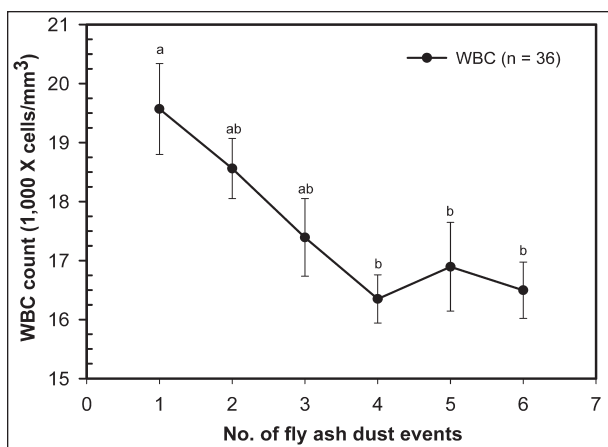


Figure 2—Mean \pm SEM total WBC count versus the fly ash dust event number. Each dot represents an average of WBC counts taken at 0, 24, and 72 hours after treatment for 12 goats. ^{a,b}Mean values with different letters are significantly ($P < 0.05$) different.

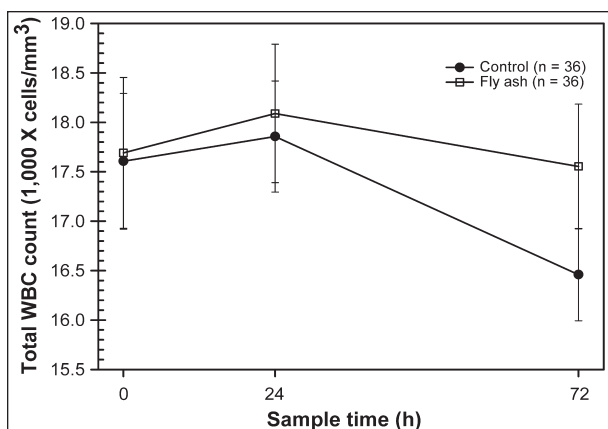


Figure 3—Mean \pm SEM total WBC counts for aerosolized fly ash-treated goats confined to a tent were compared with control (nontreated) goats confined to a tent.

clinical signs of pneumonia after we acquired the goat. However, data from this goat were removed from the lesion analysis. Histologic evaluation of the lung lobes revealed patchy atelectasis in the right cranial and right

middle lobes and the left middle lobe of all 6 principal goats. Microscopic light polarization of lung tissues did not reveal any crystalline materials present in airways or in macrophages.

Discussion

The use of fly ash has a large literature base, but unfortunately, it is about equally divided between its positive and negative attributes. When coal is burned in a power plant, it produces ash. Bottom ash falls to the bottom, and fly ash is carried upward where it is collected.⁹ There are 3 classes of fly ash: C, F, and N.¹⁰ They are identified as artificial (classes C and F) and natural (class N) pozzolans (siliceous or siliceous and aluminous materials).¹¹ Class C ash is normally produced from burning lignite or subbituminous coal, class F is normally produced from burning anthracite or bituminous coal, and class N includes raw or natural pozzolan-like diatomaceous earth, opaline chert, or shale.¹² These types of fly ash are characterized by their chemical and physical specifications.¹³ Fly ash is frequently used to surface feedyard cattle pens, as a road base, as a structural fill, in waste stabilization, as a soil modifier, and as a backfill material.¹¹

The negative attributes of fly ash are as follows: it is a byproduct of coal plants in the western United States that produce 8.766 million metric tons annually and, of this, only 3.831 million metric tons (44%) are used¹¹; and it is a dusty material that has spherical particles small enough to enter the respiratory tract to the alveoli. The respirable fraction has 20% to 40% of particles that are $< 7 \mu\text{m}$ in diameter, and 1% to 7% is quartz (crystalline silica). Repeated inhalation of the dust can cause bronchitis, silicosis, and lung cancer¹⁴; particulate air pollutant residual-oil fly ash can cause airway inflammation and increased susceptibility to infections.³ Toxic constituents of fly ash are considered to be metals, polycyclic aromatic hydrocarbons, and silica¹⁵; fly ash has been incriminated as causing acute lung disease,¹⁶ bronchitis obliterans,¹⁷ alterations in pulmonary immune response,¹⁸ and chronic bronchitis and emphysema in humans.¹⁹

Rodents are frequently used in the study of selected toxic fly ash pollutants, such as residual-oil

fly ash and soluble metals. Most of these studies²⁰⁻²³ challenge expose rodents by intratracheal instillation. One paper²⁴ described the use of a nebulizer to disburse a residual-oil fly ash aerosol to newborn mice on days 6, 8, and 10 after birth. The nebulizer sprayed 15 mL of the residual-oil fly ash solution into a compartmentalized pie-shaped mouse chamber for 30 minutes on each of 3 days. The toxic component of residual-oil fly ash is a complex combustion particle that induces pulmonary inflammation and fibrosis in rats.²⁵ Bioavailable transition metals help in the mediation of residual-oil fly ash-induced acute lung injury.²⁶

The effects of aerosolized class C fly ash given in 4-hour doses for 6 treatments over 3 months to weaning goats were considered to be nontoxic on the basis of the lack of positive results on clinical, necropsy, or histologic examinations. The 3.2-fold increase in mean area of atelectatic lung tissue of the principal goats, compared with the control goats, was significant; however, 24-hour exposure to fly ash was considered excessive to what would occur under usual conditions of applying fly ash to the surface of feeder calf pens. The fly ash particle sizes were analyzed, and it was determined that there were respirable particles present (particles < 5 µm in diameter) that could easily be inhaled into the alveoli of the lungs. It is possible that goats could be a resistant host to fly ash toxicosis. Mostly rats and guinea pigs have been used in the testing of fly ash toxicosis; however, the ruminant was our target species. It is also possible that 3 months of treatment was not long enough for quartz (crystalline silica) to induce fibrosis or for other induced histologic lung lesions to develop. We were surprised with the apparently low toxic effect of fly ash in goats. Aerosolized fly ash appeared to be rather biologically inert. The 3.2-fold increase in atelectatic lung lesions of the principle goats, compared with control goats, was apparently the result of the fly ash aerosolized treatments. If we had not removed data from a control goat (which previously had pneumonia before we acquired it) from analysis, a significant 2-fold increase in atelectatic lesions in the principal goats would still have been found. We assume the fly ash would have had more toxic effects had it contained a residual-oil pollutant or heavy metals. However, under the conditions of our study, the effects of fly ash aerosol treatments were considered to be nontoxic.

- a. Ivomec, MSD AGVET, Merck & Co Inc, Rahway, NJ.
- b. Amprolium, MSD AGVET, Merck & Co Inc, Rahway, NJ.
- c. Class C fly ash, Depaw Fly Ash, Amarillo, Tex.
- d. Malvern Mastersizer 2000, version 5.1, Malvern Instruments Ltd, Malvern, UK.
- e. Fritted-glass funnels, United Glass Technologies, Duryea, Pa.
- f. Filters (47-mm prefilters), Millipore Corp, Bedford, Mass.
- g. Millipore reverse-osmosis water system (3216), Continental Water Systems, Lubbock, Tex.
- h. Custom-fabricated canvas tent, Wolfe Canvas, Amarillo, Tex.
- i. AccuRate dry material feeder, Hopper, Whitewater, Wis.
- j. Jet-O-Mizer, Fluid Energy Processing & Equipment Co, Hatfield, Pa.
- k. Five-stage cyclone device, In-Tox Products, Albuquerque, NM.
- l. Rectal thermometer, high-speed digital rechargeable, GLA, San Luis Obispo, Calif.

- m. Unopette (365856) WBC chambers, Becton, Dickinson & Co, Franklin Lakes, NJ.
- n. Butorphanol tartrate, 10 mg/mL, 50-mL vial, Fort Dodge Animal Health, Fort Dodge, Iowa.

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