

# Dust Emissions from Cattle Feeding Operations

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## Sources, Factors, and Characteristics

With the trend toward larger and more concentrated animal feeding operations (CAFOs), particulate matter (PM) emissions from open-lot CAFOs are an increasingly prominent environmental issue. This is particularly true for CAFOs located in arid and semi-arid climates where dry conditions favor dust emissions.

Particulate matter, or solid-phase aerosols, is classified by aerodynamic diameter, which refers to the diameter of a spherical water droplet that would have the same settling velocity in air as the aerosol particle in question. Fine particles with a mean aerodynamic diameter of about 2.5 micrometers (PM<sub>2.5</sub>) or less can be breathed deep into the lungs, potentially impairing respiratory function and contributing to premature death. The “inhalable” fraction of PM consists generally of particles with a mean aerodynamic diameter less than 10 micrometers (PM<sub>10</sub>) and includes the PM<sub>2.5</sub> fraction plus a range of coarser particles known as PM<sub>coarse</sub>, PM<sub>c</sub>, or PM<sub>10-2.5</sub>. The coarse fraction of inhalable PM

may be accompanied by a wide range of malodorous compounds, and is associated with reversible human health effects such as allergic reactions. It is also related to quality-of-life factors such as impaired visibility, unpleasant odors, limited outdoor activity, diminished sense of well-being, and reduced property value. Fugitive PM from cattle feedyards can reduce visibility to the extent that it interferes with both ground and air travel (Fig. 1).



**Figure 1:** Dust generated by open-lot CAFOs may reduce ground-level visibility on nearby roadways. (Photo courtesy of S. Preece)

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Aerosol sources are classified as *primary* or *secondary*. Primary aerosols are generated directly by mechanical (grinding, scouring) or chemical (combustion) processes. On a cattle feedyard, the main sources of primary PM are hoof action on uncompacted manure, vehicle traffic on unpaved roads, feed processing (hay grinding, grain delivery), and combustion of diesel fuel, gasoline, and natural gas. The coarser, mechanically derived particles generally contribute to near-field to local environmental air pollution; the finer, chemically derived particles can have environmental significance on a regional to national scale.

*Secondary* PM forms in the atmosphere as a product of acid/base or sunlight-mediated redox reactions (oxidation-reduction reactions in which electrons are transferred between molecules, atoms, or ions). Secondary aerosols associated with CAFOs come principally from gas-phase ammonia (a base) that dissolves into atmospheric moisture and reacts with dissolved sulfate, nitrate, and/or chloride ions (all acids) to form fine particles. Because secondary PM tends to form fine to very fine particles, which can be carried long distances by air currents, the environmental implications of secondary PM are regional to transnational.

### Regulatory matters

Fugitive dust emissions from open-lot CAFOs receive increased regulatory scrutiny, especially in the San Joaquin Valley of California and in southern Arizona, where PM concentrations characteristically exceed federal standards. Currently, odors associated with dust are regulated only under nuisance provisions. Complaints to the state regulatory authority or nuisance litigation drive this enforcement.

The National Ambient Air Quality Standards (NAAQS) establish the threshold concentrations for certain criteria pollutants above which sensitive individuals may experience adverse human health effects. Particulate

matter is one of those *criteria pollutants*. As of November 2011, the NAAQS contain three independent, primary standards for PM. These standards are directed at protecting public health. For PM<sub>10</sub>, which was first regulated under the NAAQS in 1987, the only remaining standard is a 24-hour average concentration of 150 micrograms PM<sub>10</sub> per cubic meter (µg/m<sup>3</sup>). For PM<sub>2.5</sub>, there are currently two standards, a 24-hour average concentration of 35 µg/m<sup>3</sup> and an annual average concentration of 15 µg/m<sup>3</sup>.

Any airshed in which PM concentrations exceed the NAAQS<sup>1</sup> for any criteria pollutant is classified as a nonattainment area (NAA). At present, southern Arizona and south central California are designated as nonattainment areas for PM<sub>10</sub>, and central and southern California have a number of nonattainment areas for PM<sub>2.5</sub>. In both states, the state implementation plan (SIP) for returning to NAAQS compliance involves beneficial management practices (BMPs) for agricultural sources, including CAFOs.<sup>2</sup>

State air pollution regulatory authorities administer and enforce air pollution regulations. Many states have their own regulations which are more stringent than those set by federal agencies. These states administer programs to monitor ambient air quality, issue operating permits, conduct compliance inspections and enforcement actions.

### Emission factors and characteristics

High concentrations of fugitive dust from open-lot CAFOs result from three primary factors. The raw material for dust emissions

<sup>1</sup>"Violation" of the standard does not mean a single instance of a measurement exceeding the numerical standard; rather, "violation" is defined statistically. In the case of the 24-hour PM<sub>10</sub> standard, three measurements exceeding the standard within a 3-year period constitute a violation of that standard. The statistical provisions for the two PM<sub>2.5</sub> standards are slightly more complicated.

<sup>2</sup>See e.g. <http://www.azda.gov/ACT/CMPCostEff.pdf> (accessed 17 Oct. 2012).

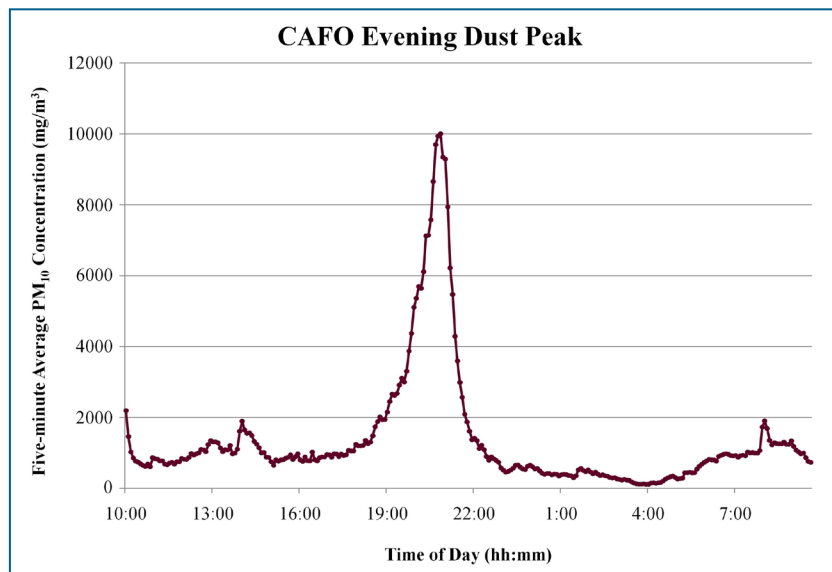
is uncompacted manure (often mixed with soil) on corral surfaces. The drier that manure is, the more susceptible it is to emission as dust.<sup>3</sup>

The mechanical energy required to emit the dust is either animal hoof action or wind scouring, therefore, elevated concentrations may occur during periods of increased animal activity or during high-wind events. Most importantly, relatively stable atmospheric conditions known as *inversions* may confine ground-level emissions to a shallow layer of air at the ground level rather than dispersing it to higher elevations through atmospheric turbulence.

A daily pattern of dust emissions peaking shortly after sunset is common at many CAFOs in the semi-arid West. This phenomenon, known as the evening dust peak (EDP), results from the temporal coincidence of three primary factors. First, pen surface moisture is at its daily minimum in the late afternoon to early evening so that dry pen-surface conditions predominate. Second, as the sun angle and daytime temperatures decrease, cattle become more active and the increased hoof action suspends more manure particles in the air. Third, atmospheric stability increases, the boundary-layer mixing height decreases, and winds diminish, reducing atmospheric dispersion. When these three conditions coincide, the peak short-term concentration (5- to 30-minute averages) may be 10 to 15 times higher than the 24-hour average (Fig. 2).<sup>4</sup>

## Dust Abatement Measures

Dust abatement plans for cattle feeding operations (CAFOs) encompass feeding strategies, manure management, pen design and



**Figure 2:** Five-minute average PM<sub>10</sub> concentrations immediately downwind of the pen area showing the diurnal (daily) pattern of the evening dust peak typical of cattle feedyards in the West. Note that these data are *not* property-line concentrations.

maintenance, and water application. In general, dust-control tactics for CAFOs are also effective at controlling odor emissions, particularly in the case of pen-surface management.

## Manure harvesting

Regular removal of uncompacted manure from corral surfaces is important for reducing dust emissions. Benchtop studies confirm that the dust potential of a corral surface grows with the increasing depth of uncompacted manure. The fundamental reason appears to be that cattle characteristically drag their rear hooves

<sup>3</sup>See Razote et al. (2006), "Laboratory Evaluation of the Dust-Emission Potential of Cattle Feedlot Surfaces," *Transactions of the ASABE* 49(4): 1117–1124; and Guo et al. (2011), "Laboratory Evaluation of Dust-Control Effectiveness of Pen Surface Treatments for Cattle Feedlots," *Journal of Environmental Quality* 40(5): 1503–1509.

<sup>4</sup>These values of the peak-to-mean ratio are characteristic of open-lot beef feedyards. For open-lot dairies, which feature significantly different patterns of animal behavior and increased shaded area as compared with feedyards, the peak-to-mean ratio is considerably smaller. See Auvermann (2011), "Texas/New Mexico Open-Lot Research," *Proceedings of the Western Dairy Air Quality Symposium*, Sacramento, CA, April 20.

across the corral surface. Dragging the rear hoof accounts for most of the mechanical shearing that resuspends the manure as PM. As the rear hoof penetrates more deeply into uncompacted manure, the mass of manure resuspended in the air increases. Reducing the depth of uncompacted material decreases the rear hoof's depth of penetration, limiting dust emissions.

The objective of good manure-harvesting operations is to keep corral surfaces smooth, firm, and well drained by maintaining a 1- to 2-inch surface layer of well-compacted manure and soil. A variety of machinery may be used to good effect, with paddle scrapers moving tremendous volumes of manure out of the larger pens, and box scrapers, which are used more frequently, collecting smaller volumes of looser, drier material. Machinery operators should be given a clear description of the management objective and solid training in machinery settings and operation.

Attentively harvesting manure from pens containing cattle improves pen conditions and has little effect on cattle performance or stress (Fig. 3). Some feedyards in the southern Great Plains continually operate manure-harvesting equipment across the yard regardless of the presence or absence of cattle in the pens. Where seasonal demand for manure creates logistical challenges for manure removal, and where pen slopes are sufficient to sustain good drainage without building manure mounds, a year-round composting operation provides an outlet for manure that would otherwise have to be stockpiled in the pens and compacted in place for longer-term storage.

When using mounds for seasonal manure storage and/or enhanced drainage, the manure should be moistened to 20 to 30 percent and compact it in place with a front-end loader or other wheeled machinery. (Track-driven tractors don't produce the desired degree of compaction.) The upper limit on the amount of water to add so the uncompacted, harvestable manure reaches



**Figure 3:** Harvesting manure from populated pens improves pen conditions in feedyards with little effect on cattle health or performance. Note that the pen surfaces in the background are hard, smooth, and well drained. (Photo courtesy of B. Auvermann)

the 30 percent (wet basis) moisture content conducive to good compaction is about 650 gallons per acre of pen surface per inch of collectable manure depth.<sup>5</sup>

### **Manure harvesting frequency**

Cattle liveweight, feed intake and composition, pen conditions, and stocking density (or its inverse, cattle spacing) together determine how often to harvest manure from pens. Minimize accumulations of uncompacted surface manure by frequent harvesting, but take care to maintain a 1- to 2-inch layer of dense, compacted manure and soil above the underlying mineral soil. Harvesting manure too frequently or with poor technique—especially with “push” blades like front-end loader buckets—may damage the underlying layers, making future pen surface maintenance difficult, exacerbating odor and dust conditions, and decreasing the

<sup>5</sup>For a more detailed treatment of water-based and corral-management tactics for feedyard dust control, see Auvermann and Casey (2011), *Feedyard Dust Control in an Epic Panhandle Drought, 2010–2011*, Texas A&M AgriLife Extension Service Bulletin SP-417, College Station, TX.





**Figure 4:** Although animal behavior and rainfall are the most obvious causes of wallows and holes, they may also be initiated by poor manure harvesting techniques that break into the underlying layers of the pen surface, expose caliche or clay palatable to the animals, and create areas that trap rainfall runoff. (Photo courtesy of S. Preece)

fertilizer and/or biofuel value of the harvested manure (Fig. 4).

Economic and operational needs also determine the optimal frequency for harvesting manure. Operationally, it is easiest to harvest manure from empty pens than occupied ones. Open-lot dairies may have a daily opportunity to harvest manure when the cows head to the milking parlor, but daily manure harvesting is probably not necessary for most dairies. Pens in beef feedlots may be continuously occupied for 25 weeks or more. A common practice on many feedlots is to remove the accumulated manure from pen surfaces only when the cattle are shipped out of the pens. Monitor pen condi-

tions and remove the uncompacted surface layer of manure before it accumulates too deeply, even if animals occupy the pens. A reasonable threshold depth to trigger box-blade removal of uncompacted manure is 1.5 to 2 inches.

The depth to which manure is harvested from pens also affects its quality for use as a fertilizer or biofuel. Most fresh manure contains at least 15 percent (dry basis) non-volatile solids (or *ash*). Over time, organic matter on the pen surface oxidizes to carbon dioxide, increasing the remaining ash content. Hoof action, especially in wetter areas of the pen surface, may mix the manure with the mineral subsoil. In such cases, ash contents from 30 to 70 percent of dry matter in harvested manure are common.

Ash content is undesirable because it adds weight to manure and decreases the average concentration of active ingredients. For fertilizer, these ingredients include nitrogen, phosphate, and potassium; for biofuel feedstocks, they include carbon, hydrogen, and oxygen. High ash content indicates that mineral soil has been incorporated into the manure, which can occur if the machinery penetrates the manure/soil interfacial layer rather than skimming only the uppermost, primarily organic layers.

### **Manure harvesting equipment and practices**

There are several kinds of manure removal equipment and different practices used to harvest manure from a pen surface. Examples of equipment are box blades, front-end loaders, elevating scrapers, and maintainers (followed by box blades and/or loaders). Some practices include scraping and removal, scraping and compaction for temporary in-pen storage, and building manure mounds to enhance pen drainage. The equipment combination most commonly used in the Texas Panhandle (and apparently the cheapest to operate) is box blade, front-end loader, and dump truck (Fig. 5).



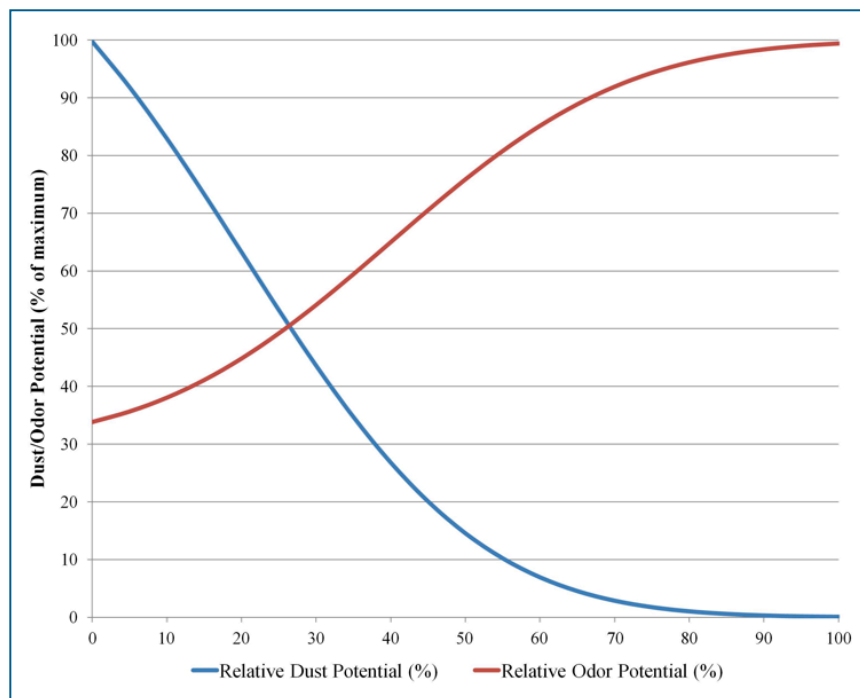
**Figure 5:** Box blades are effective at maintaining a smooth, hard pen surface without gouging the interfacial layer and exposing mineral soil. The manure being harvested in this photo will have a higher heating value of about 5,000 Btu/lb (British thermal unit per pound) as collected and would be considered a relatively high-value biofuel feedstock. (Photo courtesy of S. Preece)

Manure harvesting equipment run by trained, skilled operators should be capable of leaving about 1 to 2 inches (2 to 5 centimeters) of hard, smooth, and evenly sloped manure/soil mixture over the underlying mineral soil. Different types of equipment vary in their effectiveness at ensuring rapid drainage and efficiently removing manure. Machinery intended for digging or scooping, such as a front-end or bucket loader, may make it more difficult to avoid gouging the pen surface through the underlying compacted layers of manure and soil. Box blades are pulled rather than pushed and can be more easily adjusted for penetration depth. Such features allow equipment operators to maintain an optimal pen surface. Once a box blade stacks the manure, a bucket loader may be used to remove the manure from the pile.

## Moisture balance

Another important dust-abatement strategy for feedyard surfaces is to optimize the moisture content of the surface manure. Dust predominates when moisture levels are low, and odor potential increases as moisture increases (Fig. 6). However, feedyard dust is also associated with odors because some odorous compounds adsorb to the particles. The optimal moisture content for minimizing both dust and odor lies in the range of 25 to 45 percent on a wet basis.

Water may be applied to alleys, pen surfaces, and unpaved roadways by using solid-set sprinkler systems, tank trucks, or water wagons. These systems should be capable of uniformly delivering a minimum of  $\frac{2}{3}$  centimeter ( $\frac{1}{4}$  inch) of water across the back two-thirds (the two-thirds farthest from the feed bunk) of each pen. A study found that solid-set sprinkler systems reduce downwind PM concentrations by 55 to 80 percent.



**Figure 6:** The semi-quantitative relationship between dust and odor potential as a function of manure moisture content on a feedlot pen surface. (Source: Auvermann, 2009).

A survey of 41 feedyards in the southern High Plains found that 54 percent of the feedyards applied water for dust suppression. The most common ways to apply water were water trucks and solid-set sprinkler systems; a couple of feedyards used traveling gun systems. The estimated costs associated with water application using different systems are summarized in Table 1.

Solid-set sprinklers had the lowest operational cost and were easiest to use because they can be automated. However, they are capital-intensive, especially as a retrofit on existing feedyards. Water trucks or wagons require less capital outlay and are more versatile for applying water to alleys or roadways, but they have higher fuel, labor, and maintenance costs when compared to solid-set sprinkler systems. Of the options analyzed, a traveling gun system had the lowest total cost but was less practical than

solid-set sprinklers or water trucks. Traveling guns require more management, operate properly only on straight lines of travel, and can temporarily block alleys, interfering with other feedyard operations.

### **Additional design considerations**

Good pen design can make manure harvesting and surface maintenance more effective, more efficient, and reduce dust and odor emissions. The shape of a pen should allow for complete manure harvest from edge to edge. Pen surfaces should slope away from aprons, feed bunks, and water troughs at a 3 to 5 percent grade. They should drain separately into a runoff channel rather than into each other wherever possible. Pen-to-pen drainage is undesirable because runoff exits the pen area more slowly and creates persistent wet conditions in downstream pens. Those conditions are even more pronounced as hoof action creates manure

**Table 1. Estimated costs (investment, fixed, operational, total annual costs, and total cost in dollars per head marketed) for a solid-set sprinkler system, traveling gun, and water truck for different sized feedyards**

Head Capacity (x 1,000)	Initial Investment (x \$1,000)	Fixed Cost \$/hd Capacity	Operational Cost \$/hd Capacity	Total Cost \$/hd Capacity	Total Cost <sup>1</sup> \$/hd Marketed
<b>Solid Set Sprinkler<sup>2</sup></b>					
10	307	3.63	0.46	4.09	2.05
30	649	2.56	0.40	2.96	1.48
50	1,015	2.40	0.39	2.79	1.40
<b>Traveling Gun<sup>3</sup></b>					
10	45	0.62	1.05	1.67	0.83
30	96	0.44	0.94	1.38	0.69
50	151	0.41	0.95	1.36	0.68
<b>Water Truck<sup>4</sup></b>					
10	155	1.97	1.80	3.77	1.89
30	310	1.32	1.74	3.06	1.53
50	464	1.18	1.72	2.90	1.45

<sup>1</sup>Assumes annual turnover rate of 2 head marketed per head of one-time capacity.

<sup>2</sup>Source: Amosson et al., 2006.

<sup>3</sup>Source Amosson et al., 2007.

<sup>4</sup>Source: Amosson et al., 2008.



ridges beneath fencelines, further retarding runoff. Where pen-to-pen drainage cannot be easily avoided, maintain maximum drainage by eliminating ridges of manure where fencelines cross the drainage channel.

In-pen manure mounding improves drainage in pens lacking adequate slope, provides livestock with dry areas to rest, and reduces hoof traffic in low-lying areas susceptible to damage during wet conditions. In some cases, in-pen mounding may be more economical than stockpiling manure in a dedicated staging area before land applying or composting it.

Pen surfaces may also be paved with fly ash or crushed bottom ash,<sup>6</sup> concrete, or a soil/cement blend. Where mineral soil is unpaved, compact it to near Proctor density<sup>7</sup> and keep it undisturbed by animal activity or machinery operations.

### Other dust mitigation strategies

Other effective dust mitigation options (some experimental) include:

- Vegetative barriers, such as a shelterbelt or windbreak of one or more rows of tall trees, capture airborne particles and gases on leaf or needle surfaces. Shelterbelts provide the added advantages of reducing erosion and serving as an aesthetic visual screen.<sup>8</sup>
- Increasing stocking density may reduce dust emissions, but this effect is highly dependent on pen surface moisture and may negatively affect cattle performance. Still, where unallocated water resources are marginal and seasonal moisture deficits are not extreme, stocking density manipulation may be a cost-effective option to reduce direct water applications.
- Pen surface amendments that are effective for dust control on unpaved roadways (usually resins or oils) are being investigated for use on feedyard pen surfaces. This approach may not be cost-effective

because, unlike roadways, manure is constantly being added to the pen surface and any pen surface amendment would require frequent reapplication. In theory, other topical applications of crop residues (cotton gin trash, hay, peanut hulls, or straw) may reduce evaporation, absorb the energy from hoof action that would otherwise resuspend manure particles, reduce the amount of particulate matter picked up by air currents, and increase the quality of manure for land application or composting.<sup>9</sup>

- Feed-management techniques that may reduce dust emissions include changing the time of day livestock are fed and changing the fat content in cattle diets. Delaying the last feeding of the day until late afternoon may reduce animal activity during the critical dust-peak conditions near sunset. Increasing fat in cattle diets may increase the cohesiveness of manure, making it more resistant to being pulverized by hoof action.<sup>10</sup>
- Unpaved roadways and feed mills are other sources of dust emissions on feedyards. Vehicular traffic on feedyards may

<sup>6</sup>Fly ash, crushed bottom ash, and hopper ash are combustion residues from coal-fired power plants. In general, these ash products have excellent cementing properties and good mechanical strength when installed properly, but are not as durable as structural concrete.

<sup>7</sup>Proctor density is the maximum density obtained in compacted soil at an optimal moisture content. A standard Proctor test determines the optimal moisture content needed to obtain the maximum density of a soil sample.

<sup>8</sup>For a more thorough assessment of shelterbelt potential for trapping feedyard dust, see Li Guo, *Measurement and Control of Particulate Emissions from Cattle Feedlots in Kansas*, PhD dissertation, Kansas State University, 2011.

<sup>9</sup>Several of these surface amendments have been tested at the benchtop scale for efficacy in feedyard dust control. See Guo, *Measurement and Control*, pp. 90ff.

<sup>10</sup>Increasing dietary fat has not been evaluated on a large commercial scale and has several drawbacks, including reduced feed intake or feed-to-grain performance and safety concerns for pen riders and their horses working on slick pen surfaces.



include feed, livestock, water, and service trucks. Operating these vehicles at very slow speeds on dry, unpaved roads helps reduce dust emissions. Regular watering of unpaved surfaces at the beginning of the day, before heavy vehicular activity begins, is also useful. Applying resins or petroleum derivatives to caliche, dirt, or stone roadways may be more expensive than frequent watering, but is effective at reducing dust emissions caused by vehicular traffic on feedyards.

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