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PRELIMINARY EVALUATION OF A WATER CURTAIN FOR EDGE-OF-FEEDYARD SUPPRESSION OF FUGITIVE DUST

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ABSTRACT

We present the results of preliminary tests on a field-scale water curtain to control fugitive dust from a commercial feedyard in the Texas Panhandle. The water curtain is an open-air wet scrubber consisting of a linear array of elevated spray nozzles oriented such that the conical spray patterns are directed toward the ground. The spray patterns overlap to form a curtain of fine water droplets that "scrub" dust particles from the air. Previous, small-scale prototypes removed nearly 80% of total suspended particulate (TSP), but the system tested at that time operated at an extremely high specific flow rate of nearly 112 l min-1 m-1. The present, field-scale system operates at a more realistic specific flow rate of 15 l min-1 m-1, which is approximately equal to the water used by a conventional, solid-set sprinkler system operated 6 hours per day to suppress dust emissions from a cattle feedyard having a 1.6-km critical downwind frontage. Using an upwind/downwind sampling paradigm on three ideal monitoring dates in August 2002 and May 2003, the curtain appeared to remove about 40% of suspended particulate matter (PM) along the centerline of the water curtain's zone of influence. As the design is optimized, we expect the effectiveness of the water curtain to be greatest when winds are light and when turbulent mixing of the air is minimal – that is, atmospheric conditions under which human exposure to ground level, airborne PM is likely to be the greatest.

KEYWORDS. Fugitive dust, Feedyards, Water curtain, Dust control, PM10.

INTRODUCTION

For many years, the two major options for controlling fugitive dust from cattle feedyards have been (a) active water application to corral surfaces via water trucks or solid-set sprinkler systems and (b) frequent harvesting of the dry, uncompacted manure layer on the corral surfaces (Auvermann et al., 2000). More recently, cattle feeders have considered another approach, passive water application via increased stocking density, which yielded inconclusive results (Auvermann and Romanillos, 2000). Sprinkler systems are capital-intensive, and both manure harvesting and water trucks involve high operating and labor costs. Still, because of the ease of automation, cattle feeders are increasingly prone to install solid-set sprinkler systems on new construction or expansions of existing facilities if sufficient capital is available to install them and sufficient water is available to operate them.

Retrofitting existing feedyards with sprinkler systems, however, may cost twice as much as systems installed on new construction, so older feedyards needing to control fugitive dust need innovative alternatives. Moreover, for some feedyards the dust-related challenges may be limited to short distances downwind, such as periodically reduced visibility on adjacent highways or nearby residences. For feedyards with limited water and/or short-range dust challenges, are there other dust-control options that can meet those challenges requiring less water and less capital, and reducing the potential for dramatically increased odor production sometimes associated with sprinkler use?

In 1999, we began a small-scale pilot test of an edge-of-property abatement technology known as the "water curtain." The objective was to determine whether or not an open-air wet scrubber could reduce fugitive dust concentrations immediately downwind of cattle feedyards. The early results were promising (up to 77% reduction in airborne PM), but the water consumption of the pilot-scale prototype would have increased the daily water use of a commercial feedyard by up to 700% between the months of April and October. With the proof of concept in hand, our next task was to scale up the prototype but reduce the water use per unit length of curtain (henceforth, "specific flow rate," in units of $l\ min^{-1}\ m^{-1}$). With funding commitments from the feedyard, the producer association, the state regulatory agency, local stakeholders and the Texas Agricultural Experiment Station, a second-generation, water-curtain prototype was built in 2002 on a commercial feedyard in the southwest Texas Panhandle. In the following sections, we present our preliminary findings.

OBJECTIVE

The main objective of this preliminary study was to determine the decrease in the mass concentrations of TSP and PM_{10} downwind of the water curtain as compared to those measured immediately downwind of the cattle feedyard but upwind of the water curtain. In statistical form, the null hypothesis tested was,

H_o:

$$\frac{C_{up} - C_{dn}}{C_{up}} = 0$$

[1]

with the one-tailed alternate hypothesis,

H_a:

$$\frac{C_{up} - C_{dn}}{C_{up}} > 0$$

[2]

as applied to both the TSP and PM_{10} fractions. The statistical analysis will use a one-tailed, paired t-test of the upwind and downwind mass-concentration data.

WATER CURTAIN DESIGN

Research was conducted at a large (capacity > 50,000 hd), commercial cattle feedyard in the southwest Texas Panhandle. We erected the experimental water curtain in May 2002. It consists of six sections of standard, galvanized, center-pivot irrigation pipe (16.8 cm diameter) suspended 13.7 m above ground from a horizontal, high-tensile, stranded steel cable (0.95 cm dia.). The cable stretched through the tops of seven heavy-duty wooden poles (similar to those used for rural electrical transmission lines) in an E-W line approximately 82.3 m long, with the poles spaced 13.7 m on center. A water supply main (20.3 cm OD) ran above ground from the pumping plant to an elbow at the base of the center pole, then turned up the pole to a galvanized tee 76 cm below the high-tensile steel cable. Three sections of irrigation pipe were suspended from the cable on each side of the tee and bolted together at flange joints. The terminal flange on each lateral was capped. The two laterals were suspended from the cable by 22 wire slings affixed to rolling blocks riding on the cable. The curtain was located in a cultivated, dryland field immediately N (normally downwind) of a major section of the commercial feedyard. The curtain was approximately 30 m N of and parallel to a paved road adjacent to the corrals and was located within the core of the feedyard's usual dust plume under prevailing S-SSW winds.

The irrigation pipe has standard, threaded outlets (1.9 cm dia.) at an interval of 76.2 cm designed to receive standard irrigation goosenecks and drop tubes. Three of every four outlets were plugged to create an effective nozzle spacing of 3.05 m. Stainless steel, precision spray nozzles (Spraying Systems, Inc., Wheaton, IL; WhirlJet model 1/2BX-SS60) generating a hollow cone pattern were attached to the drop tubes and oriented to spray vertically downward. The nominal droplet diameter and discharge at the design operating pressure of 206.7 kPa (gage) were 300

Figure 1. Contractors raising the irrigation pipe into place and attaching it to the high-tensile, braided steel cable with rolling blocks and wire slings.

microns and 38.2 liters per minute, respectively. There were 28 nozzles along the full length of the curtain, for a design flow rate of 1,070 l min^{-1}. The specific flow rate (flow per unit length of curtain), which is the design criterion that should be used as the basis for scaling the system up or down for other applications, is 13.0 l min^{-1} m^{-1}. The system was pressurized from an existing, below-grade, 20.3 cm (dia.) supply main using a 20 kW, 3-phase centrifugal booster pump (Goulds, Inc., Seneca Falls, NY; model 3656M) upwind of the curtain.

Experimental Methods

The field protocol for evaluating the performance of the water curtain is based on a traditional upwind/downwind monitoring paradigm. For every monitoring event, we deployed Federal Reference Method (FRM) samplers for total suspended particulate (TSP) (General Metal Works, Smyrna, GA) and PM_{10} (Wedding and Associates, Ft. Collins, CO) at predetermined locations upwind and downwind of the curtain (Figure 2).

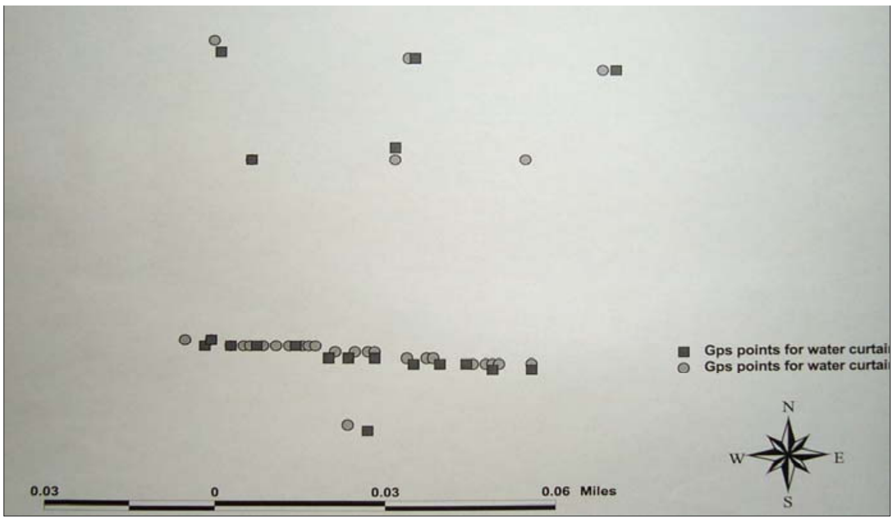

Figure 2. Sampler layout for evaluating the water curtain.

The six downwind sampler locations were along two E-W lines 53.5 and 74.1 m N of the curtain and were distributed in a fan-like configuration with respect to a vertex at the upwind sampler location. This configuration is intended to ensure that at least one complete axis of samplers (one upwind and two downwind sampler locations) lies within the zone of influence of the water curtain irrespective of modest fluctuations in wind direction.

When dust conditions warranted and evening weather conditions were projected to meet specifications (wind speed <6.7 m s^{-1}, southerly +/- 45 degrees) from 6 pm to midnight, a monitoring event was initiated at the onset of the evening dust peak by turning on the samplers and pressurizing the water curtain. All systems were allowed to run for a minimum of three hours while favorable weather conditions persisted.

Time-averaged PM concentrations were determined gravimetrically using standard methods. Rectangular, glass fiber filter media (20.3 cm x 25.4 cm) were preconditioned for 18 h in a drying oven at 90 degrees Celsius prior to exposure and weighed on a precision microbalance (Mettler-Toledo, Inc., Columbus, OH; model AG245) to a precision of 0.1 mg. Following exposure, filters were conditioned again and weighed. The mass of each filter was reported as the mean of three measurements. The time-averaged concentration of PM collected by a sampler was computed as

$$C_{\Delta t} = \frac{(M_f - M_i)}{Q \bullet \Delta t}$$

[3]

in which $C_{\Delta t}$ was the time-averaged concentration (mg m^{-3}), M_i and M_f represent the post-conditioning filter mass (mg) before and after exposure, respectively, Q is the volumetric flow rate of air (m^3 min^{-1}) and Δt is the sampling duration (min). Mesoscale weather conditions were monitored during each sampling event using an automatic weather station (Campbell Scientific, Inc., Logan, UT).

RESULTS AND DISCUSSION

Raw Monitoring Data

Three evaluations of the water curtain took place on August 8 and August 15, 2002, and May 21, 2003. Sample, normalized raw data from the first two events are shown in Figure 4. (Data from the third test are similar and of even better quality). Because only three sampling events have taken place, field data do not yet support a rigorous statistical test of the null hypotheses, but the trends appear clear. On August 8, winds were SSE-SE throughout most of the monitoring period, and the greatest reductions in both TSP and PM_{10} concentrations were found along the center and

SSE-NNW sampling axes, as expected. 26-38% reduction in PM_{10} and a 25-41% reduction in TSP along those axes were measured compared to the upwind concentrations at the edge of the feedyard. Similarly, on August 15, winds were SSW-SW throughout the monitoring period, and the greatest reductions were found along the center and SSW-NNE sampling axes, corresponding with the rotation in the water curtain's zone of influence associated with the wind direction. Concentrations decreased by 63% (PM_{10}) and 75% (TSP) along the centerline of the zone of influence.

"End Effects" and Other Sources of Error

It was apparent from inspection of the data in Figure 4 that "end effects," or leakage of airborne feedyard dust around the ends of the water curtain, were easily detectable in the sampling layout used. The aspect ratio of the water curtain was 6:1 (length:height), which would appear to be too low to prevent end effects in the sampler layout. We have proposed to lengthen the pilot-scale water curtain by a factor of 3 if funds can be acquired. In addition, the influence of dry deposition (settling) of coarse particles, which undoubtedly occurs irrespective of the operation of the water curtain, has not yet been measured. This deficiency in the sampling layout will be addressed during the spring and summer of 2003.

PM_{10}/TSP Ratios

The currently accepted value of the PM_{10}/TSP ratio for feedyard dust is 0.25, which represents a weighted average of the ratios published by Sweeten et al. (1998). (See also Grelinger and Lapp, 1996.) Sweeten et al. (1998) recognized that such an average is, in part, an artifact of irregularities in sampler operation during their ambient monitoring activities. Recently, faculty members of the Texas A&M University Center for Agricultural Air Quality Engineering and Science (CAAQES) have questioned the validity of that published ratio and have sought to revise it based on additional, collocated monitoring data. Upwind sampling data (i. e., samples unaffected by the water curtain) from the first two water-curtain evaluations showed that the correct PM_{10}/TSP ratio for feedyard dust is about 19%, although many more collocated data points will be needed to confirm that result with statistical certainty. As expected, the downwind PM_{10}/TSP ratios in Table 1 suggest that the water curtain removes larger particles more efficiently than it removes smaller particles.

Figure 3. Photograph of the water curtain operating during the nozzle- and pressure-testing phase, June 2002.

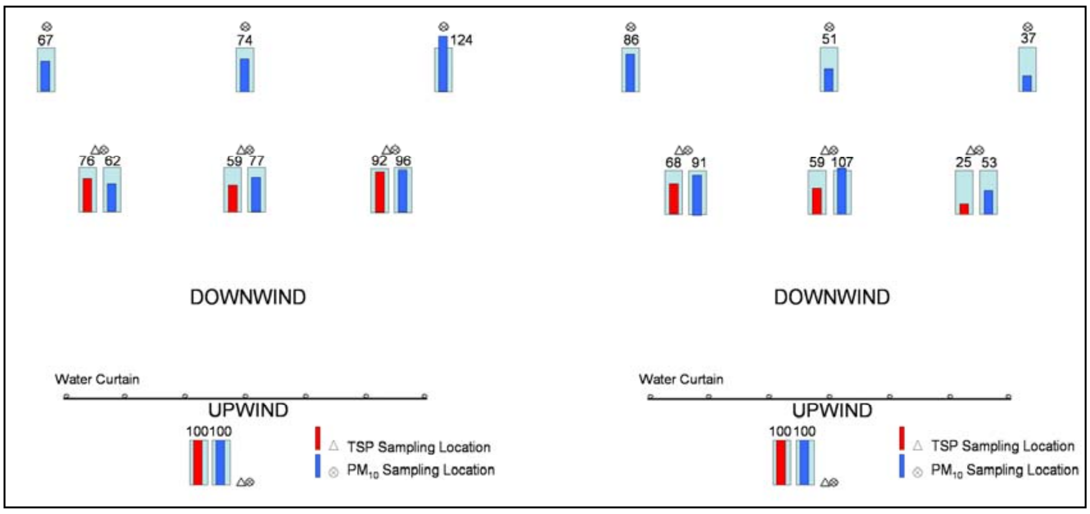

Figure 4. Preliminary results from the August 8 (left) and August 15 (right) sampling events to evaluate the water curtain. Three-hour average concentration data are normalized such that upwind=100 for each PM fraction. (Note that this normalization does not preserve the PM10/TSP ratio at a given location; readers should not infer PM10/TSP ratios from these data.)

	8/8/02				8/15/02			
Fraction	Upwind	Down W	Down C	Down E	Upwind	Down W	Down C	Down E
PM_{10}	217.15	134.87	168.06	208.45	105.86	96.69	113.73	56.30
TSP	899.70	687.44	527.30	829.35	728.74	498.02	432.73	185.73
PM_{10}/TSP	0.24	0.20	0.32	0.25	0.15	0.19	0.26	0.30
Mean Upwind PM_{10}/TSP			0.19					
Mean Downwind PM_{10}/TSP			0.25					

Table 1. Raw TSP and PM10 concentrations (□g m-3) from two August 2002 sampling trips. To emphasize the distinction between 3-hour average measurements and 24-hour air quality standards, these data have been scaled by a factor of 0.125, or (3/24), from the actual 3-hour concentration measurements. Corresponding 24-hour average concentrations were not measured.

CONCLUSION

Preliminary evidence suggests that the present design of the water curtain reduces airborne PM within 100 m downwind by up to 40%, but the number of sampling trips thus far (n=2) does not support a statistical inference. The water curtain also appears to remove a greater mass of coarse particles than fine particles. Data collection scheduled for spring and summer 2003 should provide a reasonable basis for establishing the effectiveness of the present design. Increasing the length of the curtain prototype should reduce the influence of end effects associated with the variation in wind direction during future sampling events.

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