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Preliminary PM_{10} Emission Factor for Freestall Dairies

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Abstract. *There is currently no published data on particulate matter (PM) emission rates (factors) from dairies. The philosophy of some State Air Pollution Regulatory Agencies (SAPRA's) is to use the emission factor that had been published in AP-42 for cattle feedyards of 280 lbs/1000 head per day (lb/1000hd/d) total suspended particulate (TSP) matter or 70 lb/1000hd/d* PM_{10} *for permitting and emissions inventory purposes. Prior to EPA removing this cattle feedyard emission factor from AP-42, the Department of Biological and Agricultural Engineering at Texas A&M University had determined that a more appropriate emission factor for cattle feedyards in the relatively arid west Texas area was 19 lb/1000hd/d (uncorrected for rainfall and snow events). The source of PM from cattle feedyards and dairies is the open surface of the pens (manure pack). The major difference between dairies and cattle feedyards is the fraction of time the dairy herd is in contact with the manure pack relative to cattle on feed. It is assumed that because of the relative small fraction of time that the dairy herd is on the manure pack, the dairy* PM_{10} *emission factor will be less than 19 lb/1000hd/d. The goal of this research is to obtain a science based emission factor for dairies that can be used for SAPRA permitting purposes.*

Keywords. *PM_{10}, $PM_{2.5}$, total suspended particulate, air sampling, emission rate, Freestall dairy, emission factor, emissions inventory*

Introduction:

The agriculture industry is coming under increased scrutiny as a pollution source. This is especially true in non-attainment areas. The San Joaquin valley in California is classified as serious non-attainment for PM_{10}. State Air Pollution Regulatory Agencies (SAPRA's) are required to include in their respective State Implementation Plans (SIP) procedures whereby non-attainment areas will be brought into attainment. These procedures are based upon emissions inventories, permitting, and emission factors. This is a problem specifically in California due to the dairies location in PM_{10} non-attainment areas. The focus of the SIP is on reducing pollution from the largest sources. If the dairy emission factor is grossly in error, the emissions inventories for PM_{10} from dairies will be in error. If the SIP plan for bringing the PM_{10} non-attainment areas into attainment is based upon erroneous emissions inventories, it is unlikely the area will be brought into attainment. In order to reduce PM_{10} emissions from dairies, the SAPRA will likely require that additional controls be installed with the permitting process. The economic burdens of reducing PM_{10} emissions from dairy operations will likely result in more dairies being forced out of business. It is imperative that accurate PM_{10} emission factors be used by SAPRA's for emissions inventory and permitting purposes.

Peters and Blackwood (1978) developed an emission factor of 127 kg/1000hd/day total suspended particulate (TSP) matter (280 lb/1000hd/d TSP) for feedyards. This work was done using sampling data from Algeo et al., (1972) which represented the only data available at the time. Sweeten et al (1989, 1998) demonstrated that 25% of the TSP emitted by cattle feedyards was PM_{10}. EPA accepted this PM_{10}/TSP ratio. Hence, the PM_{10} emission factor used by SAPRA's for permitting and emissions inventory purposes was 32 kg/1000hd/d (70 lb/1000hd/d PM_{10}) The errors associated with the AP-42 emission factor based upon Peters and Blackwood's study were documented by Parnell et al (1999). Subsequent work by Texas A&M University (Parnell et al., 1999) has shown that a more appropriate number would be 6.8 kg/1000hd/day PM_{10} (15 lb/1000hd/day PM_{10}).

Feedlots for beef cattle are open pens with the pen surface serving as the manure pack. The action of the cattle on the manure pack is the source for PM emissions from the facility. Conversely, freestall dairies will keep the lactating portion of their herd in freestall barns with the rest of the cattle being kept in pasture areas or open pens similar to feedlots. A typical freestall barn consists of a feed alley down the center with feed bunks on each side. The exercise pens are only used during nighttime hours, and have the same surface composition as the open pens. Manure primarily accumulates in the alleys and is removed in one of two ways: flushing or scraping. Flushing involves introducing a large volume of water into the alley which flows into a collection system. The second method used for removing manure from the alley and the open pens is to use a mechanical scraping system. The flushing is performed multiple times daily in order to minimize manure accumulation in the alleys (EPA, 2001). Scraping of the pens is a control method used to reduce PM emissions. the frequency of scraping will vary from dairy to dairy. The frequency of manure removal in the free stall alleys minimizes PM entrainment from this section of the dairy.

Methods:

Data for this study was collected at a dairy in central Texas during one week in June, 2002. The dairy herd consisted of 1800 milking cattle with a total of 3,400 on property. The lactating herd is kept in a series of three freestall structures and two open pens. Each freestall housed approximately 460 cattle and the two open pens housed approximately 230 cattle each. The layout of the dairy is presented in Figure 1. The low producing cattle are kept in open pens one and two. The remainder of the lactating herd is kept in the freestalls during the day. They are allowed into the exercise pens at dusk.

The axis of the facility lies along a line that is approximately 15 degrees west of due north. The prevailing wind direction was from the south during the day with a shift to the east during the evening hours. This allowed for sampling along the axis of the dairy most of the time. The ideal wind direction for all samplers except D2C was along the axis of the dairy at an angle of 345 degrees. Sampler D2C was located on the west edge of freestall 1 and had an ideal wind direction of 75 degrees. Any downwind sample with an average wind direction not within 45 degrees of optimal was discarded.

During the sampling trip the dairy was also harvesting silage that is used for feed throughout the year. This process involves cutting and chopping the silage in the field and transporting it to the storage pits with large trucks. The trucks used the unpaved road on the east side of the dairy. The travel of the trucks on the unpaved roads generated significant emissions of PM. It is likely that our concentration measurements were affected by unpaved road dust. The road dust contamination could not be avoided and the data reported in this paper have not been corrected to account for this source of PM.

Sampling was conducted using high-volume (TSP) samplers that were designed by Texas A&M University to meet EPA reference device specifications (EPA, 2002). The samplers use a centrifugal fan to pull ambient air through filter media. Flow was determined using a pressure transducer (Omega, PX274, Omega, Stamford, CT) to measure the pressure drop across a sharp edge orifice plate. A data logger (HOBO H8 RH/Temp/2x External, Onset Computer Corporation, Pocasset, MA) was used to monitor the pressure transducer at twelve-second intervals. Sampling intervals ranged from two to four hours.

Ambient meteorological conditions were monitored using a Campbell Scientific weather station with sensors for temperature, pressure, relative humidity, solar radiation, wind speed, and direction. The average air density was calculated for each test and used to convert the flow rates to standard conditions.

Sampling was performed using glass fiber filters. The filters were placed in an environmental chamber for a minimum of 24-hours prior to weighing. The filters were weighed with a high precision analytic balance (AG245, Mettler Toledo, Greifensee Switzerland) before and after sampling. The mean of three weights was used to determine the mass of each filter. The weighing was conducted in the same chamber as the conditioning process.

Emission Rate Calculations:

Measured concentrations were used to calculate emission factors using the box model described by Flocchini et al., (2001). The box width was determined as the maximum width of the source area. The width of the dairy at the downwind sampling site was 140 meters. It was assumed that the height of the plume (box) corresponded to σ_z at 50 meters downwind from the source for a stability class of ‘C’ (4 meters). The height of the box for all calculations was 4 meters. For our preliminary calculations of emission factors, the box dimensions were 140 meters by 4 meters. Equation 1 was used to calculate the emission rates of PM from the area upwind of the sampler for each acceptable measured concentration.

$$ER = W \bullet H \bullet U \bullet C \bullet 10^{-6} \qquad \text{(Equation 1)}$$

where

- ER=emission rate, g/s;

- W=width of box, 140 meters;
- H=height of box, 4 meters;
- U=average wind speed during sampling period, m/s; and
- C=net measured concentration, μg/dscm.

To determine the emission factor, the emission rate was divided by the known number of cattle upwind of the sampler and converted to a 24-hour basis[1] using Equation 2.

$$EF = \frac{ER}{N} \bullet 86{,}400 \qquad \text{(Equation 2)}$$

where

- EF=emission factor, g/1000hd/day;
- ER=emission rate, g/s
- N=number cattle/1000 in upwind pens; and
- 86,400 = conversion factor.

Net concentration was determined by subtracting upwind sampler concentrations during the respective test periods from the downwind samplers. The upwind samplers were determined by wind direction. The average concentrations of upwind sampler(s) were used as the background concentration. If there was a significant difference between sampler concentrations, the sampler that had the least road contamination based on wind direction was used as background.

To convert the TSP emission factors to PM_{10}, it was assumed that the characteristics of the PM from the dairy were the same as the PM emitted by cattle feedyards. For a cattle feedyard, the PM_{10} emission rate is equal to 25% of the TSP emission rate (Sweeten et al, 1989, 1998).

Four to seven TSP samplers were operated during each sampling period. An emission factor was calculated for each concentration measurement that resulted in a net concentration greater than zero. It was anticipated (based upon previous experience with cattle on feedyards) that the emission rates would vary significantly during the day. It was assumed that short-term measured concentrations would be directly proportional to the corresponding emission factor for the time period sampled. In order to obtain an estimate of the 24-hour emission factor, it was essential that we did not average emission factors for the time periods when emission rates were always low or high. The 24-hour emission factor was calculated by equally weighting the measured emission factors for each of 6-hour time periods.

Results and Discussion:

The data yielded 29 emission factors from 12 separate tests. Net concentrations for the tests ranged from a low of 14 micrograms per dry standard cubic meter (μg/dscm) to a high of

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[1] The measured concentrations were for 2 to 4 hour periods. In effect, the individual emission factors corresponded to the time period when sampling occurred. For comparison purposes, all emission factors were converted to a 24-hour basis.

490μg/dscm. The grand mean 24-hour weighted emission factor was emission factor was 8.1 kg/1000hd/day PM_{10}. The emission factor for each sample and the corresponding average test emission factor is presented in Table 1. Table 2 represents the duration for the samples and the corresponding 6-hour intervals that each emission factor represents.

Table 1. TSP emission factors (kg/1000hd/d TSP), wind direction and speed for each test.

	Sampler ID									
Test #	D1	D2A	D2B	D2C	D3	U1	I1	Wind Dir	Wind Spd m/s	**Average kg/1000hd/day**
1	5.3	32.6			18.9			143	3.6	**18.9**
6		14.0	3.3		15.9			192	2.1	**11.0**
7		26.1	6.1		13.9			190	1.5	**15.4**
11	9.5				14.2			201	2.4	**11.9**
12	0.8	9.0	4.1			5.2		302	1.4	**4.8**
13	9.2	15.9				4.2	11.6	333	2.1	**10.2**
15				6.7				81	2.7	**6.7**
16	2.5	2.4			0.7		4.0	136	3.2	**2.4**
17				2.5				68	1.6	**2.5**
18				15.5				77	3.3	**15.5**
19				16.9				78	2.9	**16.9**
20				37.3				68	2.6	**37.3**

Table 2. Sampling time period and interval characterization. (For example: Sample 20 is in time period 4.)

	Time Period 1						Time Period 2						Time Period 3						Time Period 4					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1								■	■	■	■	■												
6									■	■	■	■												
7												■	■	■										
11								■	■	■	■	■												
12											■	■	■	■	■									
13															■	■	■	■						
15																				■	■	■	■	
16	■	■	■																					
17								■	■	■														
18												■	■	■	■									
19														■	■	■	■							
20																	■	■	■	■				

The number of concentration measurements taken during daylight hours far exceeded the number taken during the midnight to 6:00 AM period (Time period 1). By categorizing the samples into four time periods, the frequency of samples during the daylight hours does not artificially weight the 24-hour emission factor towards the daytime emission rate. Table 3 shows the variation in TSP emission factors for the different time periods.

Table 3. Time period emission factors (kg/1000hd/day TSP).

Time Period	12am-6am	6am-12pm	12pm-6pm	6pm-12am	**Weighted Average**
Average Emission Rate	2.4	8.1	15.0	6.7	**8.1**

The emission factor of 8.1 kg/1000hd/day TSP represents the 24-hour TSP emission factor for this dairy. It corresponds to an emission factor of 2.0 kg/1000hd/day PM_{10}. The variation in emission factors throughout the day can be attributed to the change in animal activity. The low calculated emission factor for the first time period can be attributed to the small amount of activity during the early morning hours. During the second time period, activity increased. Activity decreased as temperatures increased. The third time period encompasses the time of highest activity as the sun begins to set the cattle become more active once again moving towards feeding areas. The final time period represents the cattle spreading out from the shelters and bedding down for the night.

Conclusions

From sampling conducted at a single central Texas dairy in the summer of 2002, a preliminary emission factor of 2.0 kg/1000hd/day PM_{10} (4.4 lb/1000hd/d) was determined. This number does not represent the variation that will occur throughout the year as ground conditions change, though it is much more representative of PM_{10} emissions from a freestall dairy than the current feedyard emission factor of 32 kg/1000hd/day PM_{10} (70 lb/1000hd/d) that has been used by some SAPRA's. The process described in this paper represents one of several methods that can be used to calculate emission factors from measured net PM concentrations. There is significantly more work that needs to be completed before a final emission factor can be published.

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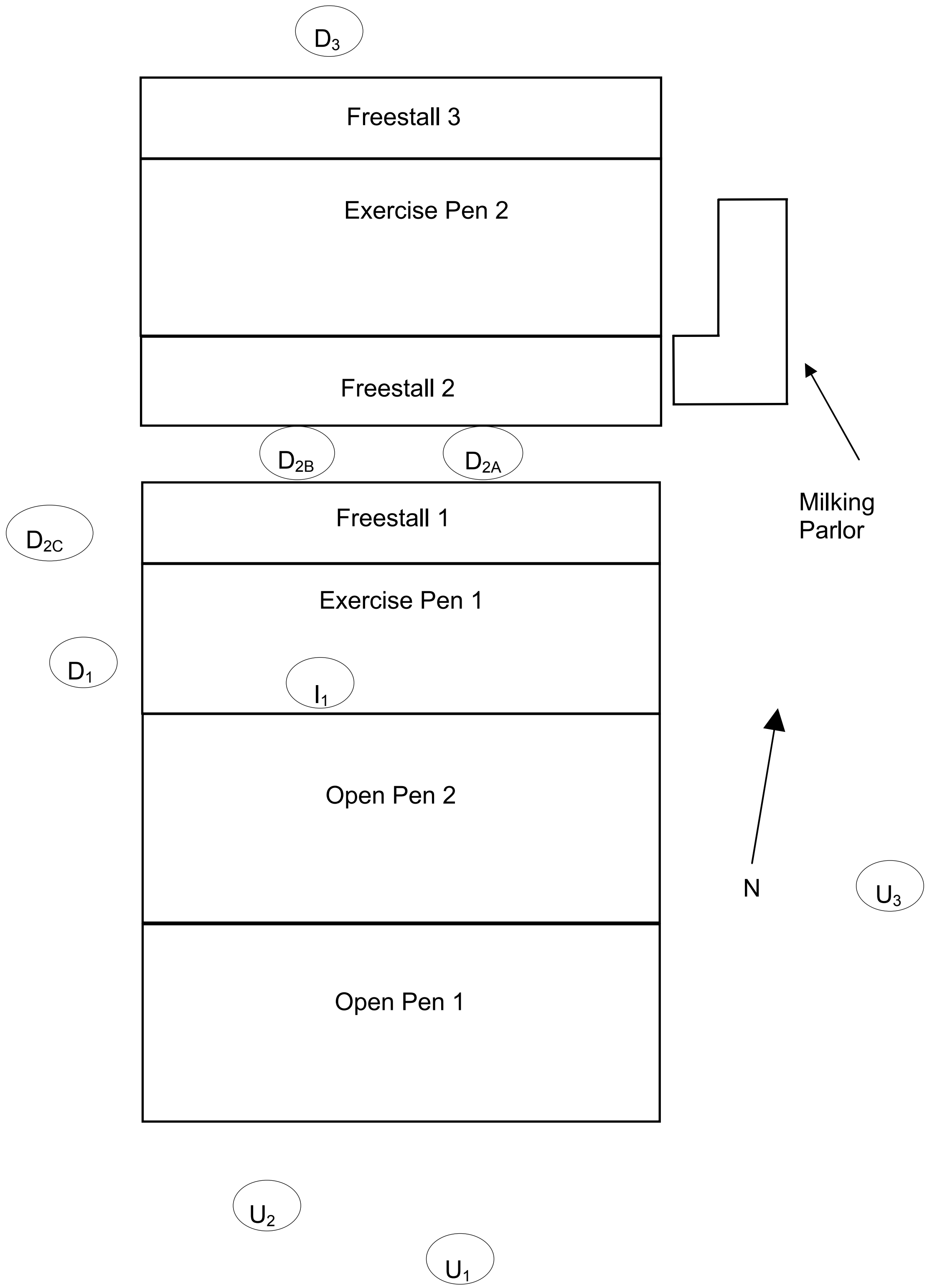

Figure 1. Schematic of the configuration of pens, milking parlor, and freestalls, and relative locations of upwind denoted by 'U' (U_1, U_2, etc), downwind denoted by 'D' (D_1, D_{2A}, etc) and inside the pen samplers denoted by I_1. Samplers are indicated with ovals.