EMISSION FACTORS FOR GRAIN RECEIVING AND FEED LOADING OPERATIONS AT FEED MILLS

B. W. Shaw, P. P. Buharivala, C. B. Parnell Jr., M. A. Demny

ABSTRACT. *The Federal Clean Air Act (FCAA) Amendments of 1990 have impacted the process used by State Air Pollution Regulatory Agencies (SAPRAs) in regulating air pollution attributed to agricultural facilities, including feed mills. The maximum allowable emission rate (AER), annual emission rate and Title V emission fee for a pollution source are calculated using AP-42 emission factors published by the Environmental Protection Agency (EPA). For proper enforcement, there is a need to be as accurate as possible in establishing emission factors for any emitting source. The 1988 AP-42 emission factors for feed mills totaled 4905 grams of particulate/tonne (9.8 lb/ton) of grain handled. These factors were grossly in error. EPA published interim factors in 1996 based on data obtained from air sampling performed at grain elevators. There are differences in the operations of grain elevators and feed mills associated with feed yards that could significantly affect emission factors. Additionally, no data was available to EPA on the emission rate and emission factor associated with loading feed. This study was directed at developing accurate emission factors for unloading grain and loading feed at feed mills associated with cattle feed yards. The resulting emission factors were determined to be 20 grams/tonne (0.04 lb/ton) for unloading grain and 2.5 gram/tonne (0.005 lb/ton) for loading feed.*
Keywords. *Federal Clean Air Act (FCAA), Air quality, Dust emission, Grain dust.*

The FCAA signed by President Bush in 1990 has impacted the process used by SAPRAs in regulating air pollution attributed to grain handling facilities including feed mills associated with cattle feed yards. The most significant impact of the FCAA Amendments of 1990 is the establishment of the Title V operating permit program (Novello, 1991). The Title V operating permit program requires that all sources of air pollution designated as major sources will be required to pay Title V annual emission fees and obtain a Federal Operating Permit (FOP). The FCAA Amendments of 1990 will have serious implications for many types of industries, including agriculture (Lesikar et al., 1996; Parnell, 1994; Wallin et al.).

Major sources in attainment areas are those emitting more than 91 tonnes (100 tons) of a regulated pollutant per year. In non-attainment areas, facilities emitting less than 91 tonnes (100 tons) of a regulated pollutant may be designated a major source. EPA has established that the annual emission rate of particulate matter less than or equal to 10 microns (PM10) would be used to determine if a grain elevator or feed mill would be a major source (Wegman, 1995). The annual emission rate and Title V emission fee for a pollution source is calculated using AP-42 emission factors published by EPA. AP-42 emission factors are also used by SAPRAs in determining the maximum AER. Hence, there is a need to be as accurate as possible in establishing emission factors for any emitting source.

The definition of air pollution can be stated as: ". . . the presence in the outdoor atmosphere of any one or more substances or pollutants in quantities which are or may be harmful or injurious to human health or welfare, animal or plant life, or unreasonably interfere with the enjoyment of life or property, including outdoor recreation," (Cooper and Alley, 1994).

The role of air pollution regulations is to protect the public (off site). Regulating air pollution includes three functions: (1) formulation of rules, regulations, and standards which establishes the criteria for enforcement; (2) "permitting" which establishes the controls required for a facility to be in compliance with the rules and regulations; and (3) enforcement which establishes the types of punishment for violators. Enforcement is dependent upon rules, regulations, and permitting. If the rules and regulations (in this case, emission factors) are inaccurate for a particular industry, it will not be possible for SAPRAs to properly regulate emissions attributed to that industry.

The AP-42 emission factors (EPA, 1988) for grain elevators and feed mills published by the EPA in 1988 were not correct (Parnell et al., 1994). The EPA recognized the errors and published interim factors for country elevators/feed mills (EPA,1995). The major changes were to reduce the emission factors associated with handling, hammer milling, flaking, cracking, and pellet cooling to zero, while calculating the total emission factor:

> "For smaller animal feed mills located at cattle feedlots, the most significant emission sources are grain unloading and bulk loadout. Material preparation/milling operations, (i.e., flaker, grain cracker, and mixing) are enclosed operations" (EPA, 1995).

Article has been reviewed and approved for publication by the Structures & Environment Div. of ASAE.

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Table 1. AP-42 Emission factors (EPA, 1988, 1995)

	1988 AP-42 Emission Factors for Feed Mills	1995 AP-42 Interim Emission Factors for Grain Elevators/Feed Mills			
	TSP, gm/tonne (lb/ton)	TSP, gm/tonne (lb/ton)		PM10, gm/tonne (lb/ton)	
Grain Type	All Types of Grain	General	Corn*	General	Corn*
Grain unloading	1250 (2.5)	30DR (0.06DR)	75 (0.15)	7.5DR (0.015DR)	18.75 (0.0375)
Feed loading	500 (1.0)	5.5DR† (0.011DR†)	13.75 (0.0275)	1.5DR† (0.003DR†)	3.75 (0.0075)

* Based on a dustiness ratio (DR) for corn of 2.5 (EPA, 1995).

† Emission factor for grain shipping would have been used for feed loading at feed mills since no data for bulk loading at feed mills existed prior to the completion of this research.

In addition, the PM10 dust content of grain was listed as 25% of total suspended particulate (TSP) in the interim AP-42 publication. The AP-42 emission factors for grain elevators and feed mills are given in table 1.

The interim AP-42 emission factors were based on sampling data collected at country elevators and not feed mills (EPA, 1995). There are inherent differences in the nature of operations at country elevators and feed mills that directly affect particulate emissions. Hence, it is imperative to collect data specifically at feed mills to calculate emission factors, instead of using emission factors for country elevators to regulate feed mills. The National Cattleman's Beef Association contracted with the Department of Agricultural Engineering at Texas A&M University to develop emission factors for feed mills associated with cattle feed yards.

The maximum AER for a facility is calculated by multiplying the emission factor by the rated capacity of the mill. Ideally, an accurate emission factor for a feed mill should be one that represents the average emission rate of particulate matter (PM) so that the mill can be in compliance with regulations at all times. If the emission factor represents the lowest particulate emission rate at the feed mill, the mill will exceed the permitted maximum AER. The feed mill will be in violation of its permit if it exceeds the permitted maximum AER. The penalties for non-compliance are severe. On the other hand, if the emission factor represents the highest particulate emission rate, the feed mill will potentially be a major source and would be required to obtain a FOP, as well as, pay emission fees. The goal of this research is to recommend new AP-42 emission factors for feed mills associated with cattle feed yards that will allow a mill to operate in compliance with SAPRA regulations.

Objectives

The objectives of this study were to:

1. Measure the TSP emission concentrations for grain unloading and feed loading operations at feed mills associated with cattle feed yards;
2. Calculate accurate TSP and PM10 emission factors for grain unloading and feed loading operations at feed mills associated with cattle feed yards; and
3. Propose new AP-42 emission factors for feed mills associated with cattle feed yards.

Feed Mills and Grain Elevators

Grain handling is an integral part of the agricultural industry. The U.S. grain handling system is the envy of the world. There are approximately 10,400 country elevators, 500 inland terminals, 300 high-throughput elevators (including export elevators), 3,000 small feed mills, and 1,000 large feed mills in the U.S. Feed mills, like grain elevators, incorporate simple grain handling systems. In the case of country elevators, grain is transported to the elevator, dumped into a pit, picked up by bucket elevators, elevated and conveyed to bins. Unlike a country elevator, the feed mill has an additional processing step in which the grain is processed into feed. This process typically includes steam flaking grain and mixing with other ingredients.

The process of handling grain at an elevator or a feed mill can result in PM being entrained. Dust can potentially get entrained at any grain transfer point. However, entrained dust does not cause air pollution until it travels outside the facility or building and affects the public, according to the definition of air pollution. Property-line particulate emissions can be calculated from emission factors by using dispersion modeling techniques. Air pollution inside an enclosed facility or building is regulated by the Occupational Safety and Health Administration (OSHA); whereas, air pollution that can impact the public (off site) is regulated by EPA. Hence, when calculating emission factors for elevators or feed mills, only sources that have the potential to affect the public (off site) should be considered.

Internal operations at grain elevators (transfer of grain from one bin to another, drying, and cleaning) and feed mills (grain handling, cleaning, milling, and pellet cooling), are enclosed operations. Internal operations at elevators and feed mills do not naturally exhaust outside the facility. PM entrained as a consequence of internal operations settles inside the enclosure and is not emitted. Hence, internal particulate emissions are assumed to be zero. In some cases, internal operations at elevators and feed mills are equipped with air pollution control systems to prevent dust explosions and to comply with OSHA regulations regarding PM. Cyclones and baghouses are the more common types of equipment used to meet the air pollution control requirements at elevators and feed mills. Particulate emissions from equipment used to control internal emissions at elevators and feed mills should be considered as separate point sources. For the purpose of this study, only particulate emissions from grain receiving and feed loading will be calculated.

The inherent differences in the nature of operations at country elevators and feed mills directly affect particulate emissions. The profit of a grain elevator operation is dependent upon the volume of grain handled. Hence, most country elevators are designed to move grain from the unloading point to the bin rather quickly during the harvesting season. In contrast, a feed mill associated with a feed yard has a primary function of providing feed for the cattle in the yard. Grain storage is limited and the speed of unloading truckloads of grain is not as critical. A feed mill will process grain at rates of 15 to 100 tonnes/h; whereas, a typical country elevator will move grain at rates of 300 to 500 tonnes/h. Due to the higher rate of movement of grain at elevators, the grain receiving pits and legs, typically, have a larger capacity than those at feed mills. It is common for the dump pit at a feed mill to fill up such that the grain backs up to the bottom of the truck. This is referred to as “choke flow” during which very little dust gets entrained. Since it takes longer to get to choke flow at a dump pit with a larger capacity, it is likely that unloading operations at country elevators encounter less choke flow than at feed mills. The particulate emissions for grain receiving operations at a feed mill will likely be lower than those at grain elevators.

The elevator shipping process involves emptying a bin, conveying grain to the elevator, elevating and loading onto trucks, rail cars or ships. The shipping of grain from an elevator is accomplished through spouts; whereas, feed trucks are loaded from clam shell bins at feed mills. Loading grain onto trucks, rail cars or ships with spouts at elevators is a much longer process (approximately 10-15 min) when compared to loading feed onto straight trucks at feed mills with a clam shell (approximately 1-3 min). It is likely that the relatively brief loading period and the bulk loading process will result in less particulate matter entrained in air. Also, loading feed at 20% moisture content or higher onto trucks at a feed mill will have a significantly lower “free” dust content than dry grain loaded into rail cars at elevators. Hence, the emission factor for feed loading at a feed mill will be less than the emission factor for grain shipping at an elevator. Based on the inherent differences in operations at country elevators and feed mills it is logical that the emission factors for feed mills should be lower than that for elevators.

Air Pollution at Feed Mills

There is potential for dust to get entrained at any grain transfer point in a feed mill. However, only those emission sources that could impact the public need to be considered while calculating emission factors. The two sources of particulate emissions at a feed mill, besides abatement system exhausts, that would potentially cause air pollution are: (1) the transfer of grain from the truck to the mill (receiving or unloading); and (2) the transfer of feed from the mill to the truck (shipping or loading).

Grain Receiving Operation

The typical length, width and height of an unloading shed at feed mills are 9 m (30 ft), 4.5 m (15 ft), and 4.5 m (15 ft), respectively. The dimensions of the entrance and exit of the shed are 3.7 × 4.3 m (12 × 14 ft). The dump pit is usually located at the center of the shed with approximate dimensions of 2.4 × 3.7 m (8 × 12 ft). During a typical grain unloading operation at a feed mill, grain from a hopper bottom truck falls into the dump pit displacing an equal volume of air in the pit. The displaced air rises from the pit against the flow of grain. This countercurrent flow of rising air and falling grain results in entrainment of PM which can move out of the shed with ambient air. Initially, when the pit is empty, the grain falls freely into the pit. Maximum rate of dust entrainment occurs during this period due to the maximum free fall distance between the hopper of the truck and the bottom of the pit. As the pit fills with grain, the level of grain in the pit rises towards the hopper of the truck, decreasing the free fall distance of the grain. The decrease in free fall distance of the grain results in “choke flow”, with little dust getting entrained. During choke flow, there is no free falling of grain and hence, no displacement of air, resulting in a lower concentration of entrained dust. Typically, a truck contains 25 tonnes (approximately 1,000 bushels) of grain in two 12.5 tonne hoppers. It takes approximately 15 to 30 min to unload the 25 tonnes (28 tons) of grain into a dump pit at a feed mill, including the time required to move the truck to align the second chamber over the pit. It is common for choke flow to occur within the first 3 to 5 min of unloading and continue throughout the rest of the unloading process.

Feed Loading Operation

The typical dimensions of a feed loading shed at a mill are the same as those for the grain receiving shed. A clam shell is located near the ceiling of the loading shed. A clam shell consists of a clam and a shell, as the name suggests. The shell serves the purpose of holding and weighing the mixed feed when the clam is shut. The opening action of the clam at the bottom of the shell helps dump the feed into the truck. Typically, the length of a clam shell is 2 to 4 m (6 to 14 ft) and the width is approximately 2.5 m (8 ft). Some feed mills have more than one clam shell. In which case, the feed loading shed is proportionately longer. The feed loading operation at feed mills is relatively simple and short compared to the grain loading operation at country elevators. The feed is conveyed into the clam shell from the storage bins using enclosed mechanical conveyors. It is loaded on a feed truck by opening the clam shell. The feed falls into the truck positioned under the clam shell. The opening of the clam shell and dumping 3 to 13 tonnes of feed into a feed truck takes approximately 10 to 60 s. Dust is entrained when the feed drops into the truck. Due to the high moisture content of the feed, low free dust content of the feed, and the short duration of the operation, very little dust gets entrained during this operation.

Sampling Methods

Three feed mills (Feed Mills B, C, and D) were selected for conducting sampling based on how well they represented feed mills in the U.S. in terms of size and operation procedures. In addition to these feed mills, a fourth feed mill (Feed Mill A) was selected based on its proximity to Texas A&M University, to test our protocols, sampling equipment, and procedures.

Conventional EPA approved fugitive and point source sampling techniques were not appropriate to measure particulate emissions at feed mills due to the unique configuration of emission sources. To obtain accurate measurements of the TSP emissions resulting from the grain receiving operations at a feed mill, two sampling procedures were developed. One procedure utilized a plastic enclosure under the truck to contain the entrained dust. The enclosure prevented the dust from moving out of the shed with the ambient air and facilitated the capture of dust with four high volume (HiVol) samplers. We referred to this protocol as “under the truck” sampling. The emission factor calculation consisted of dividing the total dust captured by the total mass of grain unloaded. The same procedure was used for feed loading wherever the physical constraints of the feed loading shed were not restrictive. This protocol was referred to as “over the truck” sampling.

The second procedure involved measuring the concentration of particulate at three different heights at the downwind exit of the shed. The particulate mass emission rate was calculated by multiplying the net average concentration at the downwind exit of the shed by the average volumetric flow rate of air through the shed during the grain unloading/feed loading periods. The ratio of the net mass of particulate leaving the shed and the tons of grain unloaded or feed loaded yielded an emission factor. We referred to this protocol as “grid sampling”.

“Under the Truck” Sampling

For sampling underneath the truck, the dump pit was enclosed along its perimeter with a continuous plastic sheet 6 ft wide, as shown in figure 1. The plastic was stapled to sections of 5 × 5 cm wood on all four sides of the pit for anchoring purposes. The sides of the enclosure were laid down flat over the dump pit before the grain truck drove into the shed. Once the truck was positioned over the dump pit, the plastic was lifted up to the sides of the truck. The plastic was clamped on all four sides of the hopper using metal clips, thus enclosing the area underneath the hopper and above the dump pit. Four sampling probes, two on each side of the truck, were introduced into this plastic at a height of about ¾ m (2.5 ft). Each sampling probe was connected to a cyclone pre-separator, specially designed for this study. A pre-weighed zip-lock bag was attached to the bottom of the cyclone pre-separator to collect the particulate separated from the air stream by the cyclone. The particulate penetrating the cyclone was captured by a 20 × 25 cm (8 × 10 in.) filter. Laboratory tests established that the cyclone pre-separator had a cut-point of 3.6 μm and a collection efficiency of 99.8% allowing negligible amounts of dust to carry over to the filter. The use of the cyclone pre-separator allowed continuous sampling of each truck without the need to change filters during sampling.

A centrifugal flow fan was used to pull air through the system. The volume rate of flow (sampling rate) through the system was measured using a calibrated orifice meter and controlled with a variable AC voltage supply (variac) connected to the fan. The sampler control panel consisted of a main switch, a digital timer, a variac and a magnehelic gauge. The samplers were turned on at the start of the unloading operation. The samplers were turned off after the first hopper was empty and during the time the truck driver was aligning the second hopper over the pit (no grain was unloaded during this period). The samplers were turned on again while unloading the second hopper.

The sampling period consisted of the entire unloading period and terminated only after all the grain unloaded was completely inside the dump pit. There was no potential for any PM to get entrained once the grain was below ground level inside the dump pit. The volumetric flow rate through each sampler was adjusted and maintained at a constant flow rate of 1.47 m^3/min (52 ft^3/min) throughout the sampling period. The volumetric flow rate of 1.47 m^3/min corresponded to the design velocity of the cyclone pre-separator. At the end of the sampling period, the run time for each sampler was recorded. The exposed filters and zip lock bags were collected, stored and returned to the lab for analyses.

“Over the Truck” Sampling

To sample over the truck, the 2.5 × 4 m (8 × 14 ft) clam shell was enclosed along its perimeter with a plastic sheet approximately 15 × 2 m (48 × 6 ft), as shown in figure 2. The plastic was clamped to the sides of the clam shell in a way that allowed it to hang freely, thus enclosing the area underneath the clam shell and above the feed truck. Once the truck was positioned under the clam shell, our intentions were explained to the truck driver. Four sampling probes were then inserted into this plastic enclosure at a height of approximately 4 m (13 ft) from the floor of the shed.

Each sampling probe was connected to the same type of cyclone pre-separator designed for sampling underneath the truck. A 3.5 m (12 ft) long, 3.8 cm (1.5 in.) diameter extension pipe was used to access the plastic enclosure above the truck. Zip lock bags were attached to the bottom of the cyclone pre-separator to collect the particulate separated from the air stream. The particulate penetrating the cyclone was captured by a 20 × 25 cm (8 × 10 in.) filter connected to the outlet of the cyclone. The same centrifugal flow fan and control panel used for the “under the truck” sampling were used to pull air through each sampler.

The samplers were turned on during the transfer of feed from the clam shell to the truck. The volumetric flow rate of air through each sampler was adjusted and maintained at a constant flow rate of 1.47 m^3/min (52 ft^3/min), corresponding to the design velocity of the cyclone pre-separators, throughout the sampling period. The samplers were turned off 30 s after the truck had been loaded. The sampling time for each sampler was recorded once the truck had left the shed. The exposed filters and zip lock bags were exchanged for new ones in preparation for the next sampling.

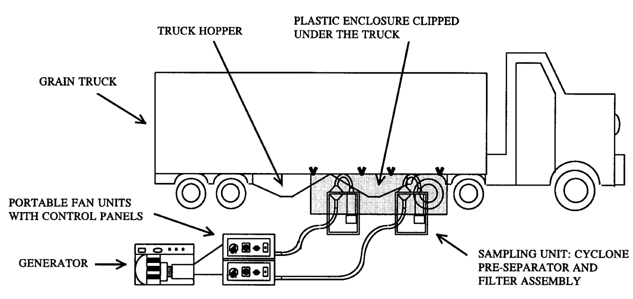

Figure 1–A schematic diagram to illustrate the “under the truck” sampling protocol.

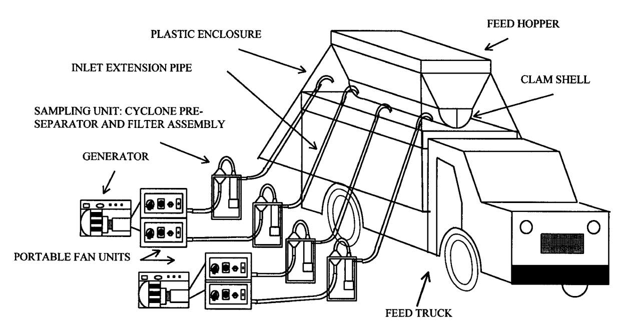

Figure 2–A schematic diagram to illustrate the “over the truck” sampling protocol.

GRID SAMPLING

The grid sampling equipment consisted of two stands with three open faced 20 × 25 cm (8 × 10 in.) filters mounted on each stand at 0.9, 1.8 and 2.7 m (3, 6 and 9 ft) above the ground, as shown in figure 3. Both stands, with three sampling points on each, were placed at the downwind exit of the grain unloading shed. The stands were positioned between the truck and the wall of the shed. One stand on each side of the truck. Air was pulled through each sampler using the same centrifugal fan and control panel designed for the "under the truck" sampling. Sampling was initiated at the start of the grain unloading operation. The volumetric airflow rate was adjusted and maintained constant at 1.13 m^3/min (40 ft^3/min), corresponding to the ambient sampling flow rate suggested by EPA, throughout the sampling period. The samplers were shut off during the short time period after the first hopper was empty and during the time the driver was aligning the second hopper over the pit. The sampling was terminated after the grain unloading operation had been completed and the unloaded grain was below ground level inside the dump pit.

After the truck left the shed, the sampling times for each sampler were recorded and the exposed filters were collected and stored. During the sampling period the wind velocity inside the shed was periodically measured with a hot wire anemometer and recorded. A weather station was set up at each site to record wind velocity, wind direction, temperature, relative humidity and barometric pressure. HiVol and PM10 (Wedding) samplers were used to measure the background TSP and PM10 concentrations upwind.

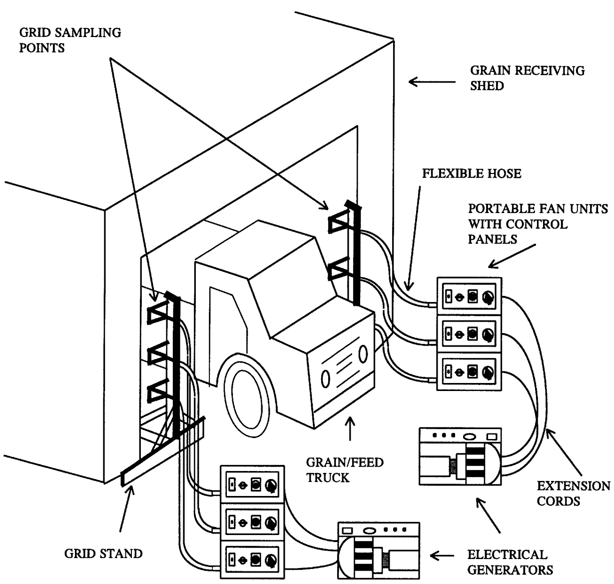

Figure 3–A schematic diagram to illustrate the grid sampling protocol.

PARTICLE SIZE DISTRIBUTION (PSD) ANALYSES

In 1995 EPA established that the annual emission rate of PM10, instead of TSP, would be used to determine if a facility is considered a major source (Wegman, 1995), as a consequence of the 1987 revision of the NAAQS. As a result, the interim AP-42 emission factors for grain elevators and feed mills were based on TSP and PM10 emissions. The results of this study to develop emission factors for feed mills associated with cattle feed yards also had to be based on TSP and PM10 emissions.

PSD analyses of all TSP samples was conducted using a Coulter Counter Multisizer in the Processing Laboratory, Department of Agricultural Engineering to calculate PM10 emission factors. A study performed to compare results obtained from cascade impaction samplers and from Coulter Counter analysis indicated that both these methods have inherent errors associated with particle sizing (Treaftis et al., 1986). A study conducted to compare results obtained with a HiVol PM10 (Wedding) sampler and a Coulter Counter analysis concluded that they were comparable (Raina et al., 1995).

The Coulter Counter analysis has been criticized because the sample preparation technique could break up agglomerates. The breaking up of the agglomerates would bias the PSD, resulting in a larger quantity of smaller particles than present in the actual sample. If percentage of PM10 was calculated from a TSP sample, it would be accurate to assume that the results of the Coulter Counter analysis would indicate a larger percentage of PM10 than actually present in the TSP sample. For all practical purposes, the results obtained from the Coulter Counter analysis would be more conservative than those from PM10 samplers.

RESULTS

Tests were conducted in the laboratory to simulate "under the truck" sampling to quantify the dust deposited in the sampling unit. Results indicated that a maximum of 3% of the total dust captured by the sampling unit was deposited inside the cyclone pre-separator and associated duct prior to the filter. To be conservative, the total dust captured underneath the truck was increased by 5% before calculating the emission factors for the grain receiving operation. The total dust captured above the truck was increased by 10% for sampling above the truck during the feed loading operation to account for the 3 m (10 ft) extension to the probe, before calculating the emission factors.

Sampling at the grain receiving shed (Feed Mill B) using both sampling protocols ("under the truck" and grid) simultaneously, indicated that the downwind grid samplers were capturing dust that had escaped from the plastic enclosure. Comparing the mass of dust captured by both protocols suggested that approximately 30% of the mass of dust captured under the truck had been caught by the grid samplers. This was attributed to the truck driver opening the hopper bottoms too quickly allowing the grain to flow into the pits at rates faster than 4.5 tonnes/min (approximately 167 bushels/min). The sampling system was designed for an unloading rate of 4.5 tonnes/min which would be equivalent to a sampling rate of 5.89 m^3/min (208 ft^3/min) for all the samplers combined.

We modified our "under the truck" protocol to include coordination by our safety director with the truck drivers to slowly open the hopper bottoms. Opening the hopper bottoms slowly decreased the duration of choke flow resulting in more dust being entrained. The increased amount of entrained dust suited our goal to be conservative in the approach to accurately measure particulate emissions. Although, very little dust escaped the plastic enclosure in mills C and D with this protocol change, the total dust mass captured utilizing the "under the truck" sampling protocol was increased by 30% to account for the possible loss of particulate escaping the plastic enclosure.

With this modification to the calculating procedure for the "under the truck" protocol, all of the emission factors using this protocol were increased by 35% (5% to account for dust deposition inside the pre-separator plus 30% to account for dust escaping the plastic enclosure). The emission factors using the "over the truck" protocol were increased by 40% (10% to account for dust deposition inside the pre-separator plus 30% to account for dust escaping the plastic enclosure).

The volumetric flow rate of ambient air through the shed was an important component in calculating the emission factors for grain unloading and feed loading operations with the grid sampling protocol. It was observed that the wind direction and velocity constantly fluctuated during the sampling periods associated with grain unloading and feed loading. We realized that errors in calculating the volumetric flow rate of air through the shed would result in errors in calculating emission factors. The following general equation was used to calculate emission factors with the grid sampling protocol:

$$EF = (C \times Q \times t)/(W) \quad (1)$$

where

EF = emission factor, g of dust entrained per tonne of grain unloaded (lb/ton)

C = concentration of TSP measured by the grid samplers, g/m^3 (lb/ft^3)

t = sampling time (min)

Q = volume rate of flow through the shed, m^3/min (ft^3/min)

W = total mass of grain unloaded, tonnes (tons)

The "Q" in equation 1 was determined by multiplying the open area (exit area of the shed not covered by the truck so as to enable free flow of air through the shed) by the average velocity. We attempted to use the hot wire anemometer velocity measurements taken during the sampling period to calculate the average velocity. There were large variations in this data due to the ever changing wind direction and velocity. Since the data collected with the hot wire anemometer had large variations we chose to use the velocity vector component from the weather station data as our average velocity during the sampling period. It is believed that this decision resulted in a higher velocity which subsequently resulted in a higher emission factor for the grid sampling protocol.

Emission factors calculated using the "under the truck" and "over the truck" sampling protocols did not require measurements of the volumetric flow rate of air through the shed. Hence, it is likely that the results obtained from the "under the truck" and "over the truck" sampling protocols provided more accurate determinations of grain receiving and feed loading emission factors than the results obtained from grid sampling.

The average wind velocity components through the grain unloading/feed loading shed at Feed Mills B, C, and D were 54, 134, and 188 m/min (2, 5, and 7 mph), respectively. The wind velocities ranged from 27 to 107 m/min (1 to 4 mph) at Feed Mill B, 54 to 268 m/min (2 to 10 mph) at Feed Mill C and 27 to 349 m/min (1 to 13 mph) at Feed Mill D. The air velocity at the inlet of the grid sampling points was 22 m/min (0.82 mph). Since the air velocity at the inlet of the grid sampling points was always less than the average wind velocity components through the grain unloading/feed loading shed, the air sampling was anisokinetic. If the sampling rate is less than isokinetic there is an overestimation of the concentration because the larger particles that were not originally in the gas volume sampled would travel into the sampling probe and would be included in the sample (Hinds, 1982), as shown in figure 4. To be conservative, the measured concentrations were not adjusted for anisokinetic sampling.

Static charge acquired by the plastic enclosure used in "under/over the truck" attracted grain dust. We conducted additional tests to quantify the amount of dust that adhered to the inside of the plastic enclosure used in the "under/over the truck" sampling protocol.

For the "under the truck" sampling protocol, results indicated that the maximum dust per unit area that would be attracted to the plastic surface if the surface had not had prior exposure to grain dust was 5.38 g/m^2 (0.5 g/ft^2). We also determined that a maximum of 0.32 g/m^2 (0.03 g/ft^2) would be attracted to the plastic surface if the surface had had prior exposure to grain dust. We estimated the total surface area of one side of the plastic exposed to the grain dust to be 14.86 m^2 (160 ft^2: two 4 ft × 8 ft walls and two 4 ft × 12 ft walls). Once the plastic is covered with dust there is very little static charge to attract more dust particles.

The results indicated that there was a maximum potential of 80 g of dust adhering to a new 14.86 m^2 plastic sheet. After sampling the first truck with a new plastic sheet, it is estimated that approximately 5 g could have adhered to the plastic during ensuing runs. Since, new plastic sheeting was only used for the first truck sampled at Feed Mills B and D, 80 g of dust was added to the total dust captured for these samples, before calculating the emission factors. For each remaining truck sampled with "under the truck" protocol, 5 g of dust was added to the total dust captured, before calculating the emission factors.

Over the truck sampling was performed for feed loading only at Feed Mill B. The process of loading feed onto the truck required approximately 30 s. As soon as the clam shell opened, the moist feed fell into the truck and there was very little dust entrained in the air. For all the 22 trucks sampled (71 tonnes of feed unloaded) with the "over the truck" sampling protocol the total amount of dust entrained (after adding 40% of the dust captured to account for the deposition of dust in the pipe and the dust that escaped from the enclosure) was 117 g. Due to the very small magnitude of numbers involved, it was assumed that there was negligible loading of dust to the plastic enclosure

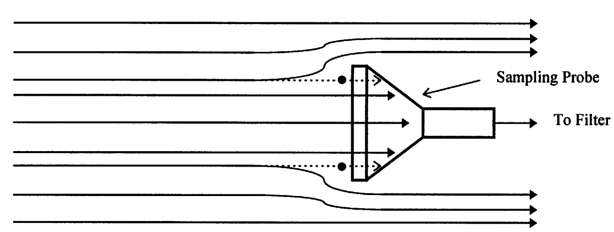

Figure 4–Anisokinetic sampling where sampling velocity < wind velocity.

Table 2. TSP emission factors for the different sampling protocols

	Grain Unloading		Feed Loading	
	"Under the Truck" Sampling	Grid Sampling	"Over the Truck" Sampling	Grid Sampling
No. of trucks sampled	13	7	6	8
Avg. emission factor, gm/tonne (lb/ton)	6 (0.012)	13.5 (0.027)	2 (0.004)	1.7 (0.0034)
Standard deviation	3.5 (0.007)	13.5 (0.027)	0.35 (0.0007)	1.1 (0.0022)

Table 3. Emission factors for sampling carried out at different feed mills

	Grain Receiving (Corn) at Feed Mills			Feed Loading at Feed Mills		
	B	C	D	B	C	D
No. of trucks sampled	7	10	3	6	5	3
Average emission factor, gm/tonne (lb/ton)	6.15 (0.0123)	10.00 (0.020)	9.65 (0.0193)	2.10 (0.0042)	1.4 (0.0028)	2.15 (0.0043)
Standard deviation	4.10 (0.0082)	12.1 (0.0242)	0.30 (0.0006)	0.35 (0.0007)	0.9 (0.0018)	1.4 (0.0028)

during over the truck sampling. However, to be conservative, 5 g of dust was added to the total dust captured to account for the dust that adhered to the plastic.

The emission factors calculated using different sampling protocols for grain receiving and feed loading are given in table 2. The emission factors for grain receiving and feed loading operations calculated from sampling data collected at the three feed mills are given in table 3.

The PSD analyses were performed on the exposed filters and the dust collected in ziplock bags using the Coulter Counter Multisizer. EPA (1995) assumed that the PM10 emission factor would be 25% of the TSP emission factor for all grains. Our results from the "under the truck" sampling suggest that 12.3% of the TSP is PM10. The PSD results from the grid sampling suggest that 15.6% of the TSP is PM10. The weighted average percentage PM10 for "under the truck" sampling and grid sampling was calculated to be 13.6 with a standard deviation of 2.79. We calculated PM10 emission factors for grain unloading as 15% of the TSP emission factors. The higher percent PM10 values from the grid samples is logical. The "under the truck" samples captured more of the particulate in the 10 to 100 μm range. Many of these particles settled out prior to being captured by the grid samplers.

The average percentage PM10 of particulate captured with "over the truck" sampling was calculated to be 6.4 with a standard deviation of 2.74. The average percentage PM10 from the PSD analyses for feed grid sampling protocol was calculated to be 32.2 with a standard deviation of 6.09. To be conservative, the PM10 emission factors for feed loading were calculated by taking 35% of the TSP emission factors. The weighted average emission factors and associated standard deviations for the grain unloading and feed loading operations at feed mills associated with cattle feed yards are given in table 4.

Table 4. Average emission factors and associated standard deviations

	TSP Emission Factor		PM10 Emission Factor	
	Grain Unloading	Feed Loading	Grain Unloading	Feed Loading
No. of trucks sampled	20	14	20	14
Avg. emission factor, g/tonne (lb/ton)	8.60 (0.0172)	1.85 (0.0037)	1.30 (0.0026)	0.4 (0.0008)
Standard deviation	8.85 (0.0177)	0.85 (0.0017)	1.35 (0.0027)	0.35 (0.0007)

SUMMARY AND CONCLUSIONS

- A summary of all the adjustments made to the sampling data collected at feed mills is given in table 5.
- There is a significant difference between the emission factors for feed mills developed by this study, the 1988 AP-42 and the 1995 interim AP-42 emission factors, as indicated by table 6.
- The average TSP emission factor for corn receiving (8.5 g/tonne or 0.017 lb/ton) developed by this study is approximately a hundred and fifty times lower than the 1988 TSP emission factor for grain receiving (1250 g/tonne or 2.5 lb/ton) and more than eight times lower than the 1996 interim TSP emission factors (75 g/tonne or 0.15 lb/ton) published by EPA. However, the average TSP emission factor for corn receiving (8.5 g/tonne or 0.017 lb/ton) developed by this study is very close to the average TSP emission factor reported by Kenkel and Noyes (1995) of 9.5 g/tonne (0.019 lb/ton). It is likely that the slower rate of unloading grain at a feed mill, as a consequence of smaller pits and slower legs compared to elevators, would result in lower emission factors.
- The average TSP emission factor for the feed loading operation (1.5 g/tonne or 0.003 lb/ton) developed by this study is more than three hundred times lower than the 1988 TSP emission factor for feed loading at feed mills (500 g/tonne or 1 lb/ton) and ten times lower than the interim TSP emission factor for corn shipping (15 g/tonne or 0.03 lb/ton) at grain elevators published by EPA (1995). There are two reasons for the low emission factor associated with loading feed at feed mills compared to loading grain at elevators: (1) Processed feed at feed mills associated with cattle feed yards is typically loaded into trucks at a moisture contents of

Table 5. Summary of adjustments made to sampling data

	Adjustments	
	Under the Truck Sampling	Over the Truck Sampling
Dust deposition inside the sampler	5% of total dust collected	10% of total dust collected
Dust lost from plastic enclosure	30% of total dust collected	30% of total dust collected
Dust adhered to the plastic enclosure	80 gms for the first truck sampled at Feed Mills B and D; 5 gms for each remaining truck	5 grams for each truck

Table 6. A Comparison of emission factors for feed mills*

	1988 AP-42 Emission Factors	Emission Factors Developed by	1995 Interim AP-42 Emission Factors		Emission Factors Developed by this Study	
	TSP	Kenkel & Noyes	TSP	PM10	TSP	PM10
Grain unloading, gm/tonne (lbs/ton)	1250 (2.5)	9.5 (0.019)	75 (0.15)	20 (0.04)	8.5 (0.017)	1.3 (0.0026)
Feed loading, gm/tonne (lbs/ton)	500 (1.0)	---	15 (0.03)	4 (0.008)	1.85 (0.0037)	0.4 (0.0008)

* The 1988 AP-42 emission factors are for all types of grain; whereas, the 1995 interim AP-42 emission factors and the emission factors developed by this study are for handling corn.

20% (wet basis) or higher. The addition of water and steam, during the processing of grain to feed, binds the fine dust so that it is not free to become entrained; (2) The use of clam shells to load 3 to 15 tonnes of feed into a truck in a period of 30 s to 3 min is not conducive to dust entrainment in air.

- EPA listed the PM10 dust content of grain as 25% of total suspended particulate (TSP) in the 1996 interim AP-42 emission factor publication. PSD results for this study suggest that the PM10 emission factor for grain unloading and feed loading should be calculated by using 15% and 35% of the TSP emission factors, respectively.
- EPA (1995) proposed the following model for interim emission factors for grain elevators:

$$EF = A \times DR \qquad (2)$$

where

- EF = emission factor, g of dust entrained per tonne of grain or feed transferred (lb/ton)
- A = emission factor normalized to wheat, g of dust entrained per tonne (lb/ton) if wheat were the grain handled (calculated by dividing the emission factor for any given grain by its DR)
- DR = dustiness ratio (relative dustiness of grain handled compared to wheat)

The "A" in equation 2 was the average emission factor reported by Kenkel and Noyes (1995). This average incorporated data from hopper bottom, receiving end dumps, and floor sweepings. Equation 2 can be interpreted as follows: If the DR represented the free fine dust (FFD) present in the grain in g/tonne (lb/ton), "A" would be the fraction of the FFD entrained by the grain or feed transfer process. It is logical that only a fraction of the FFD content of grain will be entraining during a transfer.

Recommendations

- It would not be prudent to establish an emission factor that would result in an AER that is too low. SAPRAs use EPA emission factors in calculating the facility's maximum AER. If EPA were to establish an emission factor lower than can be achieved with existing abatement technology, many facilities would emit PM at rates in violation of their permit and be subject to monetary penalties. Hence, emission factors proposed by this study were calculated by adding the average emission factors plus one standard deviation based upon actual measurements in the field (table 7).
- It is our recommendation that the model proposed by EPA with the 1995 interim emission factors be modified to facilitate broader applicability to various grain handling processes. The DR for corn reported in the interim AP-42 document (EPA, 1995), corresponds closely to FFD content values reported by Parnell et al. (1992). These FFD values represent the grams (pounds) of free dust less than 100 μm/tonne (ton) of grain as determined by the "air wash" procedure. Using the FFD content rather than the DR results in the following model:

Table 7. Proposed emission factors for feed mills handling corn

	Emission Factor for Grain Unloading, g/tonne (lb/ton)		Emission Factor for Feed Loading, g/tonne (lb/ton)	
	TSP	PM10	TSP	PM10
Average emission factor	8.5 (0.017)	1.30 (0.0026)	1.85 (0.0037)	0.40 (0.0008)
Standard deviation	9.0 (0.018)	1.35 (0.0027)	0.85 (0.0017)	0.35 (0.0007)
Proposed emission factor	20.0 (0.035 ≅ 0.04)	2.65 (0.005)	2.7 (0.005)	0.75 (0.002)

$$EF = F \times FFD \qquad (3)$$

where

- EF = emission factor, g of dust entrained per tonne of grain or feed transferred (lb/ton)
- F = fraction of the free dust in the grain entrained at a transfer point
- FFD = free fine dust content, g of free dust less than 100 μm/tonne of grain or feed (lb/ton)

The term "free" dust has been used in this report to more accurately reflect the fine (less than 100 μm) dust content of grain and feed that is available to get entrained which can subsequently result in impacting the public downwind. High moisture feed has a higher fine dust content than dry grain. But in the high moisture feed, this fine dust is not free to get entrained during feed loading. Similarly, grain treated with mineral oil will have less FFD per ton than untreated grain.

The "F" in equation 3 refers to the fraction of the FFD in the grain entrained at the transfer point. If the fraction of dust entrained during a grain unloading operation were constant, the "F" could be calculated by dividing the emission factor by the FFD. For an emission factor of 20 g/tonne (0.04 lb/ton) and an FFD of 1250 g/tonne (2.5 lb/ton) for corn, the fraction of the FFD entrained would be 0.016. Therefore, 1.6% of the FFD in the corn is entrained during the unloading process at a feed mill. This model facilitates the calculation of emission factors based on the FFD content of the material being handled and the "F" value of the handling operation. This model has an added advantage that the variables included are measurable physical characteristics of the material being handled and the handling process. It is likely that the fraction of FFD entrained is constant while unloading grain from a hopper bottom truck into a pit even though the FFD content will vary from grain to grain.

If the model described by equation 3 were to be utilized by EPA to determine emission factors for feed mills and the EPA (1995) DR values were used as FFD values, the general equations for calculating feed mill emission factors for different grains are given in table 8.

For example, the emission factor for unloading wheat at a feed mill would be calculated with the following equation:

$$EF = 0.016 \times 500 \text{ g/tonne} = 8 \text{ g/tonne}$$

$$= 0.016 \text{ lb/ton} \qquad (4)$$

Table 8. Proposed model for calculating emission factors for feed mills

Type of Grain	TSP Emission Factor, gm/tonne (lb/ton)		PM10 Emission Factor, gm/tonne (lb/ton)	
	General	For Corn	General	For Corn
Grain unloading	0.016 × FFD	0.016 × 1250 (0.016 × 2.5)	0.0024 × FFD	0.0024 × 1250 (0.0024 × 2.5)
Feed loading	0.002 × FFD	0.002 × 1250 (0.002 × 2.5)	0.0006 × FFD	0.0006 × 1250 (0.0006 × 2.5)

- The primary grain of choice at feed mills associated with cattle feed yards is corn. Using the concept of the average emission factor plus one standard deviation, our study suggests that the emission factors associated with corn unloading and feed loading should be 20 g/tonne (0.04 lb/ton) and 2.5 g/tonne (0.005 lb/ton), respectively.
- It is difficult to accurately measure the FFD of high moisture feed with an air wash test due to the requirement of maintaining the initial moisture content of the feed sample throughout the test. Estimating the emission factor for feed using the FFD value of the parent grain would be inaccurate because the FFD values of high moisture feed are relatively small compared to grain. It is our proposal that a smaller fraction of dust entrainment ("F" value) be used with the parent grain FFD value. In this case, the fraction of TSP that would be entrained while loading feed would be 0.002 (0.2%). In reality, the FFD for high moisture feed is approximately 10% of the parent grain FFD which suggests that approximately 2% of the free dust in the feed is entrained during the feed loading operation.

Expanding this concept to other grains, the expected emission factors for different grains using the EPA DR values as FFD values are presented in table 9. This concept of calculating emission factors for grain unloading and feed loading at feed mills using different grains incorporated the following assumptions: (1) The FFD content is accurately depicted by the EPA (1995d) DR values; (2) The fraction of dust entrained during grain unloading is 0.016 (1.6%) of the fine dust content of grain.

Table 9. Proposed emission factors for feed mills handling different types of grain

Type of Grain	FFD g/tonne (lb/ton)	TSP, g/tonne (lb/ton)		PM10, g/tonne (lb/ton)	
		Grain Unloading	Feed Loading	Grain Unloading	Feed Loading
Corn	1250.0 (2.50)	20.0 (0.040)	2.5 (0.005)	3.0 (0.006)	1.0 (0.002)
Wheat	500.0 (1.00)	8.0 (0.016)	1.0 (0.002)	1.0 (0.002)	0.5 (0.001)
Milo	875.0 (1.75)	14.0 (0.028)	2.0 (0.004)	2.0 (0.004)	0.5 (0.001)
Soybean	1250.0 (2.50)	20.0 (0.040)	2.5 (0.005)	3.0 (0.006)	1.0 (0.002)
Mixed	975.0 (1.95)	15.5 (0.031)	2.0 (0.004)	2.5 (0.005)	0.5 (0.001)

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ACRONYMS

AER	Allowable Emission Rate
DR	Dustiness Ratio
EPA	Environmental Protection Agency
FCAA	Federal Clean Air Act
FFD	Free Fine Dust
FOP	Federal Operating Permit
HiVol	High Volume
PM	Particulate Matter
PM10	Particulate Matter less than or equal to 10 microns
PSD	Particle Size Distribution
SAPRA	State Air Pollution Regulatory Agency
TSP	Total Suspended Particulate