ENGINEERING ANALYSIS OF THE AIR POLLUTION REGULATORY PROCESS IMPACTS ON THE AGRICULTURAL INDUSTRY

A Thesis

by

JENNIFER MARIE LANGE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2008

Major Subject: Biological and Agricultural Engineering

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Approved by:

Co-Chairs of Committee,	Ronald E. Lacey
	Calvin B. Parnell
Committee Members,	Bryan W. Shaw
	Kenneth D. Casey
	Dennis O'Neal
Head of Department,	Gerald Riskowski

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ABSTRACT

Engineering Analysis of the Air Pollution Regulatory Process Impacts on the Agricultural Industry. (May 2008)

Jennifer Marie Lange, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Calvin B. Parnell
Dr. Ronald E. Lacey

The EPA press release dated February 23, 2004 states that the three Buckeye Egg Farm facilities had the potential to emit more than a combined total of 1850 tons per year of particulate matter (PM). This number was based on flowrate calculations that were three times higher than those measured as well as a failure to include particle size distributions in the emissions calculations. The annual PM emission for each facility was approximately 35 tons per year. The EPA was unjustified in requiring Buckeye Egg Farm to obtain Title V and PSD permits as the facilities could not have met the thresholds for these permits. Engineers need to be concerned with correctly measuring and calculating emission rates in order to enforce the current regulations.

Consistency among regulators and regulations includes using the correct emission factors for regulatory permitting purposes. EPA has adopted AERMOD as the preferred dispersion model for regulatory use on the premise that it more accurately models the dispersion of pollutants near the surface of the Earth than ISCST3; therefore, it is inappropriate to use the same emission factor in both ISCST3 and AERMOD in an effort to equitably regulate PM sources. For cattle feedlots in Texas, the ISCST3

emission factor is 7 kg/1000 hd-day (16 lb/1000 hd-day) while the AERMOD emission factor is 5 kg/1000 hd-day (11 lb/1000 he-day).

The EPA is considering implementing a crustal exclusion for the PM emitted by agricultural sources. Over the next five years, it will be critical to determine a definition of crustal particulate matter that researchers and regulators can agree upon. It will also be necessary to develop a standard procedure to determine the crustal mass fraction of particulate matter downwind from a source to use in the regulatory process. It is important to develop a procedure to determine the particulate matter mass fraction of crustal downwind from a source before the crustal exclusion can be implemented to ensure that the exclusion is being used correctly and consistently among all regulators. According to my findings, the mass fraction of crustal from cattle feedlot PM emissions in the Texas High Plains region is 52%.

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I would like to begin by thanking the biggest influence in my life, God. In times of trial and tribulation I have always had God as a stronghold to cling to. He has blessed me everyday with a loving family, supportive friends, and a great graduate committee all whom have made my experience at Texas A&M amazing.

I would like to thank my committee co-chairs, Dr. Ronald Lacey and Dr. Calvin Parnell. Dr. Parnell, you have been there for me since the beginning, encouraging, supporting, and even pushing me to be the best engineer I can be. I think you know if it weren't for you, grad school would never have been an option, let alone a reality. Dr. Lacey, you came on the scene later but had a huge impact. I appreciate all the advice you have shared and the talks we've had. Thank you both for giving me three of the most challenging and exciting projects.

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I would like to thank my co-authors of the individual papers included. Dr. Calvin Parnell, Dr. Ronald Lacey, and Dr. Bryan Shaw thank you for your assistance with the Buckeye Egg Farm project. Stewart Skloss, Dr. John Wanjura, and Dr. Calvin Parnell thank you for your aid with the air dispersion modeling comparison between ISCST3 and AERMOD. Finally, thank you to Dr. Ronald Lacey and Dr. Calvin Parnell with your guidance on the crustal project. All of your help was invaluable and I cannot thank you enough for the time and effort all of you spent helping me to produce this work.

Thanks to the CREW, past and present. You have ensured that work was never boring and always interesting. You are the best guys I know and I wish you the best in your future endeavors.

Finally, thanks to my family, Mom, Dad, Grandmother, Opa, and Ericha for your love and support throughout my college years and all my life. You are very dear to me.

NOMENCLATURE

40CFR50	Title 40 of the Code of Federal Regulations Part 50
AED	Aerodynamic Equivalent Diameter
AERMOD	AMS/EPA Regulatory Model
AP-42	United States Environmental Protection Agency's Compilation of Air Pollution Emission Factors, Volume I
CAA	Clean Air Act
CAAQES	Center for Agricultural Air Quality Engineering and Science
cfm/lb-bird	Cubic feet per minute per pound per bird
EPA	United States Environmental Protection Agency
ESD	Equivalent Spherical Diameter
FRM	Federal Reference Method
GSD	Geometric Standard Deviation
ISCST3	Industrial Source Complex – Short Term version 3 dispersion model
μm	micrometer
MMD	Mass Median Diameter
MWPS	Midwest Pan Service
NAAQS	National Ambient Air Quality Standards
PM	Particulate Matter
$PM_{2.5}$	Particulate matter less than 2.5 μm AED

PM_{10}	Particulate matter less than 10 μm AED
PM_C	Particulate matter in the coarse region, between 2.5 and 10 μm AED
PSD	Particle Size Distribution
PSD	Prevention of Significant Deterioration
SAPRA	State Air Pollution Regulatory Agency
SIP	State Implementation Plan
TCEQ	Texas Commission on Environmental Quality
tpy	Tons per year
TSP	Total Suspended Particulate Matter

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CHAPTER I

INTRODUCTION

Under the Clean Air Act, the Environmental Protection Agency has been given the authority to regulate air pollution in the United States. In doing so, the EPA is constantly reviewing and, where necessary, updating air quality regulations. The regulations for air pollutions are referred to as the National Ambient Air Quality Standards (NAAQS). The NAAQS are used as a "bench mark" for determining whether an area is classified as in attainment or not in attainment. If there are sufficient numbers of measured concentrations exceeding the NAAQS, the area is classified "non-attainment" and the State Air Pollution Regulatory Agency (SAPRA) must address how the area will be brought back into attainment in their state implementation plan (SIP).

When reviewing the particulate matter NAAQS in 2005, the EPA considered adding a crustal credit for agriculture and mining PM emissions in the course size range of 2.5 to 10 micrometers aerodynamic equivalent diameter (AED) to the recent update to Title 40 of the Code of Federal Regulations Part 50 (40CFR50) (USEPA, 2006). However, when the final version was promulgated in September, 2006, the crustal credit was not included. EPA chose to promulgate a PMc NAAQS of 150 $\mu g/m^3$ and to use the Federal Reference Method PM_{10} sampler as an indicator for PMc. It is likely that within the next 5 years EPA will promulgate a PMc NAAQS lower than the current 150 $\mu g/m^3$ and would consider a crustal credit for agricultural sources for future versions of 40 CFR

This thesis follows the style of the *Transactions of the ASABE*.

Part 50. If this concept were to be adopted, agricultural sources would only be regulated on the mass fraction of PMc emitted that was not considered to be crustal. This could aid in the permitting and regulation of all agricultural sources emitting PMc.

SAPRA engineers use regulatory models to estimate the downwind concentrations from a source in order to issue air permits to industries. The EPA recently mandated a switch from using Industrial Source Complex – Short Term version 3 dispersion model (ISCST3) to the AMS/EPA Regulatory Model (AERMOD) in order to estimate downwind concentrations for permitting purposes. EPA transitioned to AERMOD as the new regulatory model because it incorporates newer science into the Gaussian dispersion model to describe pollutant dispersion in the planetary boundary layer. As such, AERMOD requires more model input data to describe meteorological conditions and terrain features than the older ISCST3. Research has shown that significant differences exist between the concentrations estimated by ISCST3 and AERMOD using identical emission factor and meteorological data. As such, the emission factor used in ISCST3 should not be used to model concentrations in AERMOD and doing so could result in unjustified enforcement actions being taken against industries.

One example of an unjustified enforcement of regulations involved PM emissions from laying hen operations. In 2004, the EPA fined Buckeye Egg Farm $880,598 for failure to obtain appropriate air permits for their facilities. However, after reviewing the contractor's report, several errors were found in the emission calculations completed by the EPA. Only 35 tons per year PM_{10} were being emitted by the Marseille

facility instead of the 740 tons per year of particulate matter as reported by the EPA, a significant difference which would not require the facility to obtain any air permits to continue operating.

CHAPTER II

ENFORCEMENT OF REGULATIONS BASED ON PARTICULATE MATTER EMISSIONS FROM LAYING HEN OPERATIONS

OVERVIEW

The EPA press release dated 02/23/2004 entitled "Ohio's Largest Egg Producer Agrees to Dramatic Air Pollution Reductions from Three Giant Facilities" indicated that Buckeye Egg Farm, L.P., the largest commercial egg producer in Ohio, agreed to pay a civil penalty of $880,598 and committed to installing and testing $1.4 million of controls. EPA's justification for this action was that "Buckeye had failed to obtain necessary air permits" for their facilities at Marseilles, Mt. Victory, and Croton. The necessary permits were Title V and PSD (Prevention of Significant Deterioration). The PM_{10} stationary source emissions threshold (in an attainment area) for a facility to be classified as a "major source" and be required to obtain a Title V permit is 100 tons per year. The threshold for a facility to be required to obtain a PSD permit is 250 tons per year of stationary source PM_{10} emissions. These thresholds do not pertain to TSP measurements.

The authors studied the EPA contractor's reported findings and found several serious errors. First, the consultants measured total suspended particulate (TSP) concentrations. These TSP concentrations were used in determining if Buckeye Egg Farm exceeded the thresholds for Title V and PSD permits. The reported particle size distribution of the particulate matter (PM) sampled and reported by the contractor

demonstrated that the PM emitted was large with approximately 10% less than PM_{10}. EPA reported that the PM emissions from the three large laying operations were 740, 650 and 550 tons per year at Marseilles, Mt. Victory, and Croton, respectively. These values would have exceeded the thresholds, but the emissions were based on TSP not PM_{10}. None of the facilities met the thresholds for requiring Title V or PSD permits based on their PM_{10} emissions. It is incorrect to use annual TSP emissions to require Title V and PSD permits. Hence, the heavy penalties incurred by this agricultural operation were not justified. In addition, the EPA chose to calculate emissions as if the 58 fans in each house were operating at an average of 14,000 cubic feet per minute (cfm) with no regard for ambient temperature. It was inappropriate for EPA to use the high flow rate per fan for both cold and hot ambient conditions. Using the consultant's report, which included the particle size distribution of the samples, it was determined that the amount of PM_{10} measured was a fraction of that reported. The PM_{10} emissions from all three operations did not meet the Title V permit threshold and therefore did not meet the PSD permit threshold.

INTRODUCTION

Particulate matter has been regulated since the introduction of the NAAQS in 1971. When the NAAQS were promulgated, TSP was the criteria pollutant for particulate matter. The NAAQS was made more stringent in 1987 when PM_{10} replaced TSP as the regulated pollutant. PM_{10} is all particulate matter with less than 10 micrometers aerodynamic equivalent diameter (AED). There is a misconception among

many that the amount of PM_{10} in the air is roughly equivalent to the TSP. Because of this misconception, many feel performing particle size distributions are an unnecessary step in regulation process. This is untrue, especially in the presence of agricultural PM. Through much research, the Center for Agricultural Air Quality Engineering and Science (CAAQES) has found that agricultural dust is approximately 10-20% PM_{10} with the majority of the dust being much larger. However, unless a particle size distribution is performed on the particulate matter samples, there is no method to accurately determine the percentage of PM_{10} in the TSP. Knowing this percentage is critical when trying to regulate facilities based on PM_{10} emissions.

The EPA press release dated 02/23/2004 entitled "Ohio's Largest Egg Producer Agrees to Dramatic Air Pollution Reductions from Three Giant Facilities" indicated that Buckeye Egg Farm, L.P., the largest commercial egg producer in Ohio, agreed to pay a civil penalty of $880,598 and committed to installing and testing $1.4 million of controls. EPA's justification for this action was that "Buckeye had failed to obtain necessary air permits" for their facilities. Shortly after this enforcement action, Ohio Fresh Egg purchased Buckeye Egg Farm. In the consent agreement, the company who bought Buckeye was obligated to install additional controls and perform monitoring. In April of 2005, the new owner of this operation was fined an additional $500,000 for non-compliance with the consent decree. Buckeye was charged with failure to obtain Title V and Prevention of Significant Deterioration (PSD) permits. If this laying hen operation did not emit PM_{10} in sufficient quantities to exceed the thresholds for Title V and PSD, the justifications for the enforcement actions did not exist. Our findings are that this

laying hen operation did not emit sufficient quantities of PM_{10} to be required to obtain Title V and PSD permits.

The CAAQES obtained copies of the consultant and EPA's reports that were cited by EPA as the base data for the enforcement actions. In an effort to determine if the EPA was justified in fining Buckeye, CAAQES evaluated the contractor's reports for any discrepancies. CAAQES suspected the reported emission values were too large to be PM_{10} emissions and that the annual PM_{10} emissions reported by EPA in the press release were not reasonable for a laying hen operation. In the contractors report, it is evident that the large amounts of particulate matter being emitted were TSP and PM_{10}. Consequently, Buckeye should not have been required to obtain Title V or PSD permits. Upon further analysis of the data in the reports, the authors found that Buckeye Egg did not emit PM_{10} at rates that would exceed the thresholds requiring Title V and PSD permits. Hence, the justifications used by EPA for the enforcement action was inappropriate.

GOALS AND OBJECTIVES

The goal of this paper is to document the errors made by EPA and EPA's contractors in the enforcement action taken against Buckeye Egg Farm. The objectives of this paper are:

1. Describe the engineering analysis we used to document these mistakes.

2. Stress the importance of specifying which pollutant is to be the regulated pollutant as it pertains to obtaining permits in order to eliminate any confusion and promote equal regulation throughout all states.
3. Promote understanding of the importance of performing a particle size distribution whenever and wherever samples are taken. This will ensure that the reported values accurately describe the measured data.

TITLE V AND PSD THRESHOLDS

Currently there are two emission thresholds that apply to particulate matter, Title V and Prevention of Significant Deterioration (PSD). Both Title V and PSD are regulated under the CAA. Additionally, Title V is regulated under 40CFR70. PSD is regulated under 40CFR52.21. Title V applies to major stationary sources with the potential to emit 100 tons per year (tpy) or more of any air pollutant in an attainment area. PSD applies to major stationary sources with the potential to emit 250 tpy or more of any air pollutant in an attainment area. According to the EPA, Buckeye Egg Farm should have procured both Title V and PSD permits for all three of their facilities. However, the concentrations measured were of TSP and not PM_{10}. PM_{10} is particulate matter with an aerodynamic equivalent diameter less than or equal to 10 μm. The EPA regulates both Title V and PSD based on PM_{10} emissions and not on TSP.

However, each state is allowed to create regulations that are more stringent than the national level. The only stipulation is state regulations are not allowed to be less stringent than the national levels. For example, EPA regulates based on thresholds for

PM_{10} emissions; if a state applies the same emissions thresholds for TSP, the state would have a more stringent regulation. In a memorandum from the EPA, dated October 16, 1995, PM_{10} is to be used in place of TSP as the regulated pollutant under Title V. When questioned, the Ohio EPA, which is the state regulatory agency in Ohio, stated "You are to base Title V applicability determination on PM_{10} (not TSP) based on [an] EPA memorandum dated October 16, 1995." This signifies that the state of Ohio does not have more stringent guidelines regarding Title V and PSD permits. The consultant's report gave results in "particulate tons per year". Further analysis was completed to determine if "particulate tons per year" referred to TSP or PM_{10}.

ASSUMPTIONS AND PRELIMINARY ANALYSIS

The EPA press release dated February 23, 2004 states that the three Buckeye facilities located in Croton, Marseilles, and Mt. Victory had the potential to emit more than a combined total of 1850 tpy of particulate matter. If this were correct, Buckeye would be the first agricultural operation of its kind to exceed the thresholds for Title V and PSD. This suspicion led CAAQES to request a copy of the consultant's reports for further review.

A study of the Marseilles report brought to attention a disagreement between the consultant and the EPA regarding the value to be used for the flow rate per fan. The EPA stated that the measured value was too low and more than doubled the flow rate for each building in their emissions analysis. Based on this disagreement, the flow rate was calculated using the Midwest Pan Service (MWPS) standards for broiler operations for

use in the CAAQES analysis. The standards for flow rate are 0.1 cfm/lb-bird for cold days, 0.5 cfm/lb-bird for mild days, and 1-1.5 cfm/lb-bird for hot days. Each bird was assumed to be four pounds and each of the 16 houses had a maximum capacity of 207,000 birds. The reported number of birds in each house was 173,000, but, in order to be conservative, the maximum possible number of birds was used in the CAAQES analysis.

Next, it was assumed that cold days would be defined as days with average temperatures less than 55^0F, mild days were days with average temperatures between 55 and 70^0F, and hot days were days with average temperatures above 70^0F. National Weather Service (NWS) documents for Columbus, Ohio for 2003 were used to determine daily average temperatures. Since Columbus is within 100 miles of each of the three facilities, the corresponding weather data provided the best weather information for the three Buckeye Egg Farm facilities. Weather data showed that there were 193 cold days, 108 mild days, and 64 hot days. Three possible scenarios were determined based on these assumptions and the consultant's measured results using the consultant's measured emission rate of $2.17*10^{-7}$ pounds per dry standard cubic foot (lb/dscf).

SCENARIOS AND ANALYSIS

Each scenario was completed using the consultant's report for the Marseilles facility which had 16 houses and a maximum of 207,000 birds per house. Scenario 1 provided a baseline model for comparison purposes using the previously stated

assumptions with the average flow rate of 1.25 cfm/lb-bird for hot days. The annual TSP emission rate for Scenario 1 was found to be 317 tpy of particulate matter. Scenario 2 used the maximum flow rate of 1.5 cfm/lb-bird for hot days. The TSP emission value for this scenario was determined to be 350 tpy of particulate matter. In Scenario 3 the actual number of birds in the house was used (173,000 as opposed to 207,000 birds), and the flow rate for hot days was assumed to be 1.25 cfm/lb-bird. The resulting TSP emission value was 265 tpy of particulate matter.

EPA's Contractor did not use an EPA approved monitor to measure particulate matter concentrations. According to the report, they used a GT-321 Aerosol Mass Monitor which can measure both PM_{10} and TSP. However, even though this monitor is capable of measuring PM_{10}, a filter is required to do so. In the schematic included in the appendices of the report, the monitor was used as a TSP sampler as the PM_{10} filter was not included. The Contractors did perform a particle size distribution on the samples collected and included the information in the report. The particle size distribution was not used in the calculations. This is due to the fact that both the EPA and Contractors assumed that PM_{10} is equivalent to TSP. This is a bad assumption to make for agricultural operations. Since agricultural operations emit mostly particles larger than 10μm, the emissions of PM_{10} from these facilities are not equivalent to the TSP emissions. This makes performing particle size distributions necessary in order to be certain the reported values match the measured values.

CAAQES analyzed the Volume Percent Distribution by Average Diameter (microns), included in the Contractor's report for the Marseilles facility in order to

determine the particle size distribution and percentage of PM_{10}. The particle size distribution was determined by first graphing the cumulative percent less than top size and determining the MMD and GSD from the resulting graph. Assuming a particle density of 2 g/cm^3, the MMD and GSD were found to be approximately 30 μm and 2.35, respectively.

While the MMD of 30 μm and GSD of 2.35 will provide the best representation of the data, CAAQES decided to use a range of three possible MMDs, 25, 30, and 35μm, with a constant GSD of 2.35 in order to accurately determine the emission rates. This range was used to account for different particle densities. Since CAAQES had no way to determine the particle density and it was not included in the reports, we assumed a density of 2 g/cm^3 based on previous experience. Including a MMD of 35μm will account for a particle density up to 2.5 g/cm^3. We then compared these possible distributions with the distribution found by Lacey et al. (2003) in his work on broiler operations in Texas. Lacey found that broiler operations have particulate matter which can be characterized by an MMD of 24 μm and a GSD of 1.6. Table 1 compares the percentages of the PM_{10} within the TSP based on the various MMDs and GSDs assumed above.

Table 1. Comparison of the percentages of PM_{10} within the TSP and based on varying MMDs and GSDs. These percentages are used to calculate the PM_{10} emission rate from the Marseilles facility based on the reported TSP values given by EPA and the EPA contractors.

Percentage of particles between 0 – 10 microns (%)	
MMD 25 - GSD 2.35	14
MMD 30 - GSD 2.35	9.9
MMD 35 – GSD 2.35	7.1
MMD 24 - GSD 1.6 (Lacey, 2003)	3.1

Table 2 shows that all of the reported values were below the 250 tpy threshold for PSD and all but one of the values were below the Title V threshold of 100 tpy when particle size distribution s are taken into account. The EPA value of 103 tpy, which does not meet the 100 tpy Title V threshold, was calculated using a particle density of approximately 1.5 g/cm^3 which does not often occur in this type of facility. The EPA reported annual emissions are more than twice the Contractor's due to the fact that the EPA increased the flow rate in their calculations by almost three times the value measured by the Contractors. When the flow rate is adjusted to more accurately model what was measured, the EPA emissions do not meet the Title V threshold. Therefore, if the particle size distribution had been incorporated in the analysis, Buckeye would not have been required to obtain either a Title V or PSD permit.

Table 2: Comparison of possible PM_{10} emissions from the Marseilles facility in tpy using CAAQES scenarios, the consultant's reported TSP values, and the EPA's reported TSP values and the particle size distribution included in the consultant's report to determine percentages of PM_{10} in the TSP.

		Calculated PM10 Emissions (tpy)		
Scenarios	TSP (tpy)	MMD =25µm GSD=2.35	MMD =30µm GSD=2.35	MMD =35µm GSD=2.35
1	317	44	31	22
2	350	49	35	25
3	265	37	26	19
Consultant's Report	325	45	32	23
EPA's Report	737	103	73	52

The consultant's report for Mt. Victory was unavailable, but was assumed to have the same setup and analysis as the report provided for the Marseilles facility with the exception of having fewer houses. Since the consultant's TSP values for this facility are unknown, the EPA's reported value of over 600 tpy was used to determine possible

PM_{10} emissions from this facility. It was assumed that the particle size distributions for the two facilities were similar. The resulting PM_{10} emissions from the Mt. Victory facility were calculated to be 85, 59, and 43 tpy with MMDs of 25, 30, and 35 μm, respectively. This is not accounting for any necessary adjustments in flow rates and is based solely on an overestimate of the TSP emission rate included in the EPA's press release. Even without adjusting the flow rate, the Mt. Victory facility does not meet the threshold for either Title V or PSD.

The consultant's report for the Croton facility was more difficult to analyze due to the different method used to determine the particle size distribution. The particle size distribution for the Croton facility was found using an Anderson In-Stack Cascade Impactor multi-stage sizing device. The Cascade Impactor has eight stages with each stage designed to filter particles less than or equal to a certain size. By the last stage of the impactor, only particles less than 10 μm should be on the filter. The consultant determined from these samples that the MMD of the particulate matter was, at most, three μm. This is impossible for an agricultural facility. In the particle sizing analysis sheets included in the report, cyclone temperature and cyclone pressure drop are measured, but no where in the report does it specify where cyclones were used. It was assumed by CAAQES that cyclones were used in conjunction with the cascade impactor and that the dust from the filter went through a cyclone before entering the impactor. If this is the case it would explain the extremely low MMD.

The results of the cascade impactor plots given in the report do not match the data shown. The data do not follow an upward trend and in some samples negative

masses are recorded. A negative mass should never be achieved when using a cascade impactor. If a negative mass was present, the filter would have lost mass. Since this cannot be the case, something must have gone wrong during the testing. Analysis of the stages and net weights of each stage for all the samples measured determined that the impactor was not operating consistently. Furthermore, one of the tests was run for only 60 minutes, as opposed to six hours, which was the run time for the other samples. The one hour run produced the highest concentration and is inaccurate because the test is so short. Figures 1 and 2 show the differences in impactor performance for the same house during back-to-back runs. Run 4 behaves more like expected with no explanation given to the variation in Run 3.

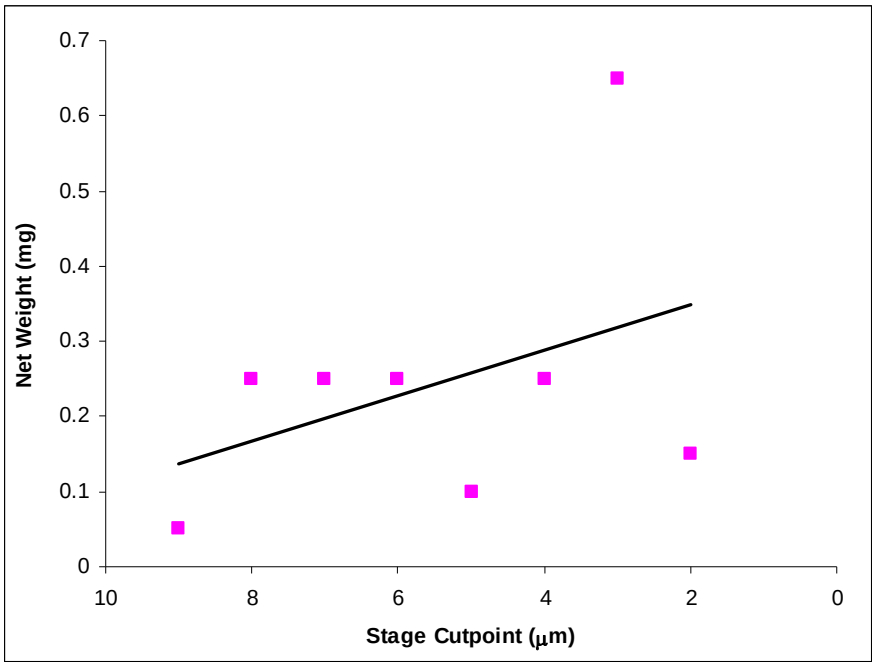

Figure 1: Particle size distribution analysis on the Croton facility house 2, sample run 3 including linear trend line.

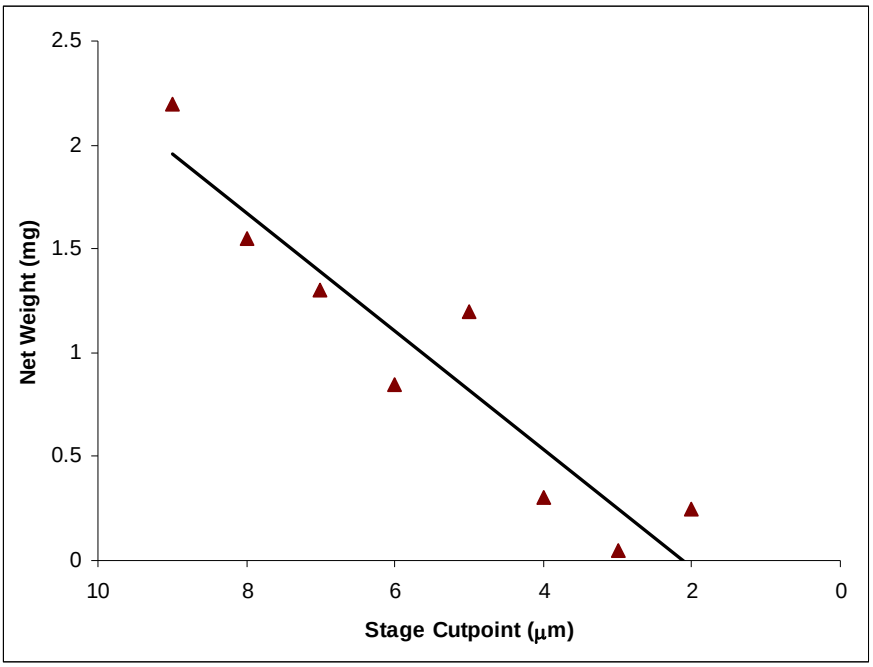

Figure 2: Particle size distribution analysis on the Croton facility house 2, sample run 4 including linear trend line.

The consultant must have performed a best fit line to the data, which is not an accurate assessment of the data, as it does not include all data points in the analysis. Finally, the consultant assumed the particle density was 1.0 g/cm^3 which is too small to be representative of airborne particulates emitted from a laying hen facility. This particle size distribution has too many errors to be used to determine more accurate MMD and GSD values for further analysis. However, if the Croton facility was assumed to have a particle size distribution similar to that of Marseilles, and given the EPA's reported emission rate of over 550 tpy, then the most the Croton facility could have been emitting was 78 tpy of PM_{10} with an MMD of 25 μm and GSD of 2.35.

INACCURATE ASSUMPTIONS

In the Marseilles facility consultant's report and the EPA press release, it was assumed that the 58 fans located in each of the 16 houses would operate continuously 24 hours per day, 365 days per year, regardless of outside air temperature. As seen with the MWPS, flow rates in buildings are lower in colder weather to protect the health of the birds. The assumption that all fans in the houses operated in this manner is unreasonable. Even with this assumption, Buckeye should not have been required to have a PSD permit. For the scenarios listed above, which take into account particle size distribution, Buckeye Egg Farm would not have been required to obtain a Title V permit.

Although a particle size distribution was included in the Marseilles report, it was not included in the calculations. The particle size distribution included in the Croton report was flawed and, consequently, unusable. Also, the consultant reported that having an MMD of 3 μm meant that everything measured was PM_{10} or less and not TSP. This gave justification for not including particle size distributions in their calculations of PM_{10} since PM_{10} would be equivalent to TSP with a distribution this small. It is possible that this was the same reasoning that the particle size distribution was not taken into account in the Marseilles analysis as well. However, the assumption that the MMD is three μm or less for an agricultural facility is incorrect. As seen in the analysis of the Marseilles facility, the largest possible percentage of PM_{10} in the TSP was 14%, and even this large percentage resulted in emission rates lower than the thresholds for Title V and PSD.

CONCLUSIONS

The EPA was unjustified in requiring Buckeye Egg Farm to obtain Title V and PSD permits as the facilities could not have met the thresholds for these permits. The contractor and the EPA's analysis of the measured data were incorrect based on the following:

1. The EPA used a flow rate that is approximately three times more than the contractors measured flowrates in their calculations without proper justification.
2. Both the contractor and the EPA assumed that all 58 fans would run continuously regardless of outside conditions.
3. Both the contractor and the EPA, either purposely or unknowingly, assumed that PM_{10} emissions were equivalent to TSP emissions and therefore did include the particle size distributions in their calculations. Performing particle size distributions is necessary when reporting emissions from any facility but most especially from agricultural facilities. Assuming that PM_{10} emissions are equivalent to TSP emissions is wrong. Particle size distributions should not only be performed but should be included in the calculations once they are completed.
4. The particle size distributions included in the Croton report were incorrectly measured and, consequently, unusable. It is important, when determining the particle size distributions, the operator pay close attention to the data that is being recorded in order to ensure the equipment is performing consistently and as expected. It the equipment is not producing usable outputs, the operator should have the equipment serviced or a different method should be used.

5. Using a cyclone before a cascade impactor will result in an unrealistically small particle size distribution. This is inappropriate methodology to use when determining the particle size distribution.

Based on these conclusions, the EPA did not have the justification to fine Buckeye Egg Farm for not obtaining Title V or PSD permits. It is important that when regulating agriculture, there is a sufficient understanding of the industry. If there is not a sufficient understanding of the industry, regulatory errors may be made based on faulty assumptions. As seen in the Buckeye example, performing and using particle size distributions can be the difference between operating a facility normally with no interruptions or being required to obtain Title V and PSD permits, pay a large fine, and install costly abatement devices in order continue operating. Assigning fines due to inaccurate analysis based on faulty assumptions is wrong and needs to be corrected.

CHAPTER III

EMISSION FACTORS FOR CATTLE FEEDLOTS IN TEXAS BASED ON PARTICLE SIZE

OVERVIEW

Cattle feedlots in Texas are often assumed to be large sources for particulate matter (PM) emissions. Previously, the Texas Commission on Environmental Quality (TCEQ) used the ISCST3 model to estimate downwind concentrations for permitting purposes. Furthermore, researchers have used ISCST3 to back calculate emission factors from cattle feedlots using concentration and meteorological data collected at the source. Recently, the Environmental Protection Agency (EPA) required all state regulatory agencies to switch to AMS/EPA Regulatory Model (AERMOD). EPA transitioned to AERMOD as the new regulatory model because it incorporates newer science into the Gaussian dispersion model to describe pollutant dispersion in the planetary boundary layer. As such, AERMOD requires more model input data to describe meteorological conditions and terrain features than the older ISCST3. However, previous research has shown that significant differences exist between the concentrations estimated by ISCST3 and AERMOD using identical emission factor and meteorological data. Therefore, the emission factor data used in ISCST3 must be updated for use in AERMOD in order to appropriately estimate the downwind influence of PM emissions from a source. This work shows that using measured data from yearly sampling trips from 2002 to 2007, the ISCST3 emission factor is 7.6 kg/1000 hd-day (17

lb/1000 hd-day). After obtaining meteorological data from the TCEQ, the AERMOD emission factor was determined to be 4.5 kg/1000 hd-day (10 lb/1000 hd-day).

INTRODUCTION

Texas is the largest producer of beef in the United States. Cattle feedlots are constantly under regulatory scrutiny at the state and national level with regard to particulate matter (PM) emissions. One such regulatory practice is the permitting of feedlot facilities based on the PM emissions which correspond to the size of the feedlot. The original emission factor published in AP-42 was used for permitting and emissions inventory purposes (USEPA, 1985). This emission factor was developed by Peters and Blackwood (1977) and was based on the TSP emissions. They reported a TSP emission factor of 127 kg/1000 hd-day (280 lb/1000 hd-day). When PM_{10} replaced TSP as the regulated pollutant, the emission factor was adjusted to reflect this change. The new emission factor was determined to be 31.8 kg/1000 hd-day (70 lb/1000hd-day) PM_{10} which is equivalent to 25% of the TSP emission factor. The PM_{10} emission factor was based on ambient sampling of cattle feedlots to determine the TSP to PM_{10} ratio determined by Sweeten et al. (1988, 1998). PM_{10} refers to particles that are equal to or less than 10 micrometers aerodynamic equivalent diameter. Parnell et al. (1993) determined that emissions rates were seasonal and varied with the time of year. Parnell et al. (1999) determined that a more appropriate PM_{10} emission factor is 6.8 kg/1000 hd-day (15 lb/1000hd-day) after completing multiple sampling tests at cattle feedlots.

OBJECTIVES

The objective of this paper is to determine updated TSP, PM_{10}, and $PM_{2.5}$ emission factors for cattle feedlots in Texas using concentration measurements from multiple feedlots in Texas between 2002 and 2007 for both ISCST3 and AERMOD.

MATERIALS AND METHODS

PM samples were collected at two feedlots on the Texas High Plains for a period of one week (per sampling trip) over four years. The two feedlots included in this study are designated Feedlot C and Feedlot D. The study began in 2002 and continued through 2007. Co-located TSP and PM_{10} samplers were placed upwind and downwind of the feedlot as shown in figure 3. The design and operation of the TSP and PM10 samplers are described by Wanjura et al. (2005) and Wang et al. (2005), respectively. Meteorological data was measured using a weather station located on the north side of each feedlot which was the most common downwind location for the sampling period. The filters on the samplers were changed every 3 h during the day and were left for 9 h overnight.

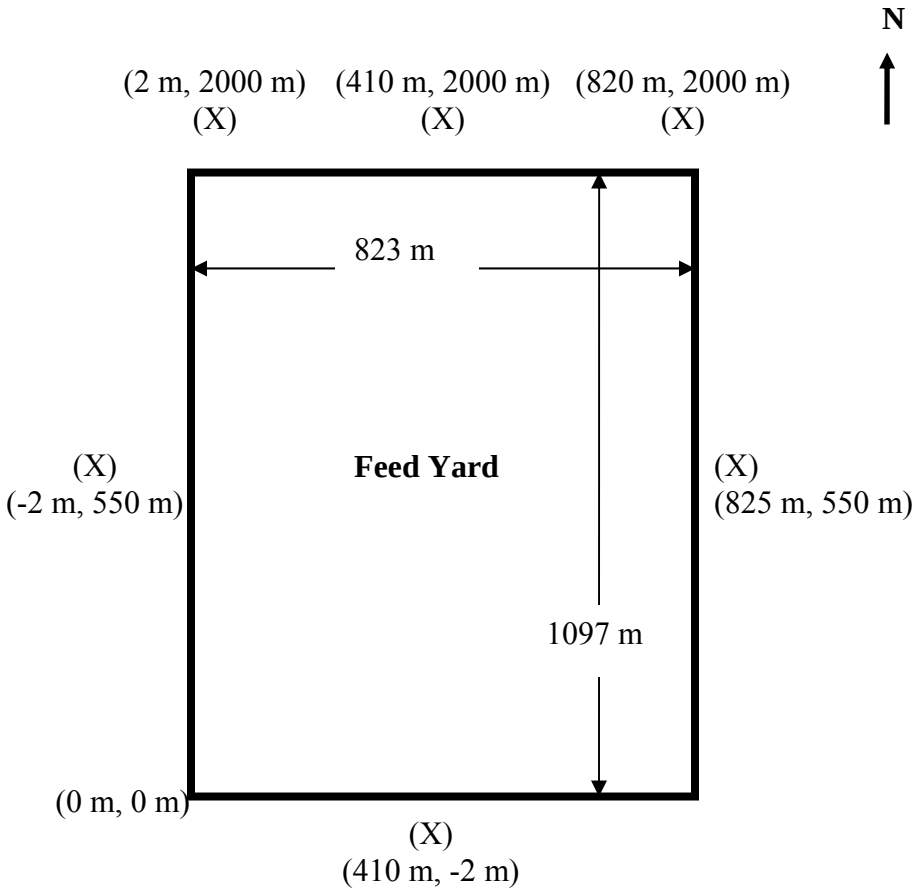

Figure 3. Feedyard C layout with sampler (X) located on each side of the yard. X represents co-located TSP/PM_{10} samplers. The north side has multiple samplers since wind direction is predominantly from the south.

The filters used in the TSP and PM_{10} samplers were 47mm diameter Teflon filters (2 μm pore size Zefluor Membrane Filters, Pall Corp., East Hills, NY). These filters were pre- and post-weighed using a 10 μg analytical balance (Mettler-Toledo International Inc., model AG245, Columbus, OH) in order to determine the mass of PM that was captured. Each filter was pre- and post-weighed three times and the average of the three weights taken as the pre- and post-weights, respectively. The change in filter mass was used to calculate the PM concentration using equation 1.

$$C = \frac{\Delta m_f}{Q_{air} \cdot t_D} \quad (1)$$

where

C = concentration (μg/m^3),

Δm_f = change in mass on the filter (μg),

Q = sampling flow rate (m^3/s), and

t_D = sampling duration time (s).

The filters with Δm_f greater than 200 μg were analyzed using a Coulter Multisizer 3 according to the procedure described by Faulkner and Shaw (2006) to determine the particle size distribution. A minimum net filter mass of 200 μg is needed for an accurate particle size distribution. The mass median diameter (MMD) and geometric standard deviation (GSD) defining the best-fit lognormal distribution of the percent mass vs. equivalent spherical particle diameter (ESD) was determined for each sample. The MMDs were converted from ESD to aerodynamic equivalent diameter as follows:

$$AED = MMD\sqrt{\rho_p} \quad (2)$$

where

AED = aerodynamic equivalent diameter (AED) mass median diameter (MMD) (μm),

MMD = equivalent spherical particle diameter (ESD) MMD (μm), and

ρ_p = particle density (g/cm^3).

The particle density was determined from particle density analyses on samples taken from the feeding pen surface. An AccuPyc 1330 (Micromeritics, AccuPyc 1330 Pycnometer, Norcross, GA) pycnometer was used to measure the particle density of the pen surface material.

ISCST3 was used to determine the emission rates of PM from the pen surface during each test. ISCST3 is a double Gaussian plume dispersion model which uses the empirically derived Pasquill-Gifford dispersion parameters (Turner, 1994). Breeze© ISC was used to facilitate the input of data to the ISCST3 model (Trinity Consultants 2002 and 2004). Using the measured meteorological data and an initial flux of 3.77 μg/m^2-s, ISCST3 calculated the concentrations at each receptor. These modeled concentrations can be approximated using multiple infinite line sources, making ISCST3 a simple model. The infinite line source equation is:

$$C_{10} = \frac{2 \cdot Q_L \cdot 10^6}{\sqrt{2\pi}(\sigma_z \cdot u)} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)\right] \quad (3)$$

where

C_{10} = 10 minute concentration (μg/m^3),

Q_L = emission rate (g/s),

σ_z = vertical dispersion coefficient (m),

u = average wind speed (m/s), and

H = effective stack height (m).

After determining the modeled concentrations at each receptor location around the feedlots using the initial flux value, the flux required to match the measured concentrations was found using the following relationship:

$$\frac{Q_1}{C_1} = \frac{Q_2}{C_2} \tag{4}$$

where

Q_1 = flux to match the measured concentration from the feedlot (μg/m^2-s),

Q_2 = initial flux (3.77 μg/m^2-s),

C_1 = measured TSP concentration at a receptor (μg/m^3), and

C_2 = modeled concentration at the same receptor (μg/m^3).

This relationship was derived from the Gaussian equation (Cooper and Alley, 2002) and is discussed by Wanjura et al. (2004). The average flux for all receptors in each test period as well as the average flux for each sampling campaign was calculated. The mass fraction of PM_{10} in each TSP sample was determined from a log normal characterization of the PSD of the sample described by the measured MMD and GSD. The mass fraction of PM_{10} was multiplied by the TSP emission factor to find the PM_{10} emission factor for each receptor, test period, and campaign.

No direct conversion factor between ISCST3 and AERMOD exists. This is because the models differ in their calculation of the downwind concentrations. ISCST is a double Gaussian plume dispersion model whereas AERMOD uses a Gaussian distribution for the stable boundary layer and a bi-Gaussian probability distribution function for the convective boundary layer. AERMOD also requires more meteorological inputs than ISCST3. The meteorological input requirements for ISCST3 and AERMOD are shown in table 3. As stated earlier, ISCST3 can be approximated using multiple infinite line sources. There is no simple approximation for AERMOD. In order to account for these differences, the emission factor for cattle feedlots based on the measured data was recalculated using AERMOD using the same method as described for ISCST3 with the AERMOD specific meteorological data.

Table 3. Meteorological inputs required by ISCST3 and AERMOD.

Meteorological Input	ISCST3	AERMOD
Year	X	X
Month	X	X
Day	X	X
Hour	X	X
Flow Vector (degree)	X	
Wind Speed (m/s)	X	X
Ambient Temperature (K)	X	X
Stability Class (1-6)	X	
Rural Mixing Height (m)	X	
Urban Mixing Height (m)	X	
Julian Day		X
Height (m)		X
Level		X
Wind Direction (degrees)		X
Sigma theta (degrees)		X
Sigma w (m/s)		X
Sensible Heat Flux (W/m^2)		X
Friction Velocity (m/s)		X
Convective Velocity Scale (m/s)		X
Vertical Potential Temperature Gradient (K/m)		X
Convective Mix Height (m)		X
Mechanical Mix Height (m)		X
Monin-Obuk Length (m)		X
Surface Roughness (m)		X
Bowen Ratio		X
Albedo		X
Temperature Reference Height (m)		X

RESULTS AND DISCUSSION

The average annual emission factor determined using ISCST3 was 7 kg/1000 hd-day (16 lb/1000 hd-day) PM_{10}. The seasonal and average annual emission factors are included in tables 4 and 6. The emboldened emission factors in Table 4 correspond to measured concentrations calculated using ISCST3 and equation 4. These emission

factors were extrapolated to seasonal emission factors using the method described by Parnell et al. (1993).

As shown in table 6, the average annual emission factor for Texas cattle feedlots determined using ISCST3 was 7 kg/1000 hd-day (16 lb/1000 hd-day) PM_{10} when corrected for rainfall events. This emission factor value is appropriate for use in the air pollution regulatory process for cattle feedlots only when using ISCST3 because ISCST3 was the model used to develop this emission factor.

The seasonal PM_{10} emission factors for cattle feedlots based on the measured data and extrapolated values were back calculated using AERMOD. These results are shown in table 5. The emboldened values in table 5 were determined from measured concentration data using AERMOD. The seasonal values reported in table 5 were extrapolated from the emboldened values using the method described by Parnell et al. (1993). The annual TSP and PM_{10} emission factors and overall emission factors for cattle feedlots in Texas based on the analysis using AERMOD are shown in table 7. The overall PM_{10} emission factor for cattle feedlots according to the analysis using AERMOD is 5 kg/1000 hd-day (11 lb/1000 hd-day) PM_{10}.

Table 4. Seasonal TSP and PM_{10} emission factors for cattle feedlots in Texas. The bold emission factors correspond to measured summer- and spring-time concentrations which were back-calculated into emission factors using ISCST3. These factors were extrapolated to seasonal emission factors using the Parnell et al. (1993) method.

	Seasonal ISCST3 Emission Factors Kg/1000 hd-day (lb/1000 hd-day)			
Year	**Season**	**TSP**	PM10	**PM2.5**
2002	Summer	**17 (38)**	**4 (8)**	**0.1 (0.2)**
	Fall	5 (10)	1 (2)	0.1 (0.1)
	Winter	5 (10)	1 (2)	0.1 (0.1)
	Spring	26 (57)	5 (12)	0.1 (0.3)
2003	Summer	**75 (166)**	**16 (36)**	**0.5 (1)**
	Fall	21 (46)	5 (10)	0.1 (0.3)
	Winter	21 (46)	5 (10)	0.1 (0.3)
	Spring	114 (250)	25 (54)	0.7 (1.5)
2004	Summer	49 (109)	12 (27)	0.4 (0.8)
	Fall	14 (30)	3 (7)	0.1 (0.2)
	Winter	14 (30)	3 (7)	0.1 (0.2)
	Spring	**74 (164)**	**18 (40)**	**0.6 (1.3)**
2005 - 1	Summer	20 (43)	4 (8)	0.1 (0.2)
	Fall	5 (12)	1 (2)	0.1 (0.1)
	Winter	5 (12)	1 (2)	0.1 (0.1)
	Spring	**29 (64)**	**6 (13)**	**0.1 (0.3)**
2005 - 2	Summer	**44 (98)**	**9 (19)**	**0.2 (0.5)**
	Fall	12 (27)	2 (5)	0.1 (0.1)
	Winter	12 (27)	2 (5)	0.1 (0.1)
	Spring	67 (147)	13 (29)	0.3 (0.7)
2006-1	Summer	52 (115)	11 (25)	0.3 (0.7)
	Fall	15 (32)	3 (7)	0.1 (0.2)
	Winter	15 (32)	3 (7)	0.1 (0.2)
	Spring	**79 (173)**	**17 (37)**	**0.5 (1)**
2006-2	Summer	**82 (181)**	**18 (39)**	**0.5 (1.1)**
	Fall	23 (50)	5 (11)	0.1 (0.3)
	Winter	23 (50)	5 (11)	0.1 (0.3)
	Spring	124 (273)	27 (59)	0.7 (1.6)
2007	Summer	**80 (177)**	**17 (38)**	**0.5 (1)**
	Fall	22 (48)	5 (10)	0.1 (0.3)
	Winter	22 (48)	5 (10)	0.1 (0.3)
	Spring	121 (266)	26 (57)	0.7 (1.5)
Average	Summer	48 (107)	11 (23)	0.3 (0.6)
	Fall	14 (30)	3 (6)	0.1 (0.2)
	Winter	14 (30)	3 (6)	0.1 (0.2)
	Spring	73 (161)	16 (35)	0.4 (1)

Table 5. Seasonal TSP and PM_{10} emission factors for cattle feedlots in Texas. The emboldened emission factors correspond to measured summer- and spring-time concentrations which were back-calculated into emission factors using AERMOD.

	Seasonal AERMOD Emission Factors kg/1000 hd-day (lb/1000 hd-day)			
Year	**Season**	**TSP**	**PM10**	**PM2.5**
2002	Summer	**40 (89)**	**9 (19)**	**0.2 (0.5)**
	Fall	15 (34)	3 (7)	0.1 (0.2)
	Winter	15 (34)	3 (7)	0.1 (0.2)
	Spring	47 (104)	10 (22)	0.3 (0.6)
2003	Summer	**12 (27)**	**3 (6)**	**0.1 (0.2)**
	Fall	5 (10)	1 (2)	0.1 (0.1)
	Winter	5 (10)	1 (2)	0.05 (0.1)
	Spring	14 (31)	3 (7)	0.1 (0.2)
2004	Summer	27 (60)	7 (15)	0.2 (0.5)
	Fall	10 (23)	3 (6)	0.1 (0.2)
	Winter	10 (23)	3 (6)	0.1 (0.2)
	Spring	**32 (70)**	**8 (17)**	**0.2 (0.5)**
2005 - 1	Summer	33 (73)	6 (14)	0.2 (0.4)
	Fall	13 (28)	2 (5)	0.1 (0.1)
	Winter	13 (28)	2 (5)	0.1 (0.1)
	Spring	**39 (85)**	**8 (17)**	**0.2 (0.4)**
2005 - 2	Summer	**33 (72)**	**7 (15)**	**0.2 (0.4)**
	Fall	12 (27)	3 (6)	0.1 (0.1)
	Winter	12 (27)	3 (6)	0.1 (0.1)
	Spring	38 (83)	8 (17)	0.2 (0.4)
2006-1	Summer	42 (93)	9 (20)	0.2 (0.5)
	Fall	11 (25)	2 (5)	0.1 (0.1)
	Winter	11 (25)	2 (5)	0.1 (0.1)
	Spring	**63 (139)**	**14 (30)**	**0.4 (0.8)**
2006-2	Summer	**51 (113)**	**11 (24)**	**0.3 (0.7)**
	Fall	14 (31)	3 (7)	0.1 (0.2)
	Winter	14 (31)	3 (7)	0.1 (0.2)
	Spring	77 (170)	17 (37)	0.5 (1)
2007	Summer	**64 (141)**	**14 (30)**	**0.4 (0.8)**
	Fall	17 (38)	4 (8)	0.1 (0.2)
	Winter	17 (38)	4 (8)	0.1 (0.2)
	Spring	96 (211)	21 (46)	0.5 (1.2)
Average	Summer	38 (84)	8 (18)	0.2 (0.5)
	Fall	12 (27)	3 (6)	0.1 (0.2)
	Winter	12 (27)	3 (6)	0.1 (0.2)
	Spring	51 (112)	11 (24)	0.3 (0.7)

Table 6. Average annual TSP, PM_{10}, and $PM_{2.5}$ emission factors (corrected for rainfall events) for cattle feedlots in Texas. These values were obtained from measured summer- and spring-time concentrations and back-calculated using ISCST3.

Year	No. Concentration Measurements	Annual ISCST3 Emission Factors kg/1000 hd-day (lb/1000 hd-day)		
		TSP	PM10	PM2.5
2002	34	10 (23)	2 (5)	0.1 (0.2)
2003	46	46 (101)	10 (22)	0.1 (0.2)
2004	94	46 (66)	7 (16)	0.1 (0.1)
2005	133	19 (43)	4 (8)	0 (0.1)
2006	240	41 (90)	9 (20)	0.1 (0.2)
2007	54	48 (107)	10 (23)	0.3 (0.8)
Overall	601	**35 (72)**	**7 (16)**	**0.1 (0.3)**
Standard Deviation		**16 (34)**	**3 (8)**	**0.1 (0.3)**

Table 7. Average annual TSP, PM_{10}, and $PM_{2.5}$ emission factors (corrected for rainfall events) for cattle feedlots in Texas. These values were obtained from measured summer- and spring-time concentrations and back-calculated using AERMOD.

Year	No. Concentration Measurements	Annual AERMOD Emission Factors kg/1000 hd-day (lb/1000 hd-day)		
		TSP	PM10	PM2.5
2002	34	23 (52)	5 (11)	0.2 (0.3)
2003	46	7 (16)	2 (3)	0.1 (0.2)
2004	94	16 (35)	4 (9)	0.2 (0.3)
2005	133	19 (42)	4 (9)	0.2 (0.2)
2006	240	28 (62)	8 (14)	0.2 (0.4)
2007	54	39 (89)	9 (19)	0.2 (0.5)
Overall	601	**22 (49)**	**5 (11)**	**0.2 (0.3)**
Standard Deviation		**11 (25)**	**3 (5)**	**0.04 (0.1)**

CONCLUSIONS

ISCST3 and AERMOD employ different algorithms by which downwind concentrations are estimated from source emissions. AERMOD requires more input data to describe the dispersion of pollutant emissions in the planetary boundary layer.

EPA has adopted AERMOD as the preferred dispersion model for regulatory use on the premise that it more accurately models the dispersion of pollutants near the surface of the Earth than ISCST3. Although the accuracy of the concentration estimates using AERMOD or ISCST3 is outside the scope of this manuscript, this work has shown that it is inappropriate to use the same emission factor in both ISCST3 and AERMOD in an effort to equitably regulate PM sources. If a model is used to determine an emission factor, then the emission factor needs to be updated if the model is replaced with a different model that uses another method to predict the downwind concentrations. Using the ISCST3 emission factor in AERMOD will produce higher modeled PM_{10} concentrations at the property line than measured concentrations. The results of this work show that for cattle feedlots in the Texas high plains region, the Texas cattle feedlot emission factor (corrected for rain events) for use with ISCST3 is 7 kg/1000 hd-day (16 lb/1000 hd-day) while the emission factor for use in AERMOD is 5 kg/1000 hd-day (11 lb/1000 hd-day).

CHAPTER IV

METHOD FOR DETERMINING THE CRUSTAL FRACTION OF CATTLE FEEDLOT PARTICULATE MATTER EMISSIONS

OVERVIEW

The EPA considered excluding the crustal component of particulate matter (PM) in the course size range of 2.5 to 10 micrometers AED for agriculture and mining PM emissions (USEPA, 2006a). It was reported that public exposure to concentrations of PM in the crustal fraction of the PM coarse (PMc) emitted from agricultural sources were not associated with health effects. The final version of 40 CFR 50 (USEPA, 2006b) did not include an exclusion for the crustal fraction of PMc. EPA defines the crustal fraction of PMc as PMc derived from soil. If the crustal credit were to be put into effect, all agricultural facilities including cattle feedlots would likely benefit. For example, if a cattle feedlot were required to meet an off-property PM_{10} concentration of no-more-than 150 $\mu g/m^3$ (NAAQS) and had a measured or modeled downwind concentration of 200 $\mu g/m^3$, then would have to put abatement strategies into place. However, if it were determined that fifty percent of the PM_{10} was crustal, the cattle feedlot could be given a fifty percent credit and would likely be regulated based on 100 $\mu g/m^3$. Currently, there is no objective scientific method for quantifying the mass fraction of crustal in the measured or modeled PM concentrations. Historically, PM speciation studies have focused on urban PM sources which are dominated by the fine particles (particles less than 2.5 micrometers). More speciation data are needed for

agricultural sources in order to obtain credit for the crustal fraction. More importantly a standard methodology is needed in order to determine the percentage of crustal material downwind from an agricultural source. This paper outlines the protocol to be used for determining a definition of the crustal fraction of PMc as well as the methodology to determine the mass fraction of crustal in the PMc emissions from cattle feedlots.

INTRODUCTION

The EPA considered adding a crustal credit for agriculture and mining PM emissions in the course size range of 2.5 to 10 micrometers AED to the recent update to Title 40 of the Code of Federal Regulations Part 50 (40CFR50) (USEPA, 2006a). However, when the final version was promulgated in September, 2006, the crustal credit was not included. EPA chose to promulgate a PMc NAAQS of 150 $\mu g/m^3$ and to use the Federal Reference Method PM_{10} sampler as an indicator for PMc. It is likely that within the next 5 years EPA will promulgate a PMc NAAQS lower than the current 150 $\mu g/m^3$ and would consider a crustal credit for agricultural sources for future versions of 40 CFR Part 50. If this concept were to be adopted, agricultural sources would only be regulated on the mass fraction of PMc emitted that was not considered to be crustal. This could aid in the permitting and regulation of all agricultural sources emitting PMc.

The NAAQS is used as a "bench mark" for determining whether an area is classified as in attainment or not in attainment. If there are sufficient numbers of measured concentrations exceeding the NAAQS, the area is classified "non-attainment"

and the SAPRAs must address how the area will be brought back into attainment in their SIP. Watson et al. (1997) published EPA guidance for the siting of samplers used for determining attainment status. The community oriented sampler sites should be in locations where (1) the public "live, work, and play", (2) locations that are not dominated by a single source, and (3) should have neighborhood- to urban-scale zones of representation.

SAPRA permit engineers and enforcement personnel have utilized a special use of the NAAQS in a number of states. This special use consists of limiting concentrations from a single source to concentrations less than the NAAQS. In effect, it is a concentration limit at the property line (and beyond) not to be exceeded. In order to utilize this special use of the NAAQS, measured or modeled concentrations at the property line and beyond are determined. Based upon EPA guidance (Watson et al., 1997), these "fence line" concentrations should not be used for determining whether areas are in attainment but some states have continued to do so. There is some disagreement as to whether SAPRAs may use fence line concentrations not to exceed the NAAQS in their respective regulatory processes. Some agricultural sources of PMc will have difficulty meeting the PMc NAAQS at the property line. However, by obtaining credit for the mass fraction of crustal PM emissions, these facilities may be able to comply with the NAAQS. It is essential that a precise definition for crustal PMc be established and an objective scientific method for determining the crustal mass fraction of PMc be developed. It is hypothesized that the crustal mass fraction of PMc will be a

function of the physical and chemical properties of the various PM sources and this relationship can be quantified for various agricultural sources, including cattle feedlots.

GOALS AND OBJECTIVES

The goal of this research is to develop a scientific basis for determining the mass fraction of crustal for ambient concentrations of PMc associated with agricultural operations. This paper will outline the approach used to address the following objectives:

1. To define the physical and chemical characteristics of crustal particulate matter.
2. Develop a procedure to determine the mass fraction of crustal in measured concentrations of PMc associated with PM emissions from cattle feedlots or other agricultural sources.

DEFINING CRUSTAL

Currently researchers and regulatory groups do not agree on a definition of the crustal fraction of PMc concentrations. Without a standard definition there can be no clear method for determining the mass fraction of crustal PM in measured or modeled PMc concentrations for regulatory purposes. When defining crustal, both the physical and chemical characteristics must be considered. This is because many particulate matter sources may have similar chemical characteristics (i.e. elemental makeup) but the physical characteristics (i.e. particle size distribution) may be very different. Including both the chemical and physical characteristics will allow researchers to better determine

which sources are contributing the crustal fraction downwind from an agricultural facility. The chemical characteristics we studied were the chemical makeup of the sources contributing to the downwind PMc and TSP concentrations as well as the samples collected downwind from the sources. The physical characteristics and supporting data were the particle size distributions (mass vs. AED) of the sources and downwind samples, the particle density of the particulate matter, the meteorological conditions during the time of sample collection, and the time and location of sample collection.

FIELD SAMPLING

High volume TSP samplers were placed on each side of the source with multiple samplers located on the downwind side. The downwind side of the source is the side which is opposite to the predominant wind direction for the time of year sampling occurs. Meteorological data were collected at the time the samplers were run using a weather station setup on the downwind side of the source. An example of sampler siting is shown in figure 4 for a feed lot in the Texas high plains area.

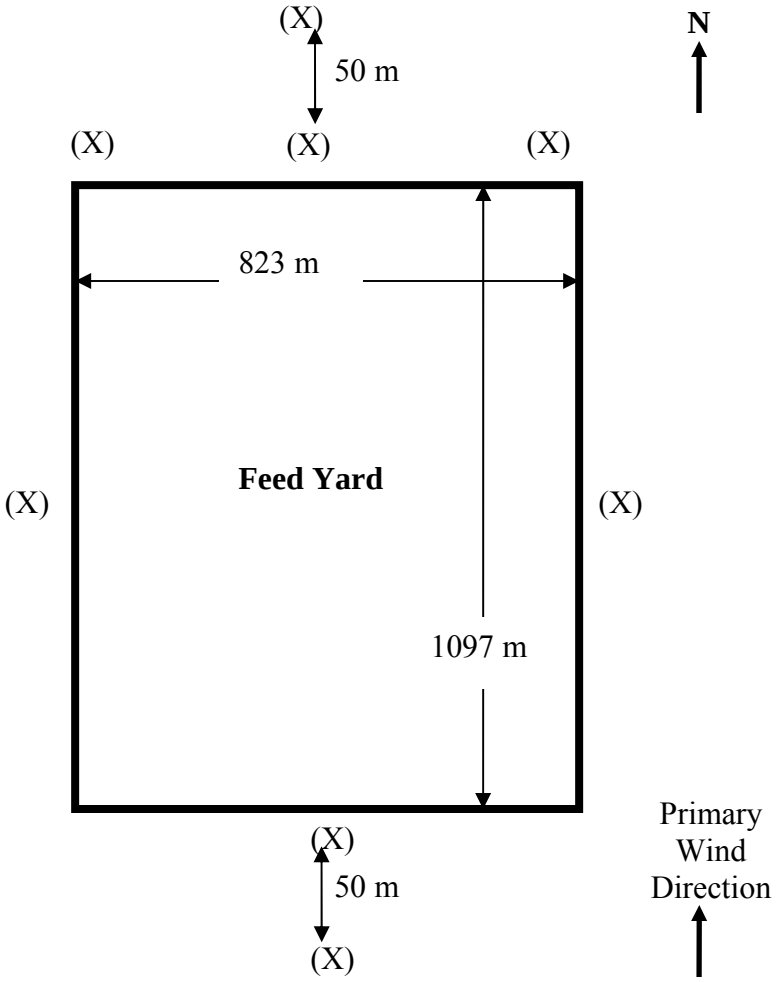

Figure 4: Feedyard C layout with sampler (X) located on each side of the yard. X represents high-volume TSP samplers. The north side has multiple samplers since the wind direction is predominantly from the south.

The samplers were operated on a continuous basis for a period of at least one week. The samplers were run for a sufficient period of time in order to get at least 200 μg of PM mass on the filters. The filters used in our sampling equipment are 20.3 by 25.4 cm borosilicate glass microfiber filters (Pall Corp., Pallflex Emfab filter material, East Hills, NY). The filters were weighed before and after the sampling event to

determine the mass collected on the filter. The filters were handled according to the methodology described by Faulkner and Shaw (2006).

One to two pound source samples were randomly taken from the major sources contributing to the downwind concentrations. For the feedyards, source samples were taken from the pens, feed, roads, and surrounding fields. These samples along with the filters were taken to the laboratory for physical and chemical analysis.

SIEVING

Before the physical and chemical analysis was conducted, source samples were sieved in order to have a more uniform sample. The shaker machine uses 10 sieves in two stacks ranging in size from 2200 to 75 μm. Start by placing 500-700 g of material into the largest sieve on the first stack. Close the lid and run the machine for 20 minutes. When the shaker has run for the allotted time, empty the material collected in the pan from the first stack into the top of the second stack. Close the lid and run the machine for 20 minutes. Once the shaker has stopped, weigh each of the 10 sieves and the two pans to the nearest 0.01 g being careful not to lose any material. Place the material collected in the second pan into a container to be used for the physical and chemical analyses to follow. There were at least 15 g of material less than 75 μm in the second pan in order to perform all the necessary analyses.

DENSITY ANALYSIS

The first physical property to consider is the particle density of the PMc collected after sieving and on the filters. An AccuPyc 1330 (Micromeritics, AccuPyc 1330 Pycnometer, Norcross, GA) pycnometer is used to measure the particle density of the samples. The pycnometer measures density using gas displacement. The pycnometer releases helium of known volume into a container with a known volume. The two volumes are then subtracted to determine the volume of the PM inside the container. The mass of the PM was measured before inserting the sample into the pycnometer. The densities were calculated using equation 5.

$$\rho = \frac{m}{V} \tag{5}$$

where

ρ = particle density of sample (g/cm^3),

m = mass of sample (g), and

V = volume of material sample less open void space (cm^3).

The densities for Feedlots C and E are shown in table 8.

Table 8: Particle densities for each of the contributing sources on or near Feedyards C and E.

Sample ID	Particle Density (g/cm3)
FYC Feed	1.4
FYC Soil	2.3
FYC Road	2.4
FYC Pen	1.7
FYE Soil	2.5
FYE Road	2.6
FYE Pen	1.7
FYE Auxiliary Pen	2.2
Soil Average	2.4
Road Average	2.5
Pen Average	1.7

PARTICLE SIZE DISTRIBUTIONS

The second physical characteristic to analyze is the particle size distribution (PSD). Approximately 3 grams of the sieved material as well as the filters that have a change in mass greater than 200 μg can be analyzed using either the Coulter Counter Multisizer^{TM} 3 (Beckman Coulter Inc, Mutisizer 3, Hialeah, FL) or Malvern Instruments Mastersizer 2000 (Malvern Instruments Ltd., Mastersizer 2000, Worcestershire, UK). These instruments provide particle size distribution data in terms of percent volume versus ESD. The particle diameter data was corrected from ESD to AED as follows.

$$AED = ESD\sqrt{\frac{\rho_p}{\rho_w}} \tag{6}$$

where

AED = aerodynamic equivalent diameter (μm),

ESD = equivalent spherical diameter (μm),

ρ_p = particle density of the sample (g/cm^3), and

ρ_w = particle density of the sample (1 g/cm^3).

The Coulter Counter Multisizer^{TM} 3 can determine particle size distributions for PM in the range of 0.4 to 1200 μm. For this study, we will be concentrating on particles with a diameter less than 100 μm in order to fully compare the samples collected on the filters with the samples collected from the sources. The collected PM samples are dispersed into a 5% Lithium Chloride Methanol electrolyte solution. Using the Coulter method, the PM and electrolyte are drawn through an aperture while a constant current is passed between two electrodes. As a particle passes through the aperture, the current flow between the two electrodes is impeded. Onboard circuitry converts the temporary current fluctuation to a voltage pulse proportional to the volume of the particle (Beckman Coulter, 2000). A normal Coulter Counter PSD will include the results of measuring at least 300,000 particles. It is assumed that the particle density is constant for the different size particles. Hence, percent volume is equivalent to percent mass. Prior to any PSD analysis, the Coulter Counter is calibrated with particles traceable to NIST standards.

The Malvern Mastersizer 2000 can determine PSDs for PM in the range of 0.02 to 2000μm. One advantage of the Mastersizer 2000 is the ability to analyze both wet and dry samples. The Mastersizer 2000 measurement principal is based on light scattering (Mie) where a red light is use to produce forward, side, and back scattering and a blue light is used to produce wide angle forward and back scattering of light once it hits the particles. Thousands of light scatter patterns (collected by the instrument) are used to develop the percent volume versus ESD PSD for the sample (Malvern Instruments, 1999). The PSDs for Feedlots C and E are shown in table 9.

Table 9: Particle size distributions for each of the contributing sources from Feedyards C and E performed on the Coulter Counter and Malvern Mastersizer.

	Coulter Counter		Malvern	
Sample ID	**MMD (μm)**	**GSD**	**MMD (μm)**	**GSD**
FYC Feed	20	1.43	19	1.80
FYC Soil	44	2.05	45	1.87
FYC Road	33	2.31	24	2.20
FYC Pen	34	1.99	38	2.40
FYE Soil	20	2.64	14	2.52
FYE Road	13	2.55	9	4.04
FYE Pen	34	1.86	34	2.38
FYE Auxiliary Pen	43	2.14	39	2.64
Soil Average	32	2.34	29	2.20
Road Average	23	2.43	16	3.12
Pen Average	34	1.92	36	2.39

ASH ANALYSIS

The first chemical characteristic studied was the ash content of the samples. Ash analysis provides the amount of organic and inorganic matter in each source. The organic matter is consumed during the ashing process while the inorganic remains. Ash analysis was conducted according to ASTM standard E 1755-01, Standard Test Method for Ash in Biomass (ASTM, 2001a). The samples were prepared according to ASTM standard E-1757-01 (ASTM, 2001b). Approximately 5 g of material from each source is needed to perform the ash analysis. The material was weighed before it is put into the furnace and after it is removed. The mass of PM remaining after the material is removed from the furnace is made up of inorganic material. The percentage of organic and inorganic material in the samples will contribute to the determination of the crustal mass fraction in the PMc concentrations. Table 10 gives the percentage of ash on a dry basis for samples taken on or near Feedyards C and E.

Table 10: Ash percentage by dry basis for Feedyards C and E including samples taken from the pens in the feedlot, the roads around and through the feedlot, feed from the feed mill, and the soil surrounding the feedlot.

Sample ID	% Ash Dry Basis
FYC Feed	8.9
FYC Soil	86.3
FYC Road	87.6
FYC Pen	39.3
FYE Soil	94.6
FYE Road	91.0
FYE Pen	37.7
FY Auxiliary Pen	76.0
Soil Average	90.5 ± 5.8
Road Average	89.3 ± 2.4
Pen Average	38.5 ± 7.1

ELEMENTAL CHEMICAL ANALYSIS

There are several chemical analysis methods available for use. One method is Neutron Activation Analysis (NAA). NAA relies on either irradiation or radioactive decay. Using NAA, it is possible to measure more than 30 elements without chemical processing. The advantages NAA has over other chemical analysis methods is that it can provide both qualitative and quantitative results, can analyze trace elements in samples, and it is more sensitive than other methods. NAA is also considered to be the "referee method" for new methods due to the fact NAA is five percent accurate and its relative precision is 0.1% (Glascock, 2006). However, samples must sit in radiation for a minimum period of 30 days for a full analysis to be completed, making this method the most time consuming. Tables 11 and 12 show the results of the NAA performed on samples collected at Feedyard E and C, respectively, from the pens, roads, soil, feed from the feed mill, and one of the high-volume TSP filters.

Table 11: Neutron Activation Analysis results for the pens, auxiliary pens, road, and soil found on or near Feedyard E and one of the high-volume TSP filters collected during sampling. The micrograms of each element contained in one gram of the sample material are provided.

		Sample Material (μg element/g sample)				
Symbol	Element	Soil	Road	Pen	Auxiliary Pen	Filter
AL	Aluminum	52640	14792	14867	29532	39581
DY	Dysprosium	6	2	1	3	0
MG	Magnesium	2320	1782	2068	1865	3833
MN	Manganese	566	143	205	243	372
TI	Titanium	4272	1215	933	2699	0
V	Vanadium	67	27	18	36	29
AS	Arsenic	6	5	2	3	0
LA	Lanthanum	37	11	8	20	17
LU	Lutetium	1	0	0	0	1
NA	Sodium	7345	2347	9645	7611	7076
SM	Samarium	6	2	1	3	3
U	Uranium	3	2	1	2	0
YB	Ytterbium	4	1	1	2	0
BA	Barium	485	640	168	362	1007
CE	Cerium	72	22	17	38	35
CO	Cobalt	8	5	3	4	43
CR	Chromium	53	19	14	34	144
CS	Cesium	4	1	1	2	2
EU	Europium	1	0	0	1	1
FE	Iron	21621	7331	5951	10929	21370
HF	Hafnium	24	10	4	16	3
ND	Neodymium	27	7	6	13	0
RB	Rubidium	78	24	35	51	78
SB	Antimony	1	0	0	1	24
SC	Scandium	7	2	2	3	4
SR	Strontium	120	602	170	146	0
TA	Tantalum	1	0	0	1	3
TB	Terbium	1	0	0	0	0
TH	Thorium	11	4	3	6	5
ZN	Zinc	72	94	296	93	1115

Table 12: Neutron Activation Analysis results for the pens, feed, road, and soil found on or near Feedyard C and one of the high-volume TSP filters collected during sampling. The micrograms of each element contained in one gram of the sample material are provided.

		Sample Material (μg element/g sample)				
Symbol	Element	Soil	Road	Pen	Feed	Filter
AL	Aluminum	44525	45060	27431	4805	33257
DY	Dysprosium	2	4	1	0	1
MG	Magnesium	3286	2344	2480	2069	2145
MN	Manganese	380	340	336	123	418
TI	Titanium	4284	3379	1502	0	0
V	Vanadium	52	53	34	0	56
AS	Arsenic	6	6	4	0	5
LA	Lanthanum	24	33	16	0	18
LU	Lutetium	0	0	0	0	0
NA	Sodium	6450	8037	8520	4102	8721
SM	Samarium	4	5	2	0	3
U	Uranium	2	3	2	0	1
YB	Ytterbium	2	3	1	0	1
BA	Barium	622	820	280	0	332
CE	Cerium	48	60	30	0	35
CO	Cobalt	6	6	4	1	7
CR	Chromium	42	55	27	2	51
CS	Cesium	3	3	2	0	3
EU	Europium	1	1	1	0	1
FE	Iron	17689	16075	8993	558	15290
HF	Hafnium	11	15	11	0	2
ND	Neodymium	11	25	8	0	12
RB	Rubidium	83	69	57	11	62
SB	Antimony	40	9	4	38	4
SC	Scandium	7	6	3	0	5
SR	Strontium	229	293	169	0	288
TA	Tantalum	1	1	0	0	1
TB	Terbium	1	1	0	0	0
TH	Thorium	8	11	5	0	6
ZN	Zinc	232	185	279	270	254

Other possible methods that can be used in place of NAA are inductively coupled plasma mass spectrometry (ICP-MS) and X-ray fluorescence (XRF). The benefit of ICP-MS is that it can detect up to thirty-six elements. This is a good method to use if you are measuring concentrations at a location that is affected by many sources (Aeschlinman et al., 2003). XRF is the most common chemical analysis method but it is the least accurate. XRF must be paired with an elemental and organic carbon (EC/OC) analysis to increase the accuracy of the results. One EC/OC analysis that can be used is the thermal optical transmittance (TOT). In general, most elements can be measured using XRF or ICP techniques in place of NAA (Flocchini et al., 1972. Marcazzab, 2004. and Schmeling, 2004). If the chemical composition on the filter is unknown then it would be best to start with NAA then include either ICP or XRF for further confirmation of the chemical analysis results.

CHEMICAL MASS BALANCE MODELING

Once the chemical analysis is completed, the results can be placed into a model to determine location and percent contributions of the major sources. There are many models available to use. The models allow the users to input the results from the chemical analysis as either element mass or element percentages. The models use the masses or percentages to determine which source the element was derived from. The US EPA developed the Chemical Mass Balance Analysis (CMB or MBA) model as well as the UNMIX model to trace elements back to their sources. (Almeida et al., 2006.

Coulter, 2004. Pekney et al., 2006. and Watson, 2004). Other available models are the Multilinear Regression Analysis (MLRA), Principal Component Analysis (PCA), and Positive Matrix Factorization (PMF). Almeida et al. compared MBA and MLRA which showed very similar results. Hopke et al. (2006) compared PCA, UNMIX, and PMF and found that regardless of the model, source determination was consistent. This gives rise to the belief that all models will provide similar source determinations for each sample. Typical model inputs for CMB are given in table 13, although all models have similar inputs which are based on the results of the chemical analyses.

The model will predict the contribution of each source to the downwind concentration. Combining the results of the chemical and physical analyses with the results from the model we determined the crustal mass fraction in the PMc emissions from an agricultural source. Figures 5 and 6 show the percent contributions each source contributes to the downwind concentration collected on each filter.

Table 13: Typical model inputs for EPA's CMB 8.2 as determined by chemical analysis.

Inputs	
General	Site ID Date Duration Start Hour
	Total Mass Concentration ($\mu g/m^3$)
Elements, ($\mu g/m^3$)	Aluminum Ammonium Bromine Calcium Chloride Chromium Copper Elemental Carbon Iron Lead Manganese Nickel Nitrate Organic Carbon Potassium Silicon Sodium Soluble Potassium Sulfate Sulfur Titanium Vanadium Zinc

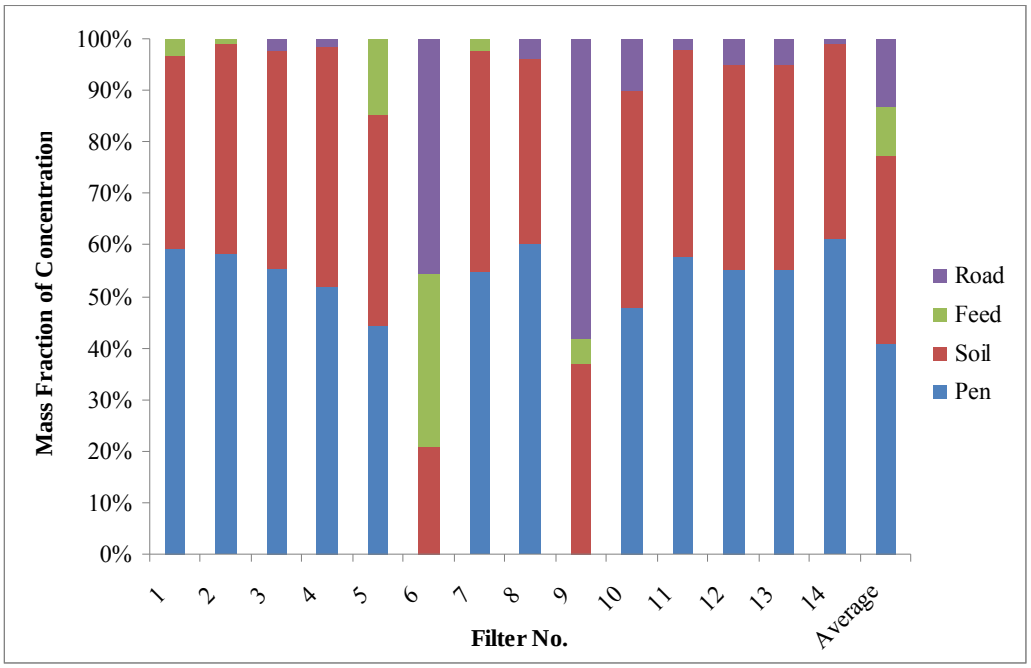

Figure 5: Percent contributions of each of the major sources for Feedyard C including the feed from the feed mill, pens, roads, and soil to the downwind concentration collected on the high-volume TSP filters.

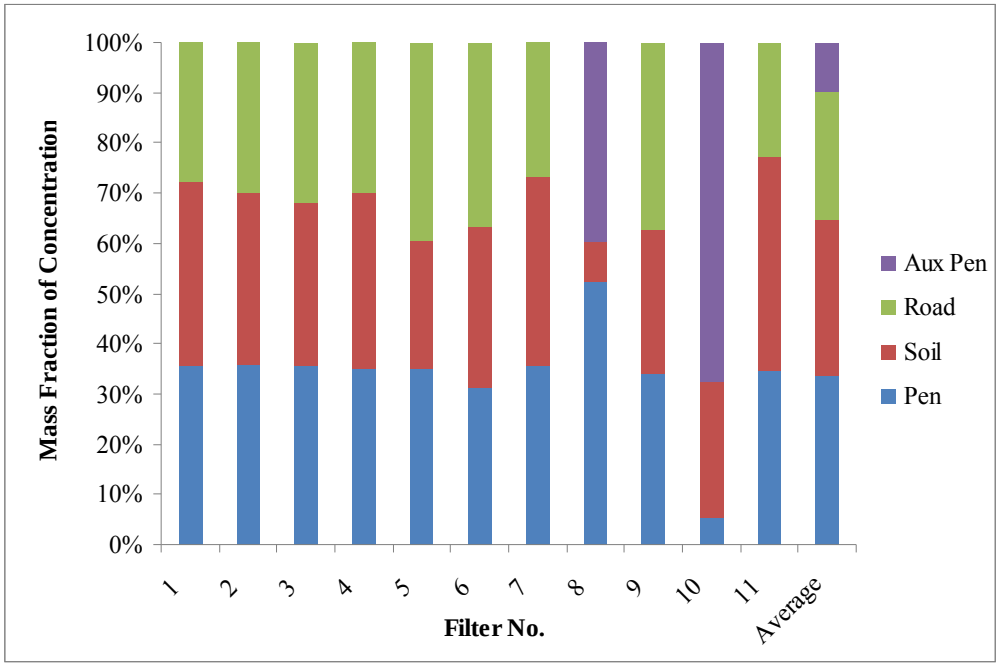

Figure 6: Percent contributions of each of the major sources for Feedyard E including the pens, auxiliary pens, roads, and soil to the downwind concentration collected on the high-volume TSP filters.

The crustal fraction is considered to be the mass fraction from the soil, roads, and any other sources which has ash content greater than 85%. Table 14 shows the percent contribution of the crustal (soil and pen) components and the non-crustal (pens and feed) components. The crustal mass fraction from Feedyards C and E are 48% and 57% respectively. Combined the two feedyards have a 52% crustal mass fraction.

Table 14: Crustal and non-crustal mass fractions for Feedyards C and E for each test and sampling period.

		Mass Fraction	
Feedlot	Test No.	Crustal	Non-Crustal
FYC	1	38%	62%
FYC	2	41%	59%
FYC	3	45%	55%
FYC	4	48%	52%
FYC	5	41%	59%
FYC	6	66%	34%
FYC	7	43%	57%
FYC	8	40%	60%
FYC	9	95%	5%
FYC	10	52%	48%
FYC	11	42%	58%
FYC	12	45%	55%
FYC	13	45%	55%
FYC	14	39%	61%
FYE	1	64%	36%
FYE	2	64%	36%
FYE	3	64%	36%
FYE	4	65%	35%
FYE	5	65%	35%
FYE	6	69%	31%
FYE	7	64%	36%
FYE	8	8%	92%
FYE	9	66%	34%
FYE	10	27%	73%
FYE	11	65%	35%
FYC Average		48% ± 15%	51% ± 15%
FYE Average		57% ± 20%	43% ± 20%
Overall Average		**52% ± 17%**	**48% ± 17%**

CONCLUSIONS AND FUTURE RESEARCH

EPA considered adding a crustal credit for agricultural and mining PMc emissions to the recent update to 40 CFR Part 50 and did not do so. It is likely that within the next 5 years, EPA will lower the PMc NAAQS and provide a crustal credit for agricultural emissions in future versions of 40CFR Part 50. In order for a crustal credit to be considered by EPA, a scientific method for determining the mass fraction of crustal in PMc concentrations downwind from agricultural sources is needed. Following the protocol presented, the mass fraction of crustal in measured concentrations of PM emitted from cattle feedlots in the Texas high plains region is 52%. In order to determine the crustal mass fraction from other agricultural sources the methodology is as follows:

1. Collect 1-2 lb source samples of all contributing sources around and on the field location
2. Collect TSP filter samples making sure each filter collects at least 500 μg of PM
3. Sieve the source samples to less than 75 μm
4. Perform ash analysis on the sieved source samples. Any samples with an ash content greater than 85% will be considered crustal sources.
5. Perform chemical element analysis on the sieved source samples and the PM collected on the filters

6. Model the results from the chemical element analysis using a chemical mass balance modeling program to determine the mass fraction each source contributes to the downwind sample.
7. Sum the mass fractions of the crustal sources in order to determine the total crustal mass fraction for each sample.

Further research should be conducted in order to verify the 52% crustal mass fraction from PM concentrations emitted by cattle feedlots in the Texas high plains region. This research needs to include multiple years of data to account for variations in weather conditions. On future sampling trips, co-located high volume TSP samplers should be used at each location. For each test, one filter should be analyzed for chemical INAA analysis and the other should be analyzed for ash content this is due to the fact that the amount of PM collected on each filter is insufficient to perform both tests using one filter. Finally, a better method for collecting PM from each of the sources needs to be determined in order to perform PSDs that will accurately represent the material collected on the filters from each of the sources.

CHAPTER V

CONCLUSIONS

The following conclusions can be drawn from the research presented here:

- The EPA was unjustified in requiring Buckeye Egg Farm to obtain Title V and PSD permits as the facilities could not have met the thresholds for these permits.
- The maximum annual emission rate from any of Buckeye's three facilities was 45 tpy, which is below the thresholds for Title V and PSD.
- Proper understanding of the agricultural industry by regulators is necessary in order to appropriately regulate the industry.
- ISCST3 and AERMOD employ different algorithms by which downwind concentrations are estimated from source emissions and therefore it is inappropriate to use the same emission factor for both models to regulate PM sources.
- Using the ISCST3 emission factor in AERMOD will result in higher modeled PM_{10} concentrations at the property line than what is measured
- The ISCST3 emission factor for cattle feedlots in Texas is 7 kg/1000 hd-day (16 lb/1000 hd-day) ± 3 kg/1000 hd-day (8 lb/1000 hd-day).
- The AERMOD emission for cattle feedlots in Texas is 5 kg/1000 hd-day (11 lb/1000 hd-day) ± 3 kg/1000 hd-day (5 lb/1000 hd-day).

- A scientific method for determining the mass fraction of crustal in PMc concentrations downwind from agricultural sources is needed in order for EPA to consider adding a crustal credit to 40 CFR Part 50.
- The mass fraction of crustal from cattle feedlot PM emissions is 52% ± 17%.

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VITA

Jennifer Marie Lange
1919 Hollyhock Cir.
Farmington, NM 87401
jlange@neo.tamu.edu

Education

Master of Science Biological and Agricultural Engineering
Texas A&M University (May 2008)
Bachelor of Science Mechanical Engineering
Texas A&M University (August 2005)

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