SMALL-SCALE BURN TESTING

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Several challenges associated with the field sampling of a burn motivated thought toward using a small-scale burn scenario to determine total particulate emissions. A setup was needed that was capable of sampling the entire plume. We anticipated using micro-quartz filters for the sampling operation. The design of the burn chamber needed to provide a mechanism for cooling the burn plume enough that the filter would not be damaged. Additionally, the material being burned needed a ready supply of oxygen to insure complete combustion.

Burn Chamber Design

The chamber used for the burn sampling test was one that was previously built for another unrelated research project. The chamber itself was 3 foot by 3 foot by 3 foot (0.914m x 0.914m x 0.914m) with an access hatch on one side. The top of the box was a pyramid like reduction that led to a 1 foot square ($0.0929m^2$) duct, that was 3 foot (0.914m) tall. See Figure 1.

A cassette loaded with a micro-quartz filter was place on top of the flume and an expansion attached to tubing that leads to the fan was placed over the filter (Figure 2). This setup pulled air from the chamber and through the filter. The holes cut near the bottom on either side allowed air to enter the chamber at the same rate it was being exhausted by the fan.

Testing Procedures

Preliminary Testing

Wheat straw collected from the site of a field sampling burn, conducted near Etter, TX, was used for our small scale burn testing. In preparation for the testing, the straw was separated into four categories and pre-weighed 1/8 lb (56.7 g), 1/12 lb (37.8 g), 1/16 lb (28.35 g), and 1/24 lb (18.9 g). These weight categories were selected as a result of preliminary testing. In the preliminary testing, several sample masses were used to insure that the samples underwent a complete burn without being smothered or oxygen starved. The maximum mass tested was a half pound. The half pound sample burned unhindered for several seconds, but well before the majority of the sample was burned, the fire became oxygen starved and was smothered by the smoke. This resulted in a very incomplete burn with only a small portion of the sample consumed. A quarter pound sample was also tested. Like the half pound sample, it burned for several seconds before becoming smothered and simply smoldering. The eighth pound samples experienced near complete burns with very little smoldering and no smothering of the fire. As a result, an eighth of a pound was set as our maximum sample mass. The smallest samples tested were 1/32 pound (14.2 g). They experienced complete burns, but after post weighing the filters we found that the mass collected was on the same order of magnitude as the resolution of our scale. As a result, a lower limit of 1/24 of a pound (18.9 g) was set for our samples. The other weights were set between the upper and lower limits.

The wheat straw was weighed and stored in plastic bags using the predetermined sample mass categories. During the actual testing, the pre-weighed samples were transferred from the bags to a copper basket. This basket was elevated with a brick to aid in the oxygenation of the fire (Figure 3). With the straw and basket in place, the straw was ignited with a small torch, while at the same time the fan was started and the door to the chamber quickly closed. The fan was run at approximately 40 cfm. This flow rate varied somewhat due to the continual increase in the filter loading. The actual flow rate was not required as we were only interested in the total collected mass.

The middle reduction portion of the chamber was equipped with two “windows”. This was where a 1' x 2' (0.305m x 0.610m) hole was cut into the wall of the chamber and was covered with quarter inch Plexiglas. This allowed for continuous monitoring of the burns. Our protocol called for running the fan until it was determined that the sample no longer had any visible red smoldering coals and no visible plume was evident. At that time the fan was shut down, the cassette was removed, and the chamber was set up for another burn.

We experienced complete burns for every sample tested. Figure 4 is a good illustration of the burning seen during the testing. Figure 5 is a picture of the ash that remains after a sample is burned. Note that there are no large unburned pieces of straw that would indicate an incomplete burn.

Results

After all of the samples were burned, the filters were conditioned for 24 hours, according to QAQC (Quality Assurance & Quality Control) guidelines, and post weighed. Figure 6 is a good example of the loading seen on the filters. It is interesting to note that the filters look to be extremely loaded, this is not the case, as the results will show. The emissions collected from the burns were so dark in color, that in contrast to the white color of the filter, the filter appeared to be heavily loaded.

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Using the pre and post weights of the filters, the mass collected on each filter was determined. This mass collected was divided by the mass of the sample that was burned during the particular test for which that filter was used. The resulting emission factor can be expressed in terms of g/kg or lbs/ton of the total mass burned. For example, if it was determined that 0.25 grams was collected, and the data recorded during the burn indicates that an eighth pound (0.0567 kg) sample was used for this test, the emission factor would be the mass collected, 0.25 g, divided by the mass burned, 0.0567 kg. This calculation gives the result 4.4 g/kg or 8.8 lbs/ton.

Emission Factors for PM10 and PM2.5

From the results of our testing, an average emission factor of 6.05 lbs/ton (3.03 g/kg) was determined. The moisture content of the straw was determined to be 3.7%, yielding a dry weight basis emission factor of 6.28 lbs/ton (3.14 g/kg). These figures have been calculated on a dry basis. These results can be seen in Tables 1 and 2. This emission factor is for total suspended particulate (TSP). Preliminary Coulter Counter analysis of the collected particulate indicates that about 85 to 95 percent of the TSP is PM10, and 25 to 35 percent is PM2.5. Using the average of these, the PM10 emission factor is 5.65 lbs/ton (2.8 g/kg), and the PM2.5 emission factor is 1.88 lbs/ton (0.94 g/kg) (dry basis). Further work is being done to determine more exact ratios of the PM10 and PM2.5 content. An example of the PSD calculation results can be seen in Table 3.

Other sources were found that reported emission factors associated with burning related to agricultural practices. Duprey (1968) reported 17 lbs/ton (8.5 g/kg) for open burning associated with landscape and agricultural refuse. No particle sizing information was reported. Darley (1975) reports emission factors from 4 to 24 lbs/ton (2 to 12 g/kg) for burning associated with sugar cane and pineapple trash burning. He also reports that 90 percent of the particulate from sugar cane leaf trash were less than 0.5 micrometers in diameter, but no information is reported on the method used for particle sizing. The EPA Guidance Document on prescribed burning reports ranges of emission factors from 15 to 150 lbs/ton (7.5 to 75 g/kg), with no particle sizing information.

We have great confidence in the emission factors that resulted from our testing. We do, however, realize that further testing on different crops, and further improvements on our methodology will give better results. For the purposes of creating an emission inventory for prescribed burning operations in the state of Texas, we propose to use our emission factors.

Emissions Inventory for Prescribed Burning in Texas

There is no comprehensive source of data for the number of acres of agricultural prescribed burning occurring in Texas. Because of this, it was necessary to obtain estimates from a variety of sources who were familiar with prescribed burning of certain crops and/or certain areas of the state. All of the estimates that were obtained are included here with their appropriate source.

It was found that throughout the state the only significant agriculturally related prescribed burning that occurs is on wheat, sugarcane, and rangeland. Therefore these are the only numbers that we will present.

Most of the state was estimated to burn less than five percent of its wheat acreage (Robinson, 1999 and Bean, 1999). We chose to use five percent as a conservative overestimation of the number of acres burned since no other data existed. The exception for this number is in the Edward's Plateau region where there is essentially no wheat stubble burning occurring (Taylor, 1999) due to the general cultural practices of the area. For this region we used a number of zero acres burned. These estimations lead to a total acreage of wheat burned to be around 191,000 acres per year (77,295 hectares per year). Biomass for the wheat burned is estimated from the Fertilizer Institute Handbook (1982). It lists a straw production of 1.5 tons (1.361 metric tons) (dry basis) for wheat with a 40 bushel per acre (139,321 liter per hectare) yield. We chose to use this number because we felt it represents a reasonable yield across the state. Therefore, we used 1.5 tons (1.361 metric tons) dry biomass burned per acre.

The vast majority of burning in the state occurs after the end of the winter wheat growing season which is around late April or May. Therefore the burning primarily occurs in late May and June. This time frame overlaps the Spring/Summer transition. We estimated that about 50% of the wheat stubble burning occurs in the Spring season and the other 50% occurs in the Summer.

The number of acres of sugar cane burned was more readily available since all of the sugar cane grown in the state is burned. All Texas sugar cane is grown in the Lower Rio Grande Valley and averages around 40,000 acres per year (16,187 hectares per year) (Rozeff, 1999). The total biomass production of sugar cane is approximately 50 tons per acre (112 metric tons per hectare) with about 15 tons per acre (33.6 metric tons per hectare), wet basis, left on the field after harvesting (Rozeff, 1999). This residue has a moisture content of around 30% (Rozeff, 1999). Therefore about 10.5 tons per acre (23.5 metric tons per hectare) of residue, dry basis, is burned. Almost all of the sugar cane is burned during the fall and winter seasons. Norm Rozeff (1999) estimated that about half of the sugar cane residue is burned in the fall and the other half is burned in the winter.

Rangeland burning varies considerably across the state depending on the predominant land use. In the Edward's Plateau region about 3,900 acres (1578 hectares) were burned this year (Taylor 1999). This number is increasing due to a prescribed burning association that has been recently formed. All of this burning occurred in late August and early September of 1999. The rest of the prescribed burn acreage we have data for are burns conducted by or were estimated by the Natural Resource Conservation Service (Stellbauer 1999). These include 13,000 acres (5,261 hectares) in the Lubbock area, 22,000 (8,903.1) around San Angelo, 30,000 (12,141 hectares) in Shackelford County, 2,000 (809.4) in the Brazos Valley, and 5,000 acres (2,023.4 hectares) in South Texas. According to an EPA document on prescribed burning, these burns occur about 30% in both the Spring and Winter and about 20 % percent in both the Summer and Fall. The total acreage of rangeland burned in Texas according to these sources is around 307,000 acres per year (124,238.7 hectares per year). The biomass for rangeland varies considerably across the state. We estimated it using the biomass for grass hay production of 2 tons per acre (4.48 metric tons per hectare), dry basis (Fertilizer Handbook, 1982). We believe that this is a conservative overestimation of the actual biomass because this number is for hay production where there are generally practices taken to produce a higher yield.

The emissions rate was found by multiplying the emission factor (TSP = 6.28 lbs/ton (3.14 g/kg) biomass, PM_{10} = 5.65 lbs/ton (2.83 g/kg) biomass, $PM_{2.5}$ = 1.88 lbs/ton (0.94 g/kg) biomass) found from the small scale burn tests by the appropriate crop acreage and by the biomass for that crop. With the appropriate conversions this will yield an emission inventory for each crop in tons per season for the state. Because accurate geographical information is not available for most of our prescribed burn acreages we chose to present the data in statewide totals and not in county or district form.

Emission from all agricultural prescribed burning activities totaled around 4146 tons (3761 metric tons) TSP, 3731 tons (3385 metric tons) PM10, and 1244 tons (1129 metric tons) PM2.5 per year.

References

Duprey, R.L., 1968, Compilation of Air Pollutant Emission Factors, U.S. Department of Health, Education and Welfare, Public Health Service, National Center for Air Pollution Control, Durham, North Carolina.

Darley, Ellis F., 1975, Air Pollutant Emissions from Burning Sugar Cane and Pineapple residues from Hawaii, Prepared for Environmental Protection Agency, Distributed by: National Technical Information Service, U.S. Department of Commerce.

Stellbauer, Mike. Natural Resource Conservation Service. September 1999. Personal Communication.

Robinson, Bob. Texas Agricultural Extension Service. Sept. 1999. Personal Communication.

Bean. Bean. Texas Agricultural Extension Service. Sept. 1999. Personal Communication.

Taylor. B. Texas Agricultural Experiment Station, Sonora. Sept. 1999. Personal Communication.

Prescribed Burning Background Document and Technical Information Document for Prescribed Burning Best Available Control Measures, prepared by Environmental Protection Agency's Office of Air Quality Planning and Standards. 1992.

Table 1: Burn Sample Data: (Sample Mass, Dry Sample Mass are mass of wheat straw burned. Delta is post-weight minus pre-weight of filter.)

Sample Mass (lbs)	Dry Sample Mass (lbs)	Dry Sample Mass (kg)	Delta (g)	Dry Basis Emission Factor (g/kg)	Dry Basis Emission Factor (lbs/ton)
0.125	0.120	0.055	0.193	3.536	7.070
0.125	0.120	0.055	0.262	4.803	9.603
0.063	0.060	0.027	0.056	2.045	4.089
0.083	0.080	0.036	0.107	2.929	5.856
0.083	0.080	0.036	0.102	2.792	5.582
0.083	0.080	0.036	0.151	4.156	8.310
0.083	0.080	0.036	0.086	2.354	4.707
0.083	0.080	0.036	0.100	2.750	5.499
0.042	0.040	0.018	0.040	2.214	4.427
0.042	0.040	0.018	0.055	3.024	6.047
0.063	0.060	0.027	0.064	2.354	4.707
0.063	0.060	0.027	0.077	2.827	5.653
0.063	0.060	0.027	0.140	5.141	10.281
0.063	0.060	0.027	0.112	4.117	8.232
0.042	0.040	0.018	0.074	4.085	8.169
0.042	0.040	0.018	0.044	2.418	4.835
0.042	0.040	0.018	0.034	1.886	3.772

Table 2: Burn Sample Final Results and Emission Factor Calculation

Dry Basis Mean (TSP)	Dry Basis Std. Dev. (TSP)	95% Confidence Interval	
		0.94	
6.28	1.98	7.22	5.35
Emission Factor:		6.05	lbs/ton
Moisture Content:		0.0368	
Dry Basis Emission Factor (TSP):		6.28	lbs/ton
Dry Basis Emission Factor (PM10):		5.65	lbs/ton
Dry Basis Emission Factor (PM2.5):		1.9	lbs/ton

Table 3: Example PSD Calculations from Coulter Counter Results

PM10 % from Coulter Counter PSD		PM2.5 % from Coulter Counter PSD	
91.3		23.7	
91.7		27.9	
90.2		25.2	
73.9		21.1	
95% Confidence		95% Confidence	
78.37	95.23	21.71	27.29

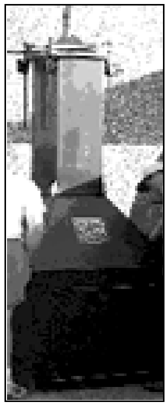

Figure 1: Burn Chamber

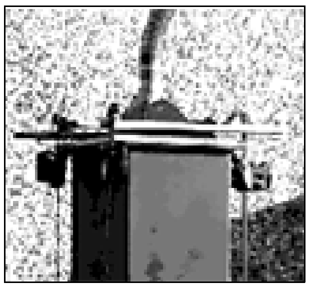

Figure 2: Cassette Placement

Figure 3: Burn Sample Placement

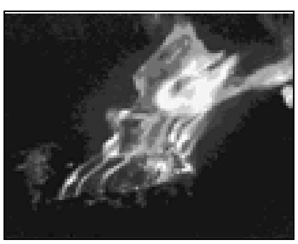

Figure 4: Sample Being Burned

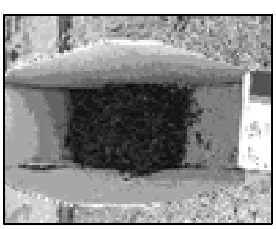

Figure 5: Remaining Ash

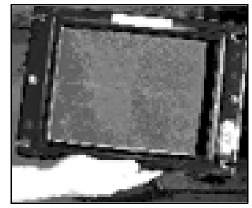

Figure 6: Filter Loading