AN ABSTRACT OF THE THESIS OF

ARTHUR EUGENE HUDSON for the MASTER OF SCIENCE
(Name of student) (Degree)
in MECHANICAL ENGINEERING presented on March 4, 1971
(Major) (Date)

Title: DEVELOPMENT OF AN EMISSION SAMPLING SYSTEM

FOR A MOBILE AGRICULTURAL INCINERATOR

Abstract approved: Redacted for privacy

Richard W. Boubel

An emission sampling system was developed to measure pollutants emitted from a mobile agricultural incinerator developed at Oregon State University. The system was designed to collect a particulate sample on an 8" x 10" fiber glass filter and collect a gaseous sample in a plastic bag. Pollutants measured were particulates and gaseous hydrocarbons. Isokinetic sampling conditions were impractical to attain on the moving source, but were approximated using velocity measurements made during fixed tests of the incinerator. In order to adjust emission values to 12 percent carbon dioxide, the carbon dioxide content of all gaseous samples was measured with a Beckman infrared analyzer. Total gaseous hydrocarbons were measured with a Perkin Elmer hydrogen flame ionization analyzer. A gravimetric analysis was performed on each particulate sample. A particulate sample was found to consist of 5 percent combustibles and
95 percent uncombustibles. That finding, along with visual observations, indicated a considerable amount of dirt was being entrained with the combustion residue.

A particle size analysis was performed by light field microscopy and bimodal distribution was discovered. Data on several typical samples is also included.
Development of an Emission Sampling System
For a Mobile Agricultural Incinerator

by

Arthur Eugene Hudson

A THESIS
submitted to
Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

June 1971
TABLE OF CONTENTS

INTRODUCTION 1

THESIS OBJECTIVE 4

DEVELOPMENT PROCEDURE 6
  Particulate Sampling Device 6
  Isokinetic Sampling 10
  Gas Sampling Device 12
  Laboratory Analysis 14

RESULTS 18

DISCUSSION 23

CONCLUSIONS 27

BIBLIOGRAPHY 29

APPENDICES 30
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Emissions from Mobile Incinerator During Field Tests</td>
<td>18</td>
</tr>
<tr>
<td>II</td>
<td>Overall Results</td>
<td>19</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>Mobile Incinerator and Combine</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Mobile Incinerator Stack with Particulate Sampling Equipment and Piping</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Close-up View of Particulate Sampling Equipment</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Diagram of Particulate Sampling System</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>30 cfm Rotometer Used in High Volume Sampler Calibration</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>Diagram of High Volume Sampler Calibration System</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>Diaphragm Pump Set Up for Gas Sampling</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>Carbon Dioxide Analytical System</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>Hydrocarbon Analytical System</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>Small Particle Mode at 430X</td>
<td>21</td>
</tr>
<tr>
<td>11</td>
<td>Large Particle Mode at 40X</td>
<td>22</td>
</tr>
</tbody>
</table>
DEVELOPMENT OF AN EMISSION SAMPLING SYSTEM
FOR A MOBILE AGRICULTURAL INCINERATOR

INTRODUCTION

Field burning in the Willamette Valley has been a topic of growing concern among a large number of citizens. The State of Oregon has recently tried to control the burning by specifying when fields can or cannot be burned, depending on meteorological conditions. An investigation into the meteorological conditions favorable to good plume rise from burning fields was made in 1969 (1).

Investigations into the composition of field burning smoke have been conducted at Oregon State University from 1965-1968 (2, 3, 9). These investigations found particulate emissions to be approximately 10 lb/ton/fuel, carbon monoxide to be approximately 100 lb/ton/fuel and unburned hydrocarbons to be approximately 9 lb/ton/fuel. It has been estimated that the particulate emission from burning one acre of grass is about $2 \times 10^{22}$ fine particles (5).

The reasons for field burning have been discussed by Hardison (8). The reasons are: (1) To control plant diseases, weeds, and insects; (2) To eliminate unuseable grass straw; and (3) To promote rapid return of nutrients to the soil.

In November, 1969, the Oregon State Legislature appropriated funds for the development of an incineration device to provide better
The development of a mobile incinerator was carried out under the supervision of a technical committee consisting of Dale E. Kirk, acting head of OSU Department of Agricultural Engineering, Dr. Richard W. Boubel, OSU Professor of Mechanical Engineering, Dr. David O. Chilcote, OSU Professor of Crop Physiology, Walter Matson, Resource Development Extension Specialist at OSU, and Glen E. Page, OSU Associate Professor of Agricultural Engineering. Russell Bonlie was Research Engineer in charge of the project.

Simultaneously, projects were underway at Oregon State University Farm Crops Department to find uses for grass seed wastes. It was hoped that a mobile incinerator could be useful in reducing the pollution problem in the valley associated with field burning until such a time as the wastes from the fields could be used economically.

The mobile incinerator consisted of two sections as seen in Figure 1. The first section was a converted combine which picked up the grass straw and conveyed it to the main incinerator. The combine was fitted with a large fan to supply combustion air. The main incinerator was a large single chamber. The large hopper in the front contained augers to convey fuel on to a stainless steel grate in the combustion chamber.
Figure 1. Mobile Incinerator and Combine
THESIS OBJECTIVE

The objective of this thesis was to develop a sampling device, or devices, to sample the particulate and gaseous emissions from the stack of the mobile incinerator under development at Oregon State University. The samples had to be collected in such a manner as to be compatible with the analytical equipment currently available.

Previous studies indicated that the pollutants of main interest were the following:

- Particulates
- Oxides of nitrogen
- Gaseous hydrocarbons
- Carbon monoxide.

Oxides of nitrogen were not included in this sampling program because during preliminary tests their concentrations were found to be negligible. Carbon dioxide was measured in order to determine compliance with air pollution standards which specify that particulate concentrations must be adjusted to 12 percent CO$_2$ or 50 percent excess air.

The sampling device or devices necessary for the purpose of this project were required to:

1. Collect as representative a sample as possible of the particulate and gaseous matter in the stack, given the physical
limitations of the source. The following items are important in obtaining a representative sample.


Isokinetic sampling is the condition where stack gas velocity and sample velocity entering the sampling probe are the same.

b. Measurement of temperature and pressure conditions of the sample in the stack and gas temperature at the metering location.

c. Collect a gas sample with little or no dilution.

d. Collection of particulates in as many points in the stack as possible. Stacks are commonly traversed on two perpendicular diameters.

2. Collect both gas and particulate samples over a relatively short time period because of the short duration of test burns with the incinerator.

3. Be rugged enough to withstand the vibration and bouncing associated with a mobile incinerator.

4. Be reliable in collecting samples with minimal adjustments.

5. Be capable of obtaining samples over a wide range of possible gas conditions and flow rates.
DEVELOPMENT PROCEDURE

Particulate Sampling Device

In development of a particulate sampling device, it was recognized that the sampling device and technique should be such that results could be reliably compared to results of earlier work. An early prototype of the field burner was sampled by using a modified high volume sampler. Field studies of emissions from open field burning also used a modified high volume sampler (2, 3). A high volume sampler was used by Shigehara in sampling veneer dryers with acceptable reproducibility. The high volume sampler used in all the previous studies was a Gelman Hurricane with an 8" x 10" glass fiber filter. A high volume sampler provided a much higher flow rate than sampling devices which would be limited by a water impingement train. A higher flow rate can cut sampling time by at least one order of magnitude depending on the situation. The U.S. Public Health Service recommended sampling train for incinerators has a maximum sampling rate of about one cfm, whereas a high volume sampler rate has a maximum of about 50 cfm.

The high volume sampler was located on a portion of the incinerator cooler than the stack so that filters could be changed readily. The sampling probe extended toward the center of the stack and
pointed vertically downward. The probe was fixed in one position because of the anticipated problems of traversing a hot and jostling stack. The deposition of particles in the 20' x 1-7/8" inside diameter tubing was considered a possible problem; however, it was found not to be a serious problem at flow rates used. The amount of deposition was checked by turning the high volume sampler on while the incinerator was not in use, and developing a high flow rate to pull out any particulate deposited on the walls of the sampling line. When the flow was turned up to about 80 cfm, with no filter in the holder, only a slightly visible puff occurred. The velocity of the gas coming out of the high volume sampler at a sampling rate of 20 cfm was 1052 ft/min. Deposition may have been considerable at lower flow rates than used. Figure 2 shows the location of the high volume sampler with respect to the stack.

Location G on the stack is the entry of the thermocouple for measurement of the stack gas temperature. Figure 3 pictures the physical layout of the particulate sampling equipment. Figure 4 describes each element in the system.
Figure 2. Mobile Incinerator Stack with Particulate Sampling Equipment and Piping
Figure 3. Close-up View of Particulate Sampling Equipment

Figure 4. Diagram of Particulate Sampling System
Isokinetic Sampling

It was anticipated that the stack velocities would be so low that they could not be measured accurately while the incinerator was jostling through the field. The first attempt to provide a velocity measuring device was the construction of a stainless steel anemometer. Problems of weight, friction, and high temperature creep resulted in the abandonment of this method of velocity measurement. Temperatures in the stack at times approached 1400°F. A micro-manometer with a "S" type pitot tube was temporarily installed to measure the stack velocity at the sampling probe. During fixed tests peak velocity heads of 0.1-0.2 inches H₂O were measured. These tests were conducted by feeding bales of hay as fuel at fuel rates similar to that in the field.

It was decided that the velocities in the stack during the fixed tests would be similar to those in the stack during field operation providing that stack gas temperatures and fuel rates were similar. Based on this assumption and a report showing that the smallest theoretical sampling error occurs during nonisokinetic sampling when probe velocities are higher than the stack velocities, 0.177 inches of velocity head or 20 cfm as read on the meter was chosen as the sampling velocity pressure for all field tests of the mobile incinerator (11). Because of the change in temperature between the stack and
the meter on the high volume sampler, the fundamental gas laws were used to adjust the flow rate for the change in specific volume of the gas.

The high volume sampler used an orifice flowmeter which was calibrated against the rotometer shown in Figure 5.

![Figure 5. 30 cfm Rotometer Used in High Volume Sampler Calibration](image)

The calibration curve is shown in Appendix I. The rotometer used was the property of Cornell, Howland, Hayes and Merryfield Consulting Engineers. Because the rotometer was approximately half the necessary capacity, the flow was divided into two streams and the pressure drops on each stream were balanced using a water
manometer to insure that the flow was the same in each stream.

The calibration system is shown in Figure 6. The calibration curve was checked by moving the flowmeter from one stream to the other and repeating calibration process.

**Gas Sampling Device**

Gas samples were drawn from the stack with a small diaphragm pump shown in Figure 7. The sample was drawn out of the stack through a copper tube and through a millipore filter. From the pump the sample was injected into an evacuated plastic bag for analysis. This gave an average concentration over the time period of the particular test.

The copper tubing was fitted with flare nut fittings to insure against leakage. Periodically during the testing the tip of the tubing was covered to determine if all the fittings and the filter holder were properly connected. When the tip was covered no flow could be detected through the vacuum pump, indicating that there were no leaks.
Figure 6. Diagram of High Volume Sampler Calibration System
The analysis of gas samples for CO$_2$ was achieved using a Bechman, Model IR-15A, Infrared Analyzer. Figure 8 shows the analytical instrumentation. The Bechman Analyzer used the infrared light absorption properties of carbon dioxide along with test gases of known carbon dioxide concentration to measure carbon dioxide in the sample. The analyzer was calibrated to full scale at 10 percent carbon dioxide.

Unburned hydrocarbons were measured with a Perkin elmer, Model 1300B, Flame Ionization Analyzer. Figure 9 shows the instrumentation for hydrocarbon analysis. A hydrogen flame is used to
Figure 8. Carbon Dioxide Analytical System
Figure 9. Hydrocarbon Analytical System
ionize the hydrocarbons. The current conducted is proportional to the number of carbon bonds in the gas sample. Known concentrations of propane were used to calibrate the analyzer.

Carbon monoxide analysis was attempted with a Mine Safety Appliances Carbon Monoxide Indicator, but it was found to be inoperative. The suggestion was made that the instrument be repaired or another instrument obtained to supply this desired data in the future.

Microscopic analyses were performed on a particulate sample taken with the high volume sampler. As shown in the results, a bimodel distribution was discovered. Each mode was treated as a separate distribution. The mode made up of relatively large, partially burned particles, was sized while the sample was still on a piece of glass fiber filter. The mode made up of relatively small, spherically shaped particles, was sized by spreading part of the sample on a glass slide and then viewing the sample on the glass slide. The transferring of the sample to a glass slide reduced the depth of field required to size the particles of the smaller mode. This was needed, as the smaller particles required a higher magnification to be sized than did the larger particles making up the other mode. Equal areas method of sizing was used with a standard calibrated Porton eye piece.
RESULTS

The sampling equipment developed was installed and tested during short stationary tests. Stack temperatures were maintained at about 1100°F and fuel rate was about 5000 #/hr. Shortly thereafter the incinerator was taken out to a grass field and actual field tests of the equipment were run. Development of the incinerator was the primary interest of the Agricultural Engineering project, so a thorough emission study was not performed as a part of this thesis project. Only enough samples were taken to demonstrate the capabilities of the sampling equipment. Given in Table 1 are the data of particular interest. Complete data taken, and sample calculations, are contained in Appendix II and III.

Table I Emissions from Mobile Incinerator During Field Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>CO₂ Percentage</th>
<th>UBHC ¹/</th>
<th>Particulate ²/ ³/</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ppm</td>
<td>Grains/ft³ @STP</td>
</tr>
<tr>
<td>1</td>
<td>2.0</td>
<td>7.0</td>
<td>4.42</td>
</tr>
<tr>
<td>2</td>
<td>4.4</td>
<td>6.0</td>
<td>1.48</td>
</tr>
<tr>
<td>3</td>
<td>4.6</td>
<td>4.6</td>
<td>2.05</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>1.0</td>
<td>3/</td>
</tr>
<tr>
<td>5</td>
<td>2.7</td>
<td>8.0</td>
<td>4.86</td>
</tr>
<tr>
<td>6</td>
<td>4.2</td>
<td>6.0</td>
<td>1.81</td>
</tr>
<tr>
<td>7</td>
<td>3.0</td>
<td>9.0</td>
<td>3.42</td>
</tr>
<tr>
<td>8</td>
<td>3.3</td>
<td>10.0</td>
<td>2.60</td>
</tr>
</tbody>
</table>

¹/ Unburned hydrocarbons
²/ Adjusted to 12 percent CO₂ at 70°F and one atmosphere
³/ Not calculated because the sample was considered invalid due to a gas leak.
Data measured had the means and standard deviations shown in Table II.

Table II Overall Results

<table>
<thead>
<tr>
<th></th>
<th>CO₂ Percentage</th>
<th>UBHC ppm as C₃H₈</th>
<th>Particulate Grains/ft³ @STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.46</td>
<td>7.23</td>
<td>2.95</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.901</td>
<td>1.75</td>
<td>1.22</td>
</tr>
</tbody>
</table>

Test four was not included because the sample was considered invalid due to a gas leak.

A velocity traverse of the incinerator stack was not made. Ideally this would have been required before a total emission rate could be calculated. The velocity in the center of the stack varied in the range of 0.1 to 0.2 in H₂O on the "S" type pitot tube. This is 30.8 ft/sec to 43.5 ft/sec. 36 ft/sec was used as the average velocity read on the manometer for the test series. The average emission rate based on the average measurement and the measured particulate quantities was calculated at 87.1 lb particulates/ton straw. The average emission rate based on 6.5 lb gas/lb straw was determined in early design work (4). Calculations are included in Appendix III.

During the field tests the incinerator was burning grass straw at rates 1/2 to 1-1/2 acres per hour or about 3000 to 9000 lb. per hour. The grass was very dry during the day but was noticeably wet
from the dew in the early morning. Excess air required to maintain
a constant exit gas temperature of $1100^\circ F$ varied with fuel rate and
moisture content of the grass. The temperature of the gas at the flow
meter was measured and stayed about $200^\circ F$. A field of orchard
grass was used for all eight test runs. The eight samples were taken
over two days.

It was observed that a considerable amount of dirt was entrained
from the ground. With no fire in the combustion chamber just the
forced air and natural draft picked up enough dirt to produce a visible
plume. A sample filter was heated in a laboratory furnace at $2700^\circ F$
for eight hours to obtain more information about the amount of uncom-
bustibles coming out of the stack. The loss of weight was only about
five percent. This indicated that the plume was mostly uncombustibles
from ash and dirt. Microscopic analysis of a particulate sample re-
vealed a bimodel distribution. The two modes of the distribution
arise from the different origins of the particles. The particles result-
ing from the incomplete combustion of straw are larger and darker
than the particles resulting from the ash of the grass and the dirt that
was entrained under the combustion chamber. The technique for
representation and analysis of the particulate modes is discussed by
Dalavalle and Orr (6, 10). By plotting each mode on log normal
probability paper as a distribution, the mean and geometric deviation
can be easily found. The plots are reproduced in Appendix IV.
These pieces of data completely describe the distribution of interest. Figure 10 is a photomicrograph of the smallest type of particles with a mean of 1.1 microns and a geometric deviation of 1.14.

Figure 10. Small Particle Mode at 430X

Figure 11 is a photomicrograph of the largest type of particles with a mean of 14.5 microns and a geometric deviation of 2.86. At 100X, where the sizing was done, the mode contained particles both too large and too small to size. However, the number of particles that could be sized made up by far the largest number of particles visible. For that reason, 100X was chosen for sizing. The photomicrograph in Figure 11 was taken at 40X because better resolution could be made at that power.
Figure 11. Large Particle Mode at 40X
DISCUSSION

The sampling system developed meets each requirement stated in the thesis objective. In terms of those requirements, the following comments are made:

1. Collect as representative a sample as possible.

The particulate sampling equipment did not collect a sample isokinetically, but an approximation to isokinetic sampling was made with experimental results from the fixed testing which yielded a sample with a minimum of errors. The results show that the stationary tests and actual field tests were similar enough to assume that stack velocities during field tests are nearly the same as the stack velocities measured during the stationary tests.

By the use of the diaphragm pump and copper tubing with flare nut fittings samples were both drawn and transferred to the analytical equipment with little or no dilution.

Temperature measurements were made in the stack and at the orifice meter. The natural draft in stack resulted in only a slight change from atmospheric pressure, therefore all calculations were at 29.9 in Hg.

A possibly significant limitation to the sampling system was the taking of a sample at only one point in the
incinerator stack. Traversing the stack with the sampling probe under operating conditions would have been most difficult, if not impossible, due to height, jostling, heat, etc. Previous work on wigwam burners, which also had a high amount of "stirring" in the combustion chamber and low exit velocity, has revealed that the location of sampling is relatively unimportant (4).

As mentioned in the results, a velocity traverse of the incinerator stack was not made. The velocity measurement made at the center of the stack fluctuated in the range of 0.1-0.2 in H₂O. At low flows this was too wide a fluctuation to follow. A velocity traverse provides the best data only when steady state conditions can be attained.

2. Collect both gas and particulate samples over a relatively short time period. Both gas and particulate samples were able to be taken during one test burn with the incinerator. The time for one burn was from 10 to 20 minutes. A suitable particulate sample took about one minute to collect. A suitable gas sample took about 10 minutes.

3. Be rugged enough to withstand vibration and bounding associated with a mobile incinerator. The sampling equipment chosen to be incorporated into the system was all of simple construction. None of the elements were made of
glass nor contained any fragile electronic equipment. During the time period that the sampling system was mounted on the incinerator, no breakage occurred.

4. Be reliable in collecting a sample with a minimum of adjustments. During the sampling, the only adjustment that was necessary was the adjustment of the flow control gate valve shown in Figures 3 and 4. This adjustment was necessary to maintain a sample flow rate of 20 cfm as measured at the calibrated pressure gage on the high volume sampler outlet.

5. Be capable of obtaining a sample over a wide range of possible gas conditions and flow rates. The gas sampling portion of the sampling system had about 30 feet of copper tubing which provided sufficient cooling so that the gas temperature entering the plastic bag was almost the same as the ambient temperature. As the flow rate is unimportant in gaseous samples, variability of flow rate was not necessary. The glass fiber filter in the particulate sampler could stand higher temperatures than the 200°F that was measured in the outlet of the high volume sampler. By installation of a smaller diameter nozzle on the end of the particulate sampling probe, particulate sampling could have been achieved at stack velocities many times larger
than the ones experienced during the testing. This, in addition to the adjustment available at the flow control gate valve, would allow isokinetic sampling at many flow rates other than the one used.

There is no practical way available to actually measure the velocities in the stack under operating conditions in the field, therefore there is no way of verifying the emission rates calculated. Visual observations have indicated that the grain loading levels are not unrealistic.
CONCLUSIONS

The sampling system provided a viable method of emission sampling for the mobile grass incinerator. This is true because of the degree to which it satisfied the unique equipment requirements as described in the discussion.

The sampling system developed can provide usable emission data for control agency evaluation provided that agreement can be reached on two points:

1. Fixed point sampling is a reasonable limitation of the mobile incinerator under design.

2. Selection of one of three methods for measuring gas flow.
   a. Making a velocity traverse.
   b. Using center line velocity as average velocity.
   c. Calculation of gas flow rate from stoichiometric conditions and measured data.

Isokinetic sampling of a mobile source was found to be very hard to achieve. No method of accurately measuring isokinetic conditions could be devised. An approximation was made using velocity measurements taken during fixed tests of the incinerator.

The sampling system has the advantage of being rugged and simple in construction. The total cost of equipment and installation was about $1000.00.
The gravimetric ash analysis that was performed indicates that reduction of entrainment of topsoil should be an objective of further design changes in the mobile incinerator.

Additional test work is needed to corroborate the results reported and an evaluation should be made to determine exactly what particulate emission levels must be achieved to allow consideration of the mobile incinerator as an alternative to field burning. Equipment development is needed to supply methods for measuring low velocities in general and specifically for mobile sources.


APPENDICES
## APPENDIX II

### Test Data

<table>
<thead>
<tr>
<th>Run</th>
<th>Time (min.)</th>
<th>Flow (cfm)*</th>
<th>CO₂ (%)</th>
<th>UBHC (ppm)</th>
<th>Stack Temp. (°F)</th>
<th>Sample Collected (grams)</th>
<th>Incinerator Velocity (ft./sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>23</td>
<td>2.0</td>
<td>7.0</td>
<td>1100</td>
<td>2.74</td>
<td>1.26</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>23</td>
<td>4.4</td>
<td>6.0</td>
<td>1180</td>
<td>1.52</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>23</td>
<td>4.6</td>
<td>4.6</td>
<td>1200</td>
<td>1.46</td>
<td>1.33</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>23</td>
<td>0.4</td>
<td>1.0</td>
<td>1160</td>
<td>1.75</td>
<td>0.66</td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>23</td>
<td>2.7</td>
<td>8.0</td>
<td>1200</td>
<td>2.03</td>
<td>1.37</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>23</td>
<td>4.2</td>
<td>6.0</td>
<td>1100</td>
<td>1.18</td>
<td>0.91</td>
</tr>
<tr>
<td>7</td>
<td>0.75</td>
<td>23</td>
<td>3.0</td>
<td>9.0</td>
<td>1150</td>
<td>1.83</td>
<td>0.68</td>
</tr>
<tr>
<td>8</td>
<td>1.0</td>
<td>23</td>
<td>3.3</td>
<td>10.0</td>
<td>1200</td>
<td>1.33</td>
<td>0.86</td>
</tr>
</tbody>
</table>

* Actual flow from calibration curve in Appendix I.
APPENDIX III

Sample Calculations

Data from Test #1

Sampling period 2 min.          incinerator velocity 1.26 ft/sec
Flow at meter 23 cfm            6500 lb/straw/acre
Stack temperature 1100°F        Burner cross section E 12' x 16'
Meter temperature 200°F         Stack diameter 7 ft
Ambient temperature 70°F        Sample weight 2.74 gram
CO₂ content 2.0%                UBHC content 7.9 ppm

\[
120 \text{ sec} \times 1.26 \frac{\text{ft}}{\text{sec}} \times 12 \text{ ft} \times \frac{\text{acre}}{43,560 \text{ ft}^2} \times \frac{6000 \text{ lb}}{\text{acre}} = 270.74 \text{ lb}
\]

Grain Loading

\[
\frac{2.74 \text{ gram}}{46 \text{ ft}^3} \times \frac{15.43 \text{ grains}}{\text{gram}} \times \frac{460^\circ + 70^\circ}{460^\circ + 200^\circ} \times 12.0\% = 4.42 \text{ grains/standard cubic foot}
\]
adjusted to STP and 12% CO₂

Sample calculation of total emissions based on measured velocity of 36 ft/sec

From the measured data the average sample weight adjusted to one minute sample time was 1.54 grams/min. The adjusted average fuel rate was 115.2 lb/min. The average temperature was 1660°F
The average flow rate can be calculated to be

\[(3.5)^2 \text{ ft}^2 \times \frac{36 \text{ ft}}{\text{sec}} \times 60 \text{ sec} = 83,000 \text{ ft}^3\]

Average emission in lb/ton of straw was

\[
2000 \frac{\text{lb}}{\text{ton}} \times \frac{1.55 \text{ gram}}{25 \text{ ft}^3} \times \frac{83,000 \text{ ft}^3}{115.26 \text{ lb}} \times \frac{460^\circ + 200^\circ}{460^\circ + 1161^\circ} \times \frac{1 \text{ lb}}{453.59 \text{ gram}}
\]

\[= 87.1 \frac{\text{lb particulate}}{\text{ton straw}}\]

Sample calculation of total emissions based on 6.5 lb gas/lb fuel.

Using the average fuel rate of 115.2 lb/min and average stack temperature of 1660°F

The average flow rate then was

\[
6.5 \frac{\text{lb gas}}{\text{lb straw}} \times \frac{359 \text{ ft}^3}{28 \text{ lb gas}} \times 115.26 \text{ lb straw} \times \frac{1660^\circ}{492^\circ} \times \frac{12\%}{3.45\%}
\]

\[
\text{Flow Rate} = 112,728 \text{ ft}^3/\text{min}
\]

Average emission in lb/ton of straw was

\[
2000 \frac{\text{lb}}{\text{ton}} \times \frac{1.54 \text{ gram}}{23 \text{ ft}^3} \times \frac{1127.28 \text{ ft}^3}{115.26 \text{ lb}} \times \frac{460^\circ + 200^\circ}{460^\circ + 1161^\circ} \times \frac{1 \text{ lb}}{453.59 \text{ gram}}
\]

\[
= 114.73 \frac{\text{lb particulate}}{\text{ton straw}}
\]
APPENDIX IV

Frequency Distribution of Particle Size for Small Particle Mode
Cumulative Frequency Distribution of Particle Size for Small Particle Mode

Percentage of Sample Particles Less Than Indicated Diameter

Diameter in Microns

Mg = 1.1 microns

\( \sigma_g = 1.14 \)
Frequency Distribution of Particle Size for Large
Particle Mode
cumulative frequency distribution of particle size for large particle mode

Mg = 14.5 microns
σg = 2.86