CHARACTERIZATION OF PARTICULATE EMISSIONS FROM GRAIN SORGHUM STORAGE AND HANDLING INSTALLATIONS

by

Bill Norman

Department of Agricultural Engineering

Submitted in Partial Fulfillment of the Requirements of the University Undergraduate Fellows Program

1976 - 1977

Approved by:

J. W. Sorenson, Jr.

J. W. Sorenson, Jr.

May 1977

ABSTRACT

CHARACTERIZATION OF PARTICULATE EMISSIONS FROM GRAIN SORGHUM STORAGE AND HANDLING INSTALLATIONS (May 1977)

Bill Norman, B.S.

Advisor: J. W. Sorenson, Jr.

Dust emissions from agricultural processes have never been considered much of a problem in years past. With most of these processes taking place in rural areas, government regulatory agencies have very often exempted agriculture from regulations placed on other industries. However, agriculture will not be so fortunate in the years to come. Agricultural processing in urban areas has already come under various government regulations; and if the present trend continues, the regulations will become stricter. Also, these regulations are beginning to affect even the smallest rural agricultural process.

The research reported in this paper involved the sampling of a small country elevator handling grain sorghum during harvest. Using high-volume samplers, upwind and downwind concentrations were observed with a net concentration level due to the installation being calculated. Also, grain sorghum was sampled to determine the amount of dust actually entering the elevator proper, via the grain.

From the findings of this study, it was determined that this installation could meet a standard of 400 micrograms per cubic meter ($\mu g/m^3$) of air sampled over any one-hour period as a property line emission level. It was also found that the weight of particulate matter less than 100 microns in diameter constituted less than 0.01% of the grain weight entering an elevator or less than 100 micrograms per gram of grain.

DEDICATION

This report is dedicated to my fiancee Gale. Without her patience and encouragement, it would have been difficult for me to see this project to the end.

ACKNOWLEDGEMENTS

I would like to express my appreciation to Dr. J. W. Sorenson, Dr. Calvin Parnell, Mr. Robert Avant, Mr. Micheal Clough, Miss Sherrie Cobb, the management of the cooperating elevator, and Mrs. Sharon Avant.

Dr. J. W. Sorenson, my project advisor, has been giving me invaluable advice since I first entered Texas A&M University. He has always offered his opinions in a constructive manner, and I have always considered them with high regard. Dr. Sorenson first interested me in the area of agricultural processing and in this project. The debt I owe Dr. Sorenson can never be repaid.

Dr. Calvin Parnell worked closely with me on this project from conception to end. His expertise in the field of air pollution was critical to the culmination of this research. Dr. Parnell's opinions and friendship are truly appreciated.

Mr. Robert Avant helped me considerably in every phase of this project. He first taught me the use of the Coulter Counter, then helped me perform the field sampling under some hot and dusty conditions. He also aided me in analyzing my results. I hope that his patience with me has not worn too thin.

Mr. Micheal Clough and Miss Sherrie Cobb aided me considerably in both the Coulter Counter analysis and in the statistical analysis. Without their help, this research would not have been completed in the allotted time. To both of them I give a hearty thank you.

I would like to thank the management of the cooperating elevator in this study for their consent in allowing the necessary air sampling. They were most generous towards aiding in this research, and I hope that the data and conclusions stated in this report will be of some value to them.

Mrs. Sharon Avant graciously consented to decipher my handwriting and to type this report. As the date drew near for the completion of this paper, her nimble fingers became a priceless asset.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

INTRODUCTION

Problems arising from air pollution near agricultural processing installations have become more serious and costly as residences and business establishments have surrounded them. Although the emissions from these installations are not toxic, they can be irritating to the respiratory tract (Shannon, et al, 1973).

The Texas Clean Air Act (1969) authorized the Texas Air Control Board to regulate the amounts and types of particulate matter that could be emitted during agricultural processing. The act states that agricultural processes would be governed by the process weight method of determining particulate emissions. However, the act also states that the Executive Director of the Air Control Board can prescribe an alternate method in lieu of the process weight method (Texas Clean Air Act, 1969).

One possible alternate method is the property line emissions method. The Texas Air Control Board has specified limits in the use of this method as follows:

a) 100 microns per cubic meter ($\mu g/m^3$) of air sampled, averaged over any five consecutive hours.

b) 200 micrograms per cubic meter ($\mu g/m^3$)

The literature cited on the following pages follows the format and style as used in the Transactions of the American Society of Agricultural Engineers.

of air sampled, averaged over any three consecutive hours.

c) 400 micrograms per cubic meter ($\mu g/m^3$) of air sampled, averaged over any one-hour period (Texas Air Control Board, 1972).

The property line emissions method is not presently being used as an alternate method by agricultural processors. However, with the premise of stricter regulations on agriculture becoming a reality in the very near future (Federal Register, 1977) agricultural processors may turn towards this method almost universally. The research presented in this paper investigated the feasibility of the property line emissions limit when applied to a country elevator handling grain sorghum.

The objective of this research was twofold. The primary objective was to determine upwind and downwind dust concentration levels and their characteristics at a country elevator. Secondly, the research focused on determining the amount of dust per amount of grain entering a typical grain elevator.

REVIEW OF LITERATURE

Perkins (1974) defines atmospheric dust as particles dispersed in a gaseous medium which range from 0.001 micron to 10 microns in diameter. However, agricultural dusts have a somewhat wider range due to their heterogeneous nature and to their large amounts of chaff, lint and trash.

Dust samples are obtained by using various types of collection systems. Two methods are used in obtaining these samples; the dust fall method and the isokinetic sampling method. The dust fall method is static sampling involving the settling of dust particles on a collection surface. This sampling type is probably best suited for obtaining samples from ambient air. The isokinetic sampling method consists of sampling dust concentrations in a duct with a probe and is the best method to determine the efficiency of an air pollution abatement device (Avant*, 1976).

There are many different types of air samplers which vary from small personal units to large stationary sampling systems (Radian, 1969). The most commonly used units are the high-volume samplers and the Andersen Head samplers. The high-volume sampler (Figure 1) uses a small variable speed fan to pull dust laden air through a fiberglass filter media (Silverman and Viles, 1948). The Andersen Head sampler is a cascade impactor sampler in that it actually fractionates the dusty air into

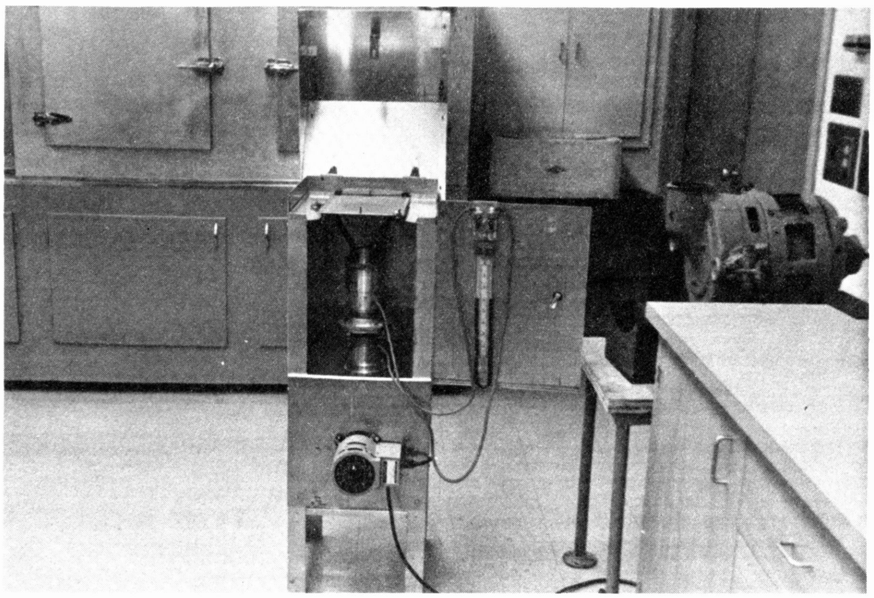


Figure 1. High-volume sampler used in this project showing manometer tap placement and variable speed control.

progressively smaller size ranges. At each stage, the fractionated dust is impacted on a filter media or collection substrate (Andersen 2000, Inc., 1975).

Both sampler types provide a dust sample for further analysis. The procedure for obtaining dust concentration requires that the tare weight of the clean filter media be predetermined by weighing under constant ambient conditions, usually in an environment chamber. The weight of the dust on the exposed filter can then be determined by subtracting the tare weight of the clean filter from the weight of the exposed filter. The dust concentration level can then be calculated by using the weight of the dust sample and the known flow rate through the sample for a specified period of time.

A particle size distribution can also be obtained by analyzing the exposed filter. There are various methods for determining particle size distributions which range from microscopic scanning to electronic sensing. The electronic method of determining a particle size distribution is the best that the state of the art has to offer at this time. It is the fastest and most reliable method (Avant*, 1976). The Model TA Coulter Counter (Figure 2) is an instrument that uses the resistance gradient technique for presenting a particle size distribution in 16 channels representing particle sizes (Table 1) (Coulter Electronics, Inc., 1975). These data can then be applied to a

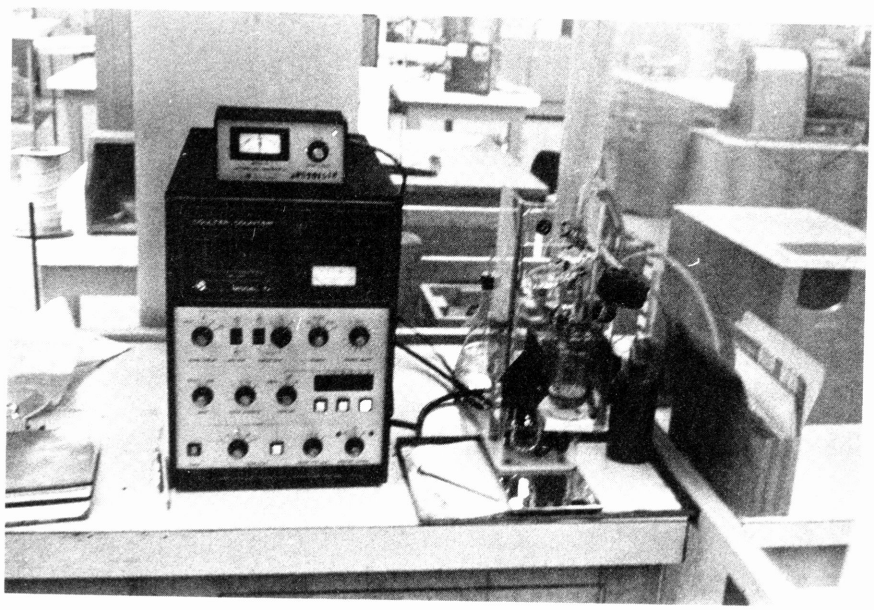


Figure 2. Model TA Coulter Counter used to determine particle size distributions.

TABLE 1. COULTER COUNTER CHANNEL SIZES USING A 100 MICRON APERTURE TUBE

Channel Number	Channel Size (Microns µm)
1	1.26
2	1.59
3	2.00
4	2.52
5	3.17
6	4.00
7	5.04
8	6.35
9	8.00
10	10.08
11	12.70
12	16.00
13	20.20
14	25.40
15	32.00
16	40.30

semi-log least squares routine programmed on a Hewlett-Packard 9810 Calculator-Plotter (Hewlett-Packard, Inc., 1971; Steel and Torrie, 1960). Generally the particle size distribution of agricultural dusts is defined by a straight line using a log-normal relationship; however, Avant (1975) determined that there is little significant difference between the log-normal function and the semi-log function when they are compared in the range between 5% and 95%.

Other important information concerning a dust analysis is the geometric standard deviation and the mass median diameter. Lee and Goransen (1972) state that the geometric standard deviation helps to better define the overall distribution of particle sizes. The geometric standard deviation is calculated by the following equation:

$$GSD = \frac{\text{MMD (microns)}}{\text{84.13\% diameter (microns)}} \qquad [1]$$

where,

GSD = geometric standard deviation, and

MMD = mass median diameter, microns.

The mass median diameter represents the 50% size range of the particle size distribution (Cadle, 1965).

To determine the amount of dust in a sample of grain, a tumbler apparatus has been developed (TEES, 1974). Although originally designed for cottonseed, the device can be adapted for all grains and seed types. The device consists of a tumbling cage lined with 100 micron screen enclosed by a larger trapezoidal box. Air enters the tumbling cage containing the grain or seed through two hollow axial supports of the cage. The dust is drawn through the box and onto a filter pad with the use of a high-volume blower (Figures 3 and 4). The maximum speed for the cage is 85 rpm. A speed below this maximum allows the seed to tumble in the cage and not be "glued" to the sides of the cage by centrifugal force.

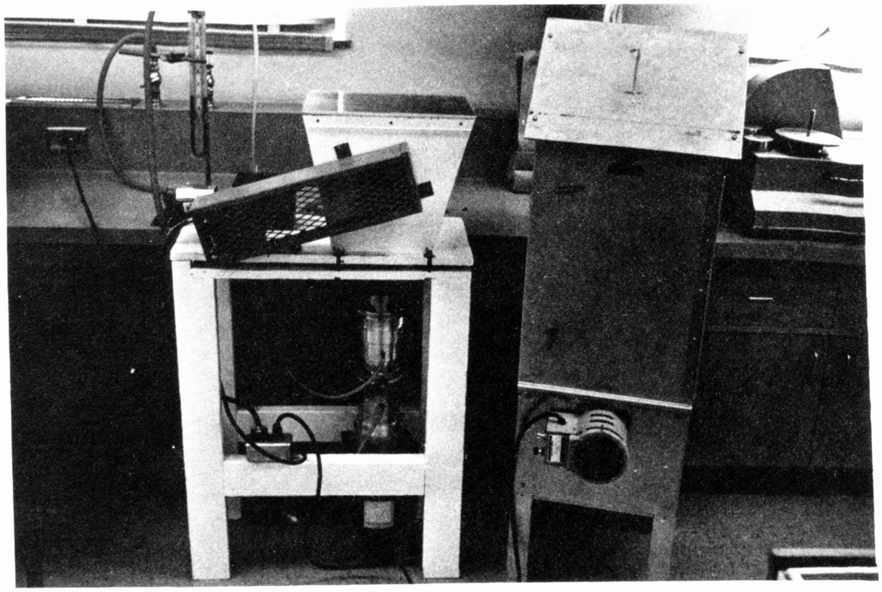


Figure 3. Grain tumbling apparatus and high-volume sampler used to collect dust samples from whole grain.

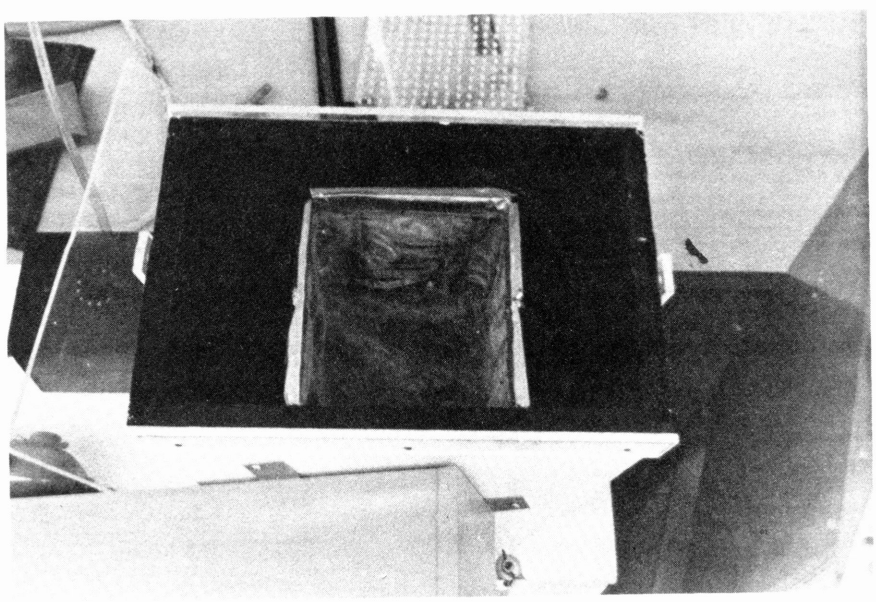


Figure 4. Interior of grain tumbler showing tumbling box lined with 100 micron (μg) screen mesh.

PROCEDURE AND ANALYSIS

Elevator Dust Sampling

A small country elevator in Central Texas was selected as the sampling site for the determination of particulate concentration levels. Five high-volume samplers were used for this sampling. One sampler was positioned at 61 meters (200 feet) from the upwind side of the elevator, while another sampler was stationed at the downwind entrance to the pit area of the elevator. The other three samplers were randomly positioned at distances of 30 meters (100 feet), 61 meters (200 feet), and 91 meters (300 feet) downwind from the pit area of the elevator. Sampling began at approximately 10:00 a.m. each morning, when field harvesting operations could usually begin, and continued until 5:00 or 6:00 p.m. depending on the number of trucks that were still coming in at the elevator.

Sampling time at each station varied depending on the dust loading at that station. For instance, the pit sampler was operated for an average of 60 minutes before changing filters because of heavy dust loading, while the other samplers were operated for intervals of approximately 120 minutes due to lighter loadings. At the beginning of a sampling period, a pre-weighed fiberglass filter was placed on the sampler. The fan motor was subsequently turned on and allowed to warm up for a short period before a beginning orifice pressure reading was taken. At the end of the sampling period, the orifice pressure readings were repeated, and an average pressure was calculated. The sampler was turned off while a new filter was being exchanged for the exposed one. This process was then repeated as before.

The exposed filters were folded and placed in a manila envelope. On the outside of the envelope, the following data were recorded:

1) Sampler location.
2) Filter number.
3) Sampling time (minutes).
4) Date and time of day.
5) Barometric pressure (inches of mercury).
6) Temperature (°F, wet bulb and dry bulb).
7) Other comments concerning wind speed and direction and elevator traffic conditions.

After this process, the filters were then ready for analysis.

Grain Dust Sampling

To determine the amount of grain sorghum dust entering a typical grain elevator, random samples of two varieties of grain sorghum were taken from trucks entering a grain elevator on the High Plains of Texas. Also, random grain sorghum heads of various varieties were cut in the field before harvest to be used as a comparison to the grain samples taken at the elevator. Each head was then individually thrashed with a small electric powered threshing machine (Figures 5 and 6). All samples were then placed in an environment chamber so that the grain would be at the same moisture and temperature conditions when dust samples were taken.

Dust samples from 250 gram grain samples were taken at a moisture content of 12% at approximately 61° Fahrenheit measured on a Steinlite moisture tester (Figure 7). The grain sample was then placed in the grain tumbler for a period of 10 minutes. The airflow rate of the high-volume samplers was set at 1.42 m^3/min (50 ft^3/min) for all grain samples. Three dust samples were taken on each grain type giving a total of nine dust samples. Following the sampling, the fiberglass filters were then folded as before and placed in an individual manila envelope with the appropriate data recorded on the envelopes.

Dust Analysis

Once sampling was completed at the elevator site and with the grain tumbler, the exposed filters were weighed and the net dust weight was determined. In the case of the tumbled grain samples, this final weight was related to the grain weight in terms of milligrams of

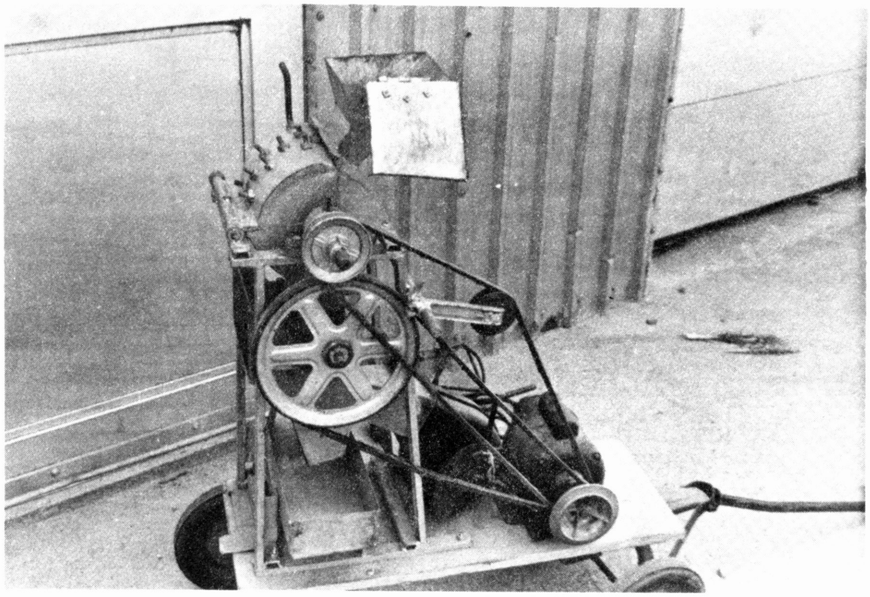


Figure 5. Electric powered head thresher with fan for removing grain chaff.

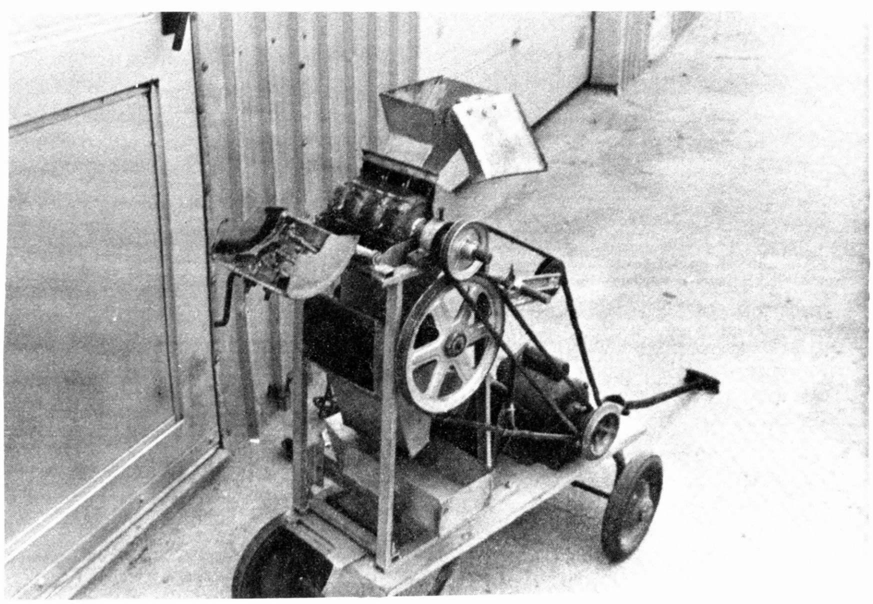


Figure 6. Head thresher interior showing threshing machine.

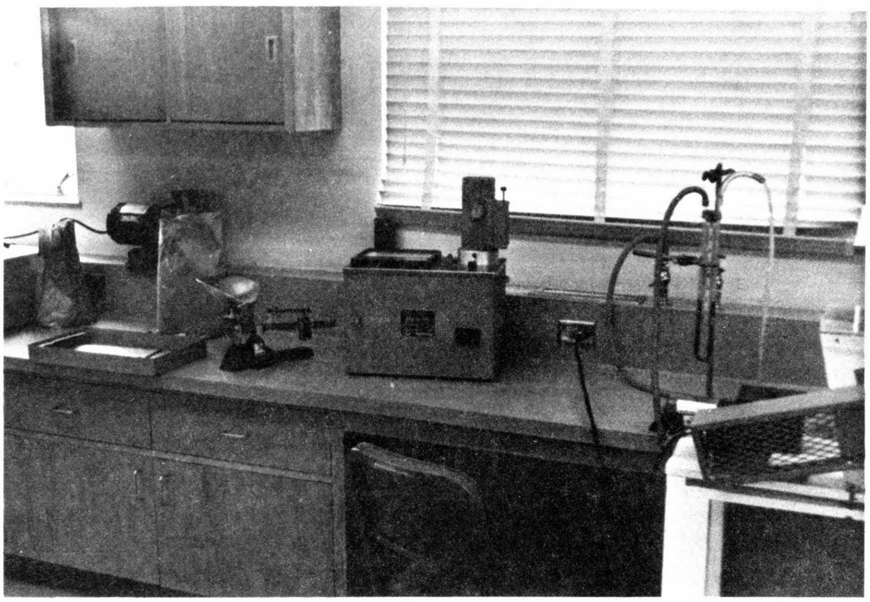


Figure 7. Steinlite moisture tester used to determine grain moisture conditions prior to sampling.

dust per gram of grain (mg/g). In the case of the elevator samples, the weight of the dust was divided by the volume of air sampled (milligrams of dust per cubic meter of air) to obtain dust concentrations.

The equation for this concentration level is given by:

$$CL = \frac{W}{QXT} \qquad [2]$$

where,

CL = concentration level, g/m^3,

W = net weight of dust on filters, g,

Q = sampler airflow rate, m^3/min, and

T = time, min.

After net weights and concentration levels for all samples were determined, a Coulter Counter analysis was performed on each sample. This analysis, coupled with a statistical analysis, revealed the geometric standard deviation and mass median diameter. Also, concentration levels for particles less than 20 microns, less than 15 microns, and less than 10 microns in diameter were calculated.

DISCUSSION OF RESULTS

Figure 8 gives a schematic view of the country elevator samples, showing sampler locations and the average values for each distance. The concentration levels shown in this figure can be broken down for each sample as shown in Table 2. To obtain a net emission level for the elevator, the upstream concentration level should be subtracted from the downstream values.

It should be noted that the upwind sampler and the downwind sampler at 61 meters and 91 meters were positioned at the property line of this installation. Thus, the dust concentrations obtained at these locations would be indicative of the property line emissions of this elevator.

Winds during the sampling were generally light to variable out of the southeast. It was impossible to position the upwind sampler in a direct line with the other samplers due to out buildings and the location of the property line on that side of the elevator. Therefore, the sampler was placed on the southwest side. This positioning should have no affect on the results since its sole purpose was to sample ambient air entering the area.

The values at the 91 meter location were greater than those at the 61 meter location due to the fact that the elevator entrance and driveway were located immediately

LOCATIONS AND CONCENTRATIONS OF THE SAMPLERS ($\mu g/m^3$)

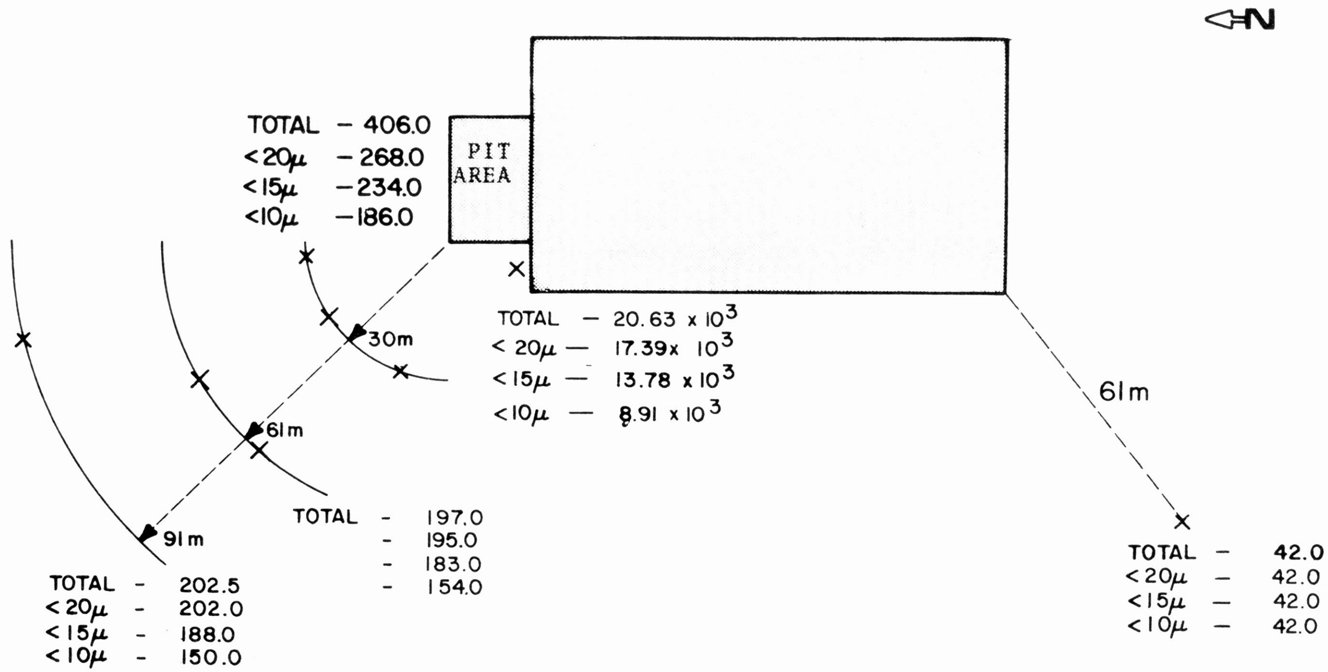


FIGURE 8.

TABLE 2. DUST CONCENTRATION LEVELS OF AIR SAMPLED AT A COUNTRY ELEVATOR

Location	Total Concentration $\mu g/m^3$	Conc. <20μm $\mu g/m^3$	Conc. <15μm $\mu g/m^3$	Conc. <10μm $\mu g/m^3$
Pit 2	34.29×10^3	30.00×10^3	23.37×10^3	14.04×10^3
3	50.09×10^3	42.86×10^3	34.63×10^3	23.03×10^3
4	29.82×10^3	25.61×10^3	19.96×10^3	12.00×10^3
5	18.75×10^3	15.21×10^3	11.79×10^3	6.98×10^3
6	6.31×10^3	5.09×10^3	3.29×10^3	2.66×10^3
7	7.46×10^3	6.01×10^3	4.99×10^3	3.56×10^3
8	16.39×10^3	14.22×10^3	11.82×10^3	8.45×10^3
9	8.06×10^3	6.48×10^3	5.22×10^3	3.44×10^3
10	14.50×10^3	11.06×10^3	8.98×10^3	6.04×10^3
Average	20.63×10^3	17.39×10^3	13.78×10^3	8.91×10^3
Standard Deviation	14.72×10^3	12.89×10^3	10.35×10^3	6.57×10^3
61 Meters 4	55.00	55.00	55.00	44.00
Upwind 5	29.00	29.00	29.00	27.00
Average	42.00	42.00	42.00	35.50
Standard Deviation	---	---	---	---
30 Meters 1-a	175.00	175.00	175.00	146.00
b	759.00	759.00	708.00	675.00
c	598.00	598.00	492.00	390.00
2-b	226.00	226.00	218.00	172.00
c	437.00	411.00	361.00	291.00
3-a	24.00	24.00	24.00	20.00
b	624.00	598.00	508.00	382.00
Average	406.00	399.00	355.00	282.00
Standard Deviation	271.00	268.00	234.00	186.00
61 Meters 1-a	177.00	177.00	177.00	158.00
b	311.00	303.00	270.00	223.00
2	104.00	104.00	101.00	82.00
Average	197.00	195.00	183.00	154.00
Standard Deviation	105.00	101.00	85.00	71.00
91 Meters 1	178.00	178.00	167.00	131.00
Downwind 2	227.00	227.00	210.00	168.00
Average	202.50	202.00	188.00	150.00
Standard Deviation	---	---	---	---

upwind of the samplers. Even though the drive was paved, entering and exiting trucks generated dust in this area which caused the increase in concentration values at this point.

To illustrate the amount of dust fallout, the breakdowns of dust concentrations at each location are shown graphically for each size range in Figure 9 through 12. These figures show the total dust concentrations less the upwind concentration. Also shown in these figures are the standard deviations for each location. The standard deviations were quite high. At some times of the day, trucks might dump at a rate of eight to twelve per hour, while at other times the rate might be two to four per hour. This could serve as one reason for the high deviations. Also, it was observed that some trucks continuously had dustier loads than others either because of poor combine field settings or because of the greater distance of the haul. With these dustier trucks dumping at regular intervals, a difference in dust concentrations was clearly evident.

Characteristics of the dust sampled at the elevator are given in Table 3. The mass median diameter and geometric standard deviation for each sample is listed in this table with an average mass median diameter for each location calculated.

Table 4 lists the dust characteristics and

CONCENTRATION LEVELS ($\mu g/m^3$) UPWIND AND DOWNWIND FROM A COUNTRY ELEVATOR

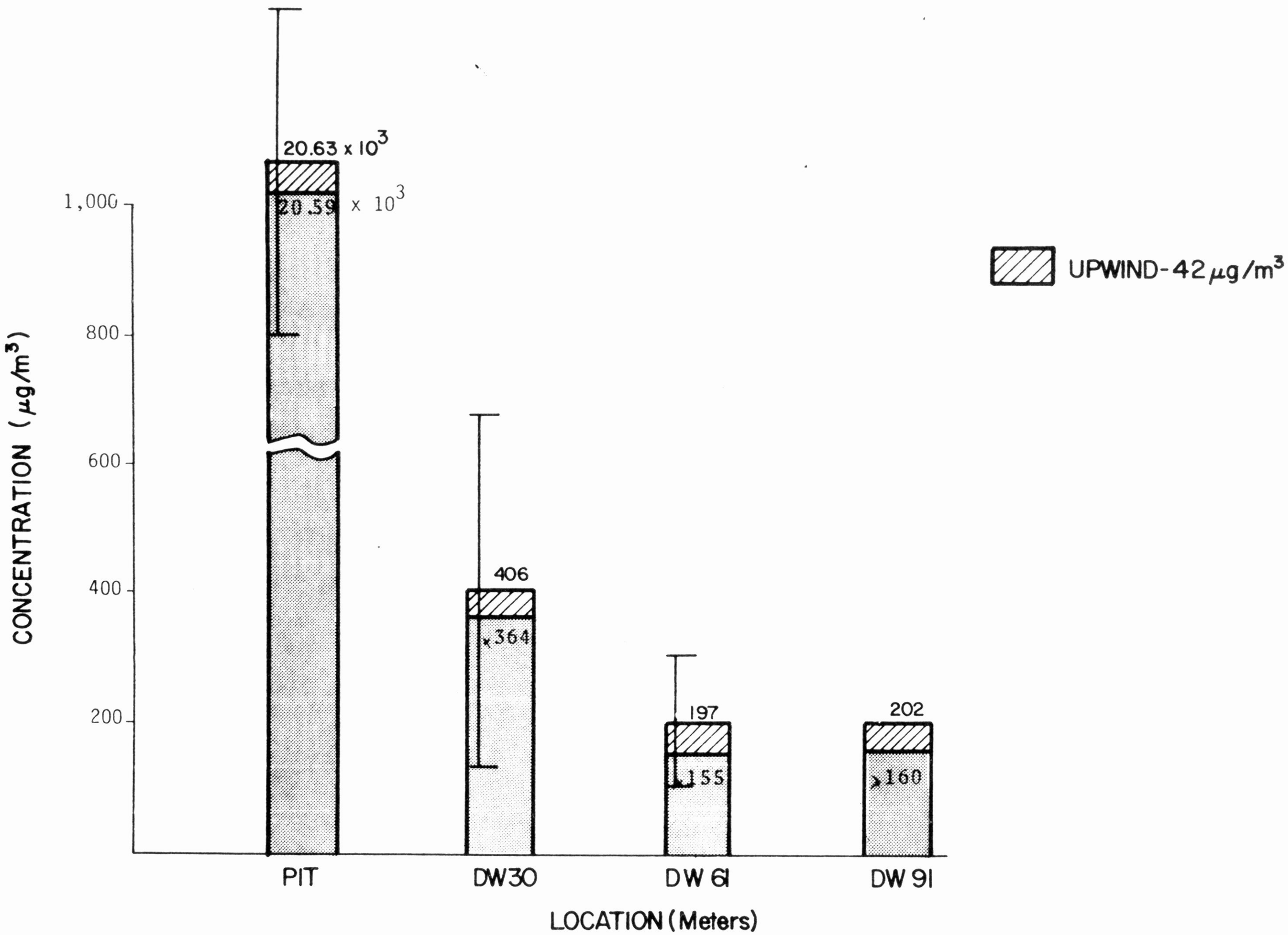


FIGURE 9

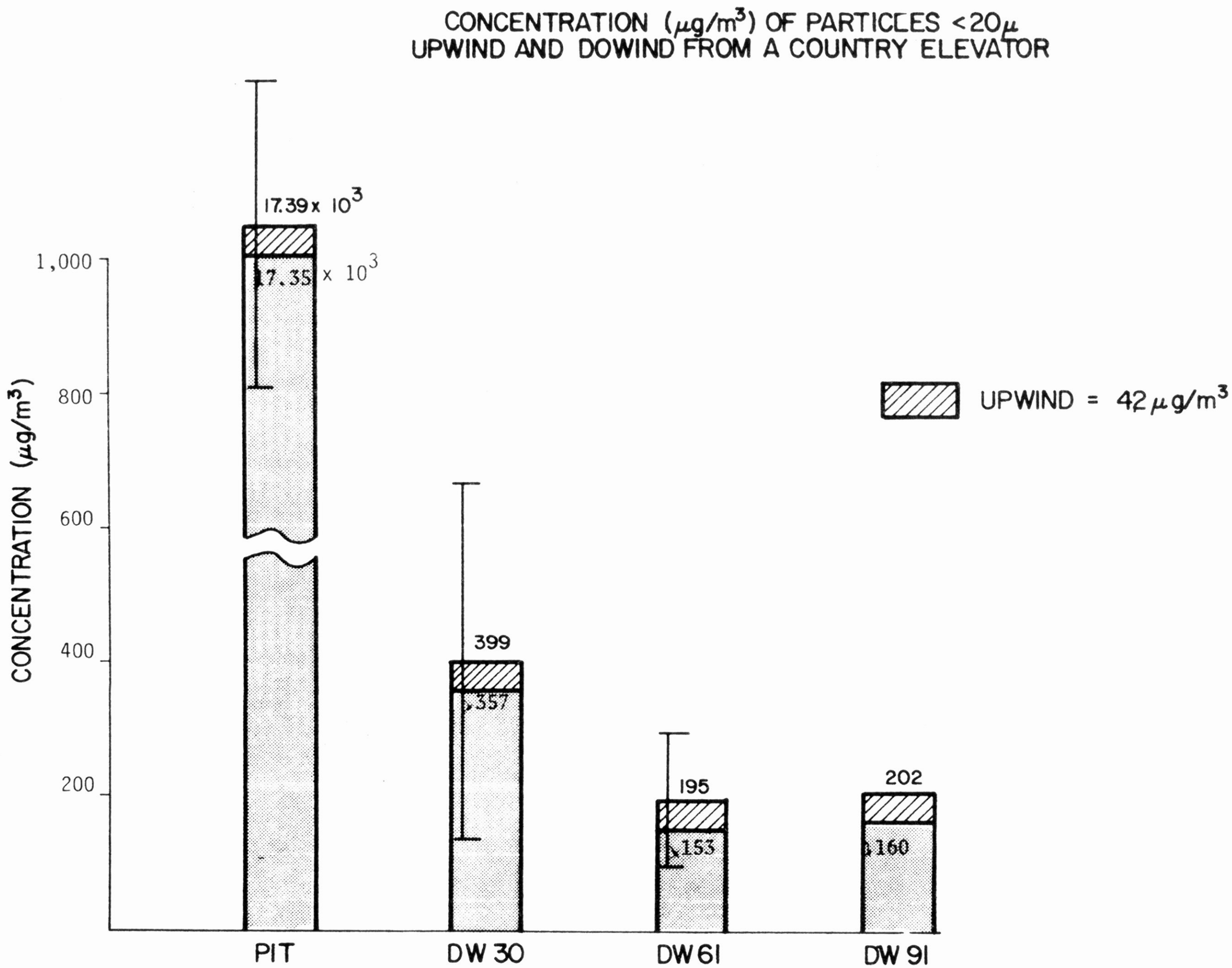

CONCENTRATION (μg/m³) OF PARTICLES <20μ
UPWIND AND DOWIND FROM A COUNTRY ELEVATOR
CONCENTRATION (μg/m³)
1,000
800
600
400
200
17.39 x 10³
17.35 x 10³
399
357
195
153
202
160
UPWIND = 42 μg/m³
PIT
DW 30
DW 61
DW 91
LOCATION (Meters)

FIGURE 10

CONCENTRATION ($\mu g/m^3$) OF PARTICLES < 15μ UPWIND AND DOWNWIND FROM A COUNTRY ELEVATOR

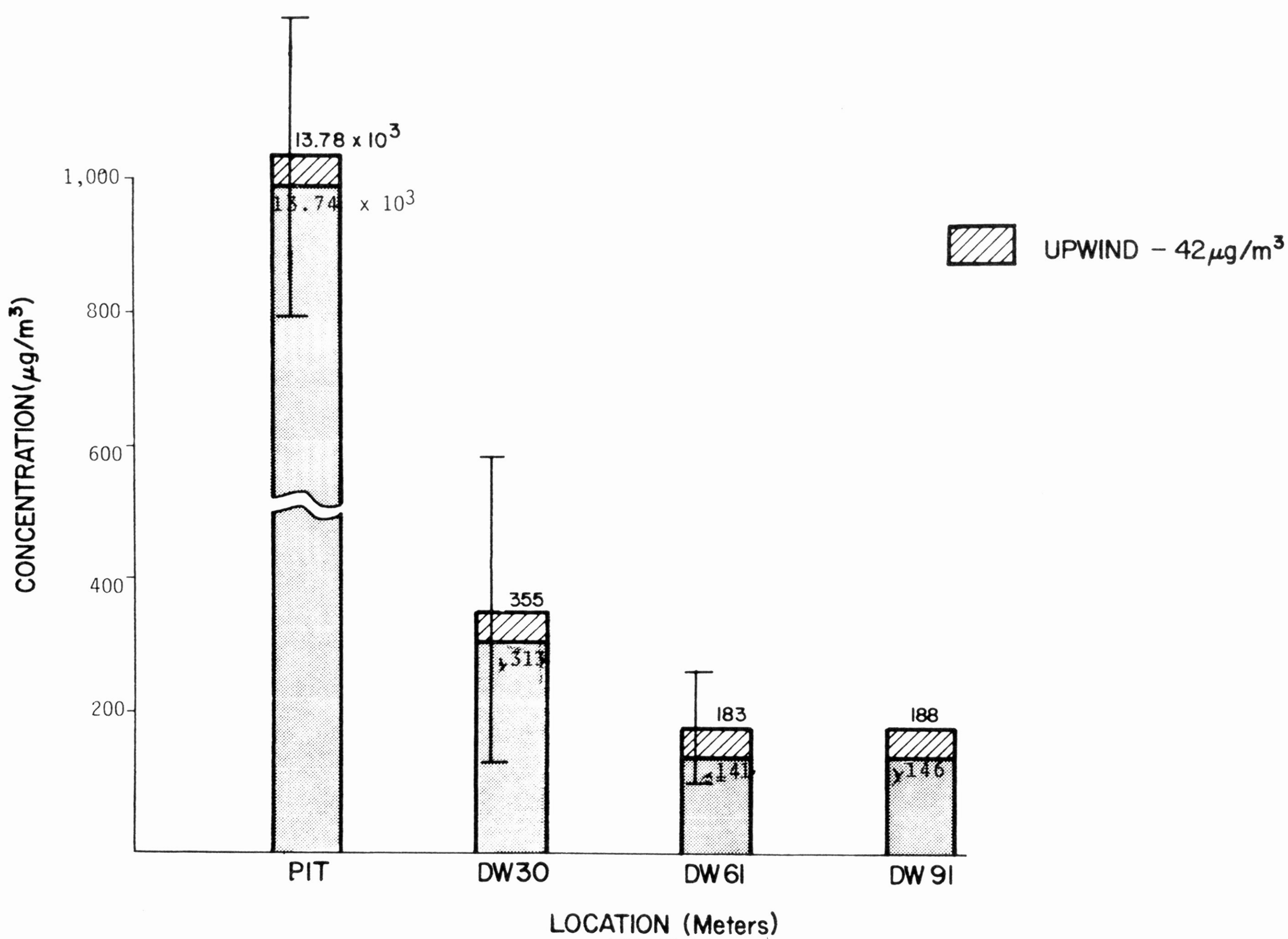
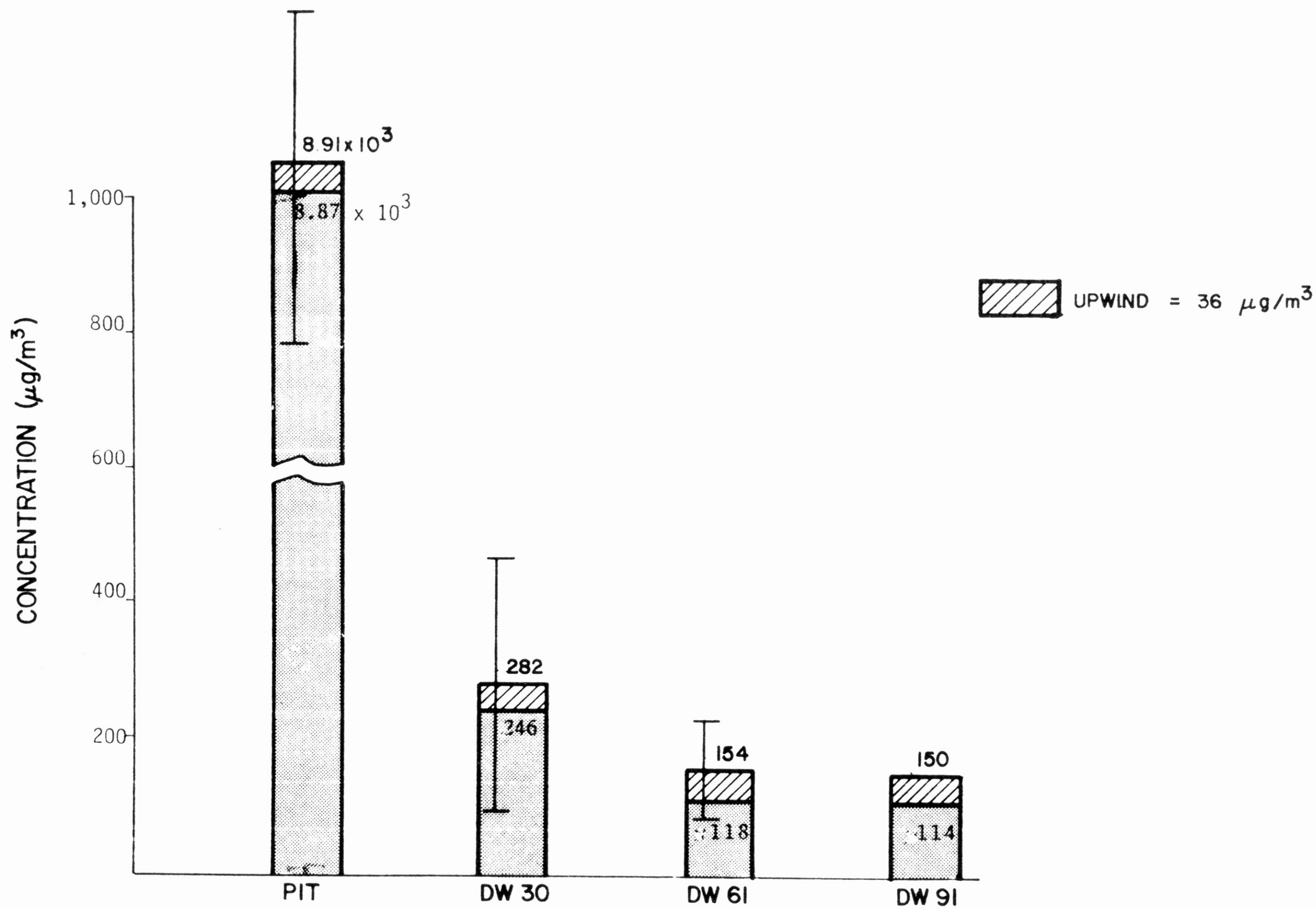


FIGURE 11

CONCENTRATION ($\mu g/m^3$) OF PARTICLES <10μ UPWIND AND DOWNWIND FROM A COUNTRY ELEVATOR



LOCATION (Meters)

FIGURE 12

TABLE 3. DUST CHARACTERISTICS OF AIR SAMPLED AT A COUNTRY ELEVATOR

Location	Mass Median Diameter (μm)	Geometric Standard Deviation
Pit 1	11.38	1.70
2	11.22	1.67
3	10.73	1.82
4	11.60	1.62
5	12.23	1.71
6	11.53	1.85
7	10.50	2.05
8	9.70	1.96
9	11.45	1.87
10	11.82	1.98
Average	11.22	
61 Meters Upwind 1	7.39	2.27
2	5.02	2.10
3	5.07	2.01
4	5.53	1.98
5	4.22	1.98
Average	5.45	
30 Meters Downwind 1-a	4.80	2.13
b	5.50	2.21
c	6.99	2.25
2-a	4.03	1.82
b	5.93	1.98
c	6.56	2.37
3-a	5.21	1.98
b	8.00	4.04
Average	5.88	
61 Meters Downwind 1-a	4.64	1.95
b	5.59	2.50
2	5.34	2.11
3	4.73	2.08
Average	5.07	
91 Meters Downwind 1	6.23	1.98
2	5.84	2.14
3	4.79	1.97
Average	5.62	

TABLE 4. DUST CHARACTERISTICS OF GRAIN AND CONCENTRATIONS ENTERING AN ELEVATOR @ 12% MOISTURE

Sample	M.M.D. (μm)	G.S.D.	Conc.<100μm ($\mu g/g_{grain}$)	Conc. <20μm ($\mu g/g_{grain}$)	Conc. <15μm ($\mu g/g_{grain}$)	Conc. <10μm ($\mu g/g_{grain}$)
Combined 1-a	9.73	1.90	96.80	85.48	70.68	49.80
b	10.50	1.96	108.88	90.94	74.16	51.72
c	10.08	1.92	115.08	98.84	81.52	57.08
Average	10.10		106.92	91.44	75.44	52.88
Standard Deviation	0.39		9.32	6.80	5.52	3.76
Combined 2-a	9.28	2.02	77.48	67.60	56.80	41.56
b	10.01	1.89	83.64	72.76	59.92	41.76
c	9.19	2.05	89.60	77.80	65.60	48.36
Average	9.49		83.56	72.72	60.76	43.88
Standard Deviation	0.45		6.08	5.12	4.48	3.88
Hand-Thrashed a	8.96	2.06	32.24	28.32	23.96	17.80
b	7.79	2.07	63.84	60.16	50.76	39.40
c	7.01	2.06	38.80	38.60	33.32	25.92
Average	7.92		44.96	42.36	36.28	27.72
Standard Deviation	0.98		16.68	16.24	14.04	10.92

M.M.D. - Mass Median Diameter
G.S.D. - Geometric Standard Deviation
μm - Microns
Conc. - Concentration
g - Grams

concentrations of grain that enters an elevator. The combined 1 and 2 sample types refer to grain sampled from two different trucks hauling from two different machines. The hand-thrashed samples refer to the head samples that were individually thrashed on the small head threshing machine (Figure 5 and 6). The concentration levels are also represented graphically by size range (Figures 13 through 16). Again, the standard deviation from the average is depicted by the black lines on the bars. However, the deviations are relatively small for these samples.

CONCENTRATION ($\mu g/gm$) OF DUST IN HAND THRASHED AND COMBINED SORGHUM GRAIN OF ≅ 12% MOISTURE

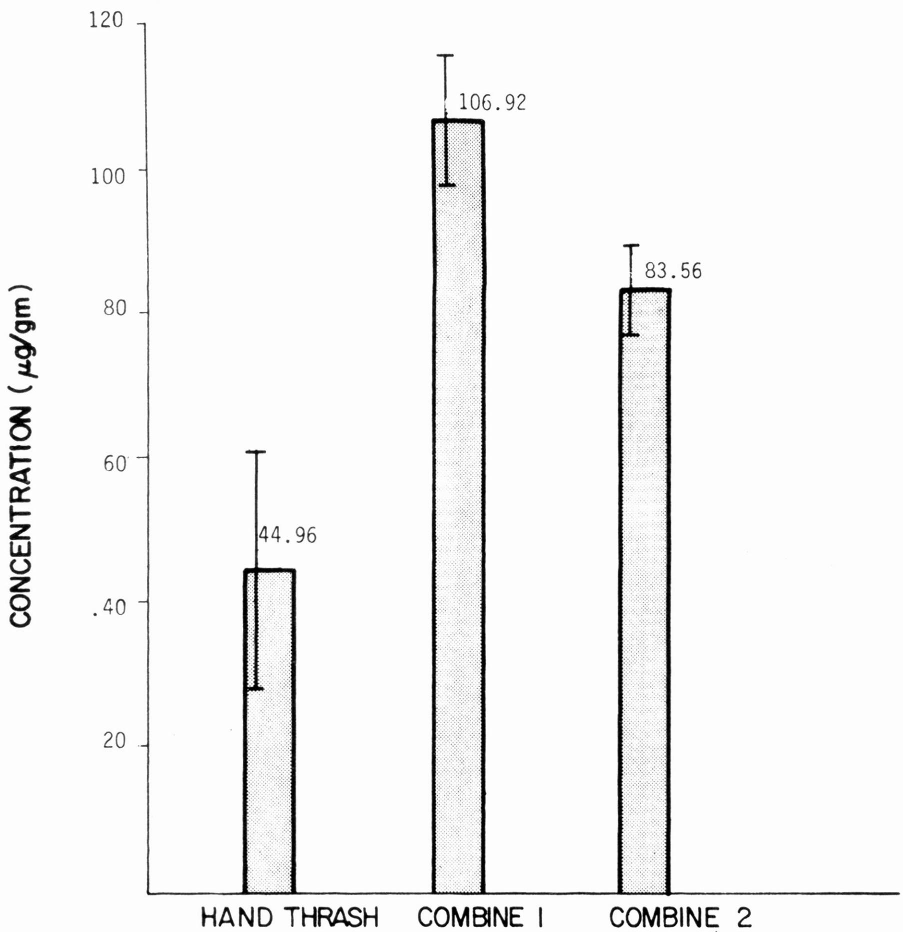


FIGURE 13

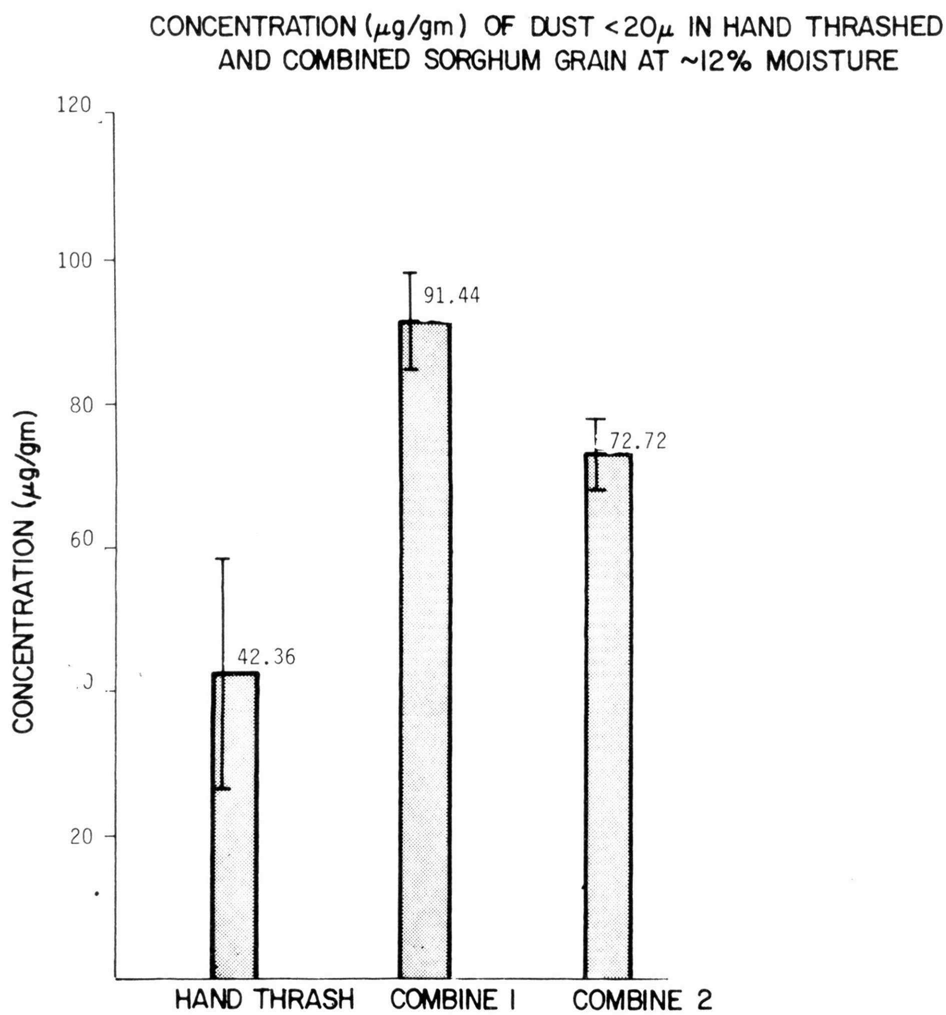

CONCENTRATION (μg/gm) OF DUST <20μ IN HAND THRASHED AND COMBINED SORGHUM GRAIN AT ~12% MOISTURE
120
100
80
60
20
CONCENTRATION (μg/gm)
91.44
72.72
42.36
HAND THRASH
COMBINE 1
COMBINE 2

FIGURE 14

CONCENTRATION (μg/gm) OF DUST <15μ IN HAND THRASHED AND SORGHUM GRAIN AT ~ 12% MOISTURE

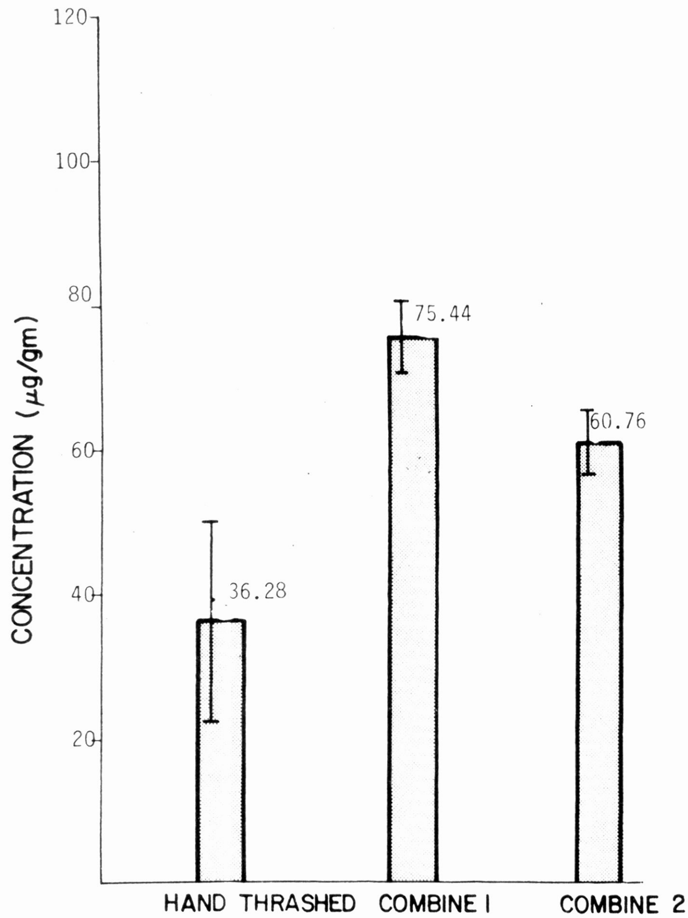


FIGURE 15

CONCENTRATION (μg/gm) OF DUST <10μ IN HAND THRASHED AND COMBINED SORGHUM GRAIN OF ~ 12% MOISTURE

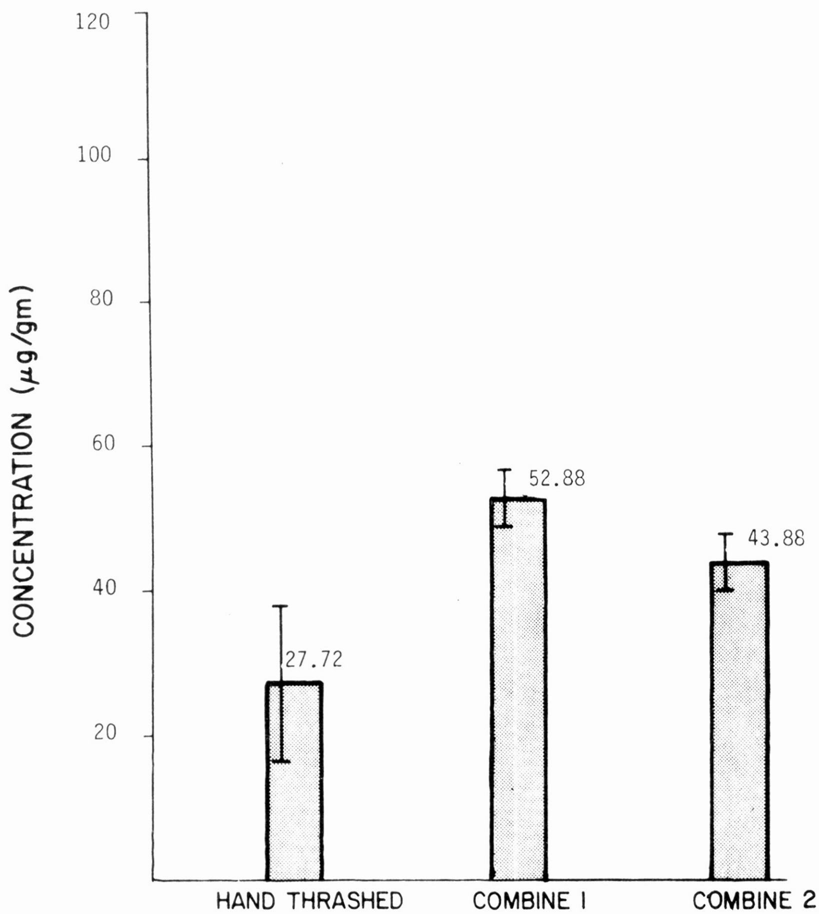


FIGURE 16

CONCLUSIONS

This research indicates that the use of a property line emissions standard as an alternate method under the Texas Clean Air Act could be feasible from the standpoint of the grain industry. Approximately 200 micrograms of particulate per cubic meter of air sampled was leaving the property limits of this elevator. It is possible that many of the existing country elevators could meet a standard of this type without having to be equipped with expensive dust abatement devices.

A comparison of combined grain to the hand-thrashed grain indicates that the combining process results in an increase in dust levels in grain delivered to the elevator. A comparison of the two combined grain samples suggests that different combines cause variations in dust levels found in grain. This indicates that combine settings, speeds and operating conditions could have a large impact on the amount of grain dust that enters an elevator.

The dust characteristics found in this report compare favorably to what was expected. These data should prove useful when incorporated into design considerations for agricultural dust abatement systems.

FUTURE WORK

More field sampling of grain handling installations needs to be performed. Any sampling data obtained in the future should be closely related to the amounts of grain entering the installation. Also, sampling periods for property line emissions should be performed over one-, three-, or five-hour periods so that a better comparison can be made with the Texas Air Control Board standards.

Sampling of different grains should be performed. It could be entirely possible that different grains contain different dust characteristics and capacities. If this is the case, the various dust characteristics will be of value in future designs of dust abatement equipment.

REFERENCES

1. Andersen 2000, Inc. 1975. Company literature.

2. Avant, Jr., R. V. 1975. Comparison of a log-normal and a semi-log equation from data from a particle size distribution of a vertical elutriator dust sample. Unpublished paper.

3. Avant, Jr., R. V. 1976. Pneumatic conveying of agricultural products. Handout for agricultural engineering students. Texas A&M University.

4. Avant*, Jr., R. V. 1976. Cyclone analysis for the abatement of grain sorghum emissions in granaries. Master's thesis. Texas A&M University.

5. Cadle, R. D. 1965. Particle size. Reinhold Publishing Corporation.

6. Coulter Electronics, Inc. 1975. Instruction and service manual for the Coulter Counter Model TA.

7. Federal Register, Volume 42, Number 9, January 13, 1977. Grain elevators - standards of performance for new stationary sources. pp. 2842-2848.

8. Hewlett-Packard, Inc. 1971. Operating manual for the HP 9810-A calculator.

9. Lee, R. E. and S. Goransen. 1972. National air surveillance cascade impactor network. I. Size distribution measurements of suspended particulate matter in the air. Environmental Science and Technology. 6(12):1019-1024.

10. Perkins, H. C. 1974. Air Pollution. McGraw-Hill, Inc.

11. Radian, Inc. 1969. Company literature.

12. Shannon, L. J., et al. 1973. Emission control in the grain and feed industry. EPA - 450/3-73-003a.

13. Silverman, L. and F. L. Viles. 1948. A high-volume air sampling and filter weighing method for certain aerosols. Journal of Industrial Hygiene and Toxicology. 30(124).

14. Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, Inc.

15. Texas Air Control Board. 1972. Control of air pollution from visible emissions and particulate matter. Regulation I. Rules 105.2.

16. Texas Clean Air Act. 1969. Vernon's Revised Civil Statues of Texas. Article 4477-5.

17. Texas Engineering Experiment Station. 1974. Procedures for cleaning and delintering cottonseed without affecting quality of protein products. Second Semi-Annual Progress Report. Appendix A.