Paper 68-164

PARTICULATE EMISSIONS FROM SAWMILL WASTE BURNERS

by

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ABSTRACT

To obtain particulate emission data from the "Wigwam" type wood residue incinerator, 100 individual samples were taken from 19 burners located in the Pacific Northwest. The samples were taken while the burners were in normal operation so they are representative of actual emissions. Gravimetric and size analyses were made on each of the samples.

Summary results are presented in the body of the paper. They indicate the extreme variability of these burners. For instance, the particulate emissions ranged from a low of 0.004 grains per cubic foot to a high of 0.607 grains per cubic foot. Data and results from the 19 individual burners are included in the appendix.

The information presented enables control officials to evaluate these burners for particulate emission quantities, size distribution, and transport characteristics of the emissions.

From an "average burner" one can expect a particulate emission of 0.168 grains of particulate per cubic foot of gas (corrected to 12% CO_2 and STP). This is equivalent to approximately 10.7 pounds of particulate per ton of fuel consumed. The particulate has two distinct size distributions, one representing the "smoke" (less than 2 microns) and one representing the material which would settle from the atmosphere downwind from the burner (larger than 10 microns).

The stokes diameter of the larger particulate was estimated to be 1/10th the actual measured diameter.

PARTICULATE EMISSIONS FROM SAWMILL WASTE BURNERS*

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One of the air pollution problems which exists in the Pacific Northwest can be traced directly to the incineration of wood residues by the lumber industry. In the manufacture of lumber or plywood, considerable waste material is produced. One way to dispose of this residue is incineration in a "Wigwam" type burner. There are over 500 of these burners in Oregon alone. Figure 1 shows a typical "Wigwam" or "Teepee" burner. This study was undertaken to learn more about the characteristics of the emissions from these incinerators.

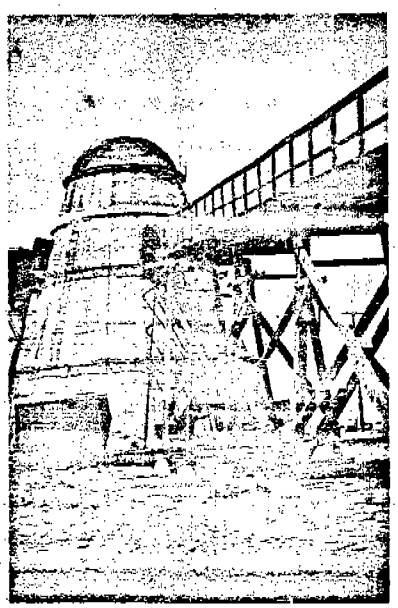

Figure 1. Typical "Wigwam" type incinerator.

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PROCEDURE

During the summer of 1967, a test crew of two men took 100 samples at 19 waste burners in the Pacific Northwest. The crew used a probe operated from the ground to obtain these samples. The probe has been previously described [1, 2]. The probe and sampling system operated satisfactorily as indicated by the fact that the 100 samples were taken by the two man crew in 42 working days. This included the travel time between sites and occasional trips to the laboratory with the samples. Some troubles were encountered, such as getting the probe stuck in the top of a burner occasionally, but these were the exception rather than the rule.

The sampling train used in all tests is shown in Figure 2. It was designed to collect all of the particulate in a form suitable for both gravimetric and size analysis.

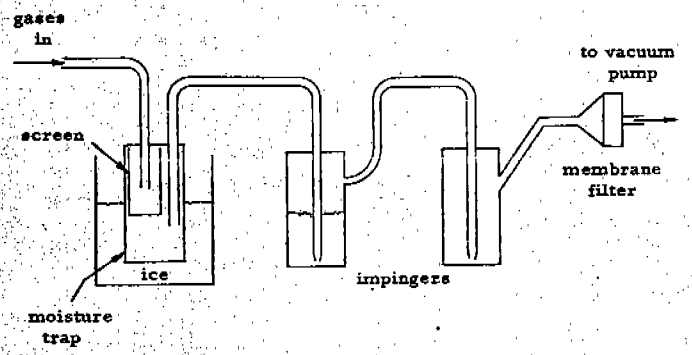

Figure 2. Sampling train.

In the early stages of the development of the sampling train attempts were made to measure the velocity of the gas stream at the top of the burner using a pitot tube and a micromanometer. A pitot tube is not a good device to measure such low velocities and the high temperature eliminates the use of devices such as anemometers. The velocity was also observed to fluctuate considerably. An average velocity value of 600 feet per minute was obtained from the more extensive data in previous studies. Therefore this velocity was matched at the sampling probe tip rather than attempting to continually vary the sampling rate to follow the fluctuating velocity.

The velocity of the gas stream was checked periodically by observing the time required by an observable parcel of smoke to rise from the flat screen to the dome shaped screen. Since this distance was known, the gas velocity could be determined with a pair of binoculars and a stop watch and the sampling velocity adjusted as necessary.

The volume of the sample through the train was determined by measuring, with a stop watch, the time required to fill a Saran plastic bag. The volume of the bag was checked periodically in the laboratory using a wet-test gas meter.

The draft at the base of the burner was determined with an inclined draft gage, range 0-3 inches of water. A copper tube, inserted through the burner shell, connected to the draft gage.

The temperature at the sampling point in the burner was continuously recorded through the use of a Chromel-Alumel thermocouple attached to the sampling probe. The thermocouple voltage was recorded on a Heathkit recorder. A typical temperature recording is shown in Figure 3.

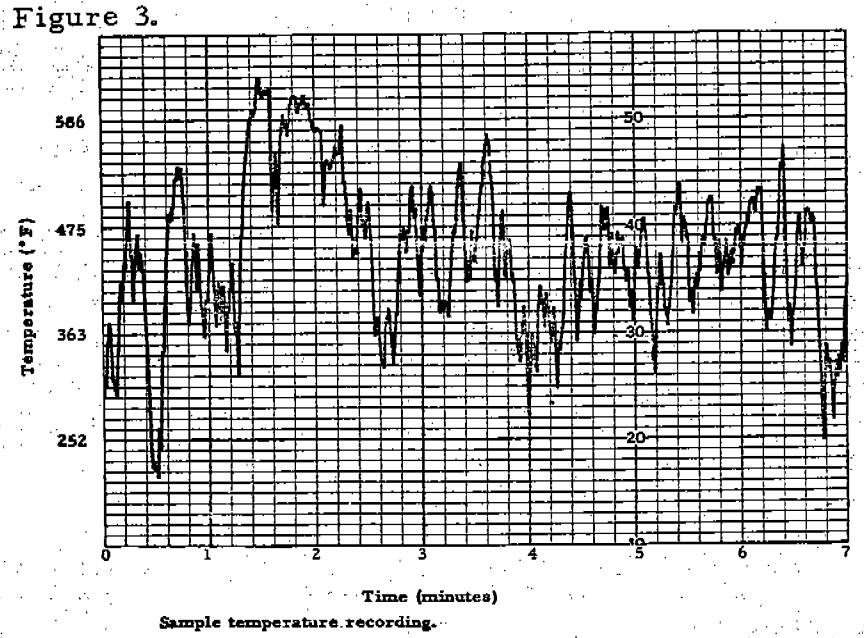

Figure 3. Temperature recording during test.

Fuel loading data were obtained by estimation. Sander dust or planer shavings, which were blown into the burner from a cyclone discharge, were estimated in pounds per minute. Sawdust from the mill was estimated similarly. Larger chunks, such as bark and trim ends, were estimated at the conveyor by determining the approximate weight conveyed by each flight and multiplying by the number of flights per minute to get the fuel rate.

The analytical procedure was to clean and dry the sampling elements before each test. After the test was completed and the components returned to the laboratory, the particulate was washed from

each collecting element, except the membrane filter, with distilled water. A drop of the liquid was then placed on a microscope slide and a particle size distribution determined. Figure 4 illustrates the particulate collected by the sample train. The remaining liquid was

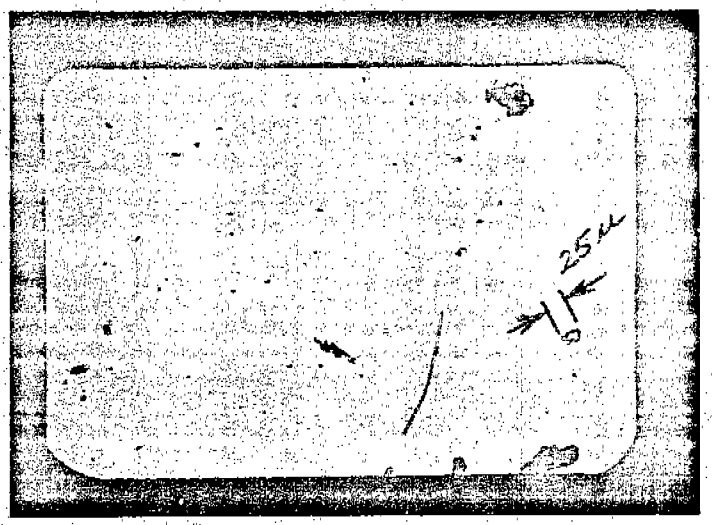

Figure 4. Particulate collected by sampling train. 100X

evaporated in a dried, tared evaporating dish. The weight of the sample was then determined. Sample weights on the order of five milligrams were collected with the sample train. The samples were then ashed by placing them in a muffle furnace at 750°C for 30 minutes. After cooling they were again weighed to determine the percent ash.

Figure 5 shows the material collected during typical runs. The membrane filter is above the respective washings.

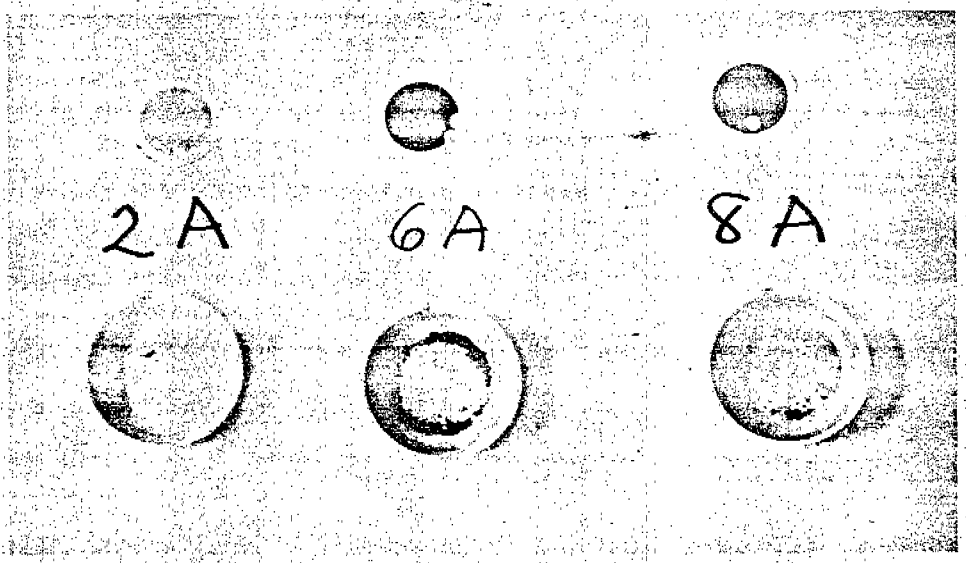

Figure 5. Particulate samples.

Figure 6 shows the same samples after ashing.

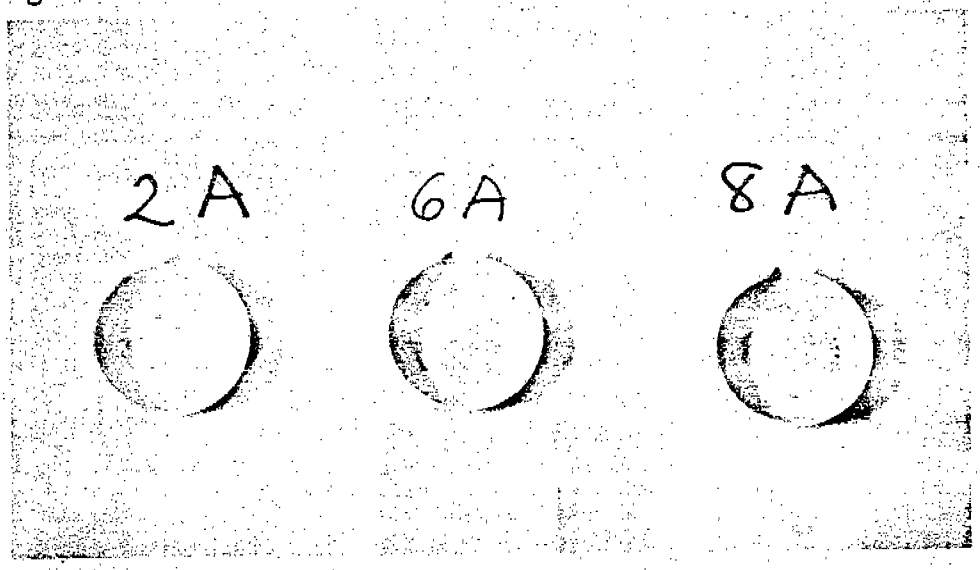

Figure 6. Particulate samples after ashing.

The small particles, collected on the membrane filter, were treated for microscopic examination by making the filter material transparent by applying a drop of dioxane. An example of the small particles collected on the membrane filter can be seen in Figure 7. The particles collected in the sampling train components followed approximately a log normal distribution.

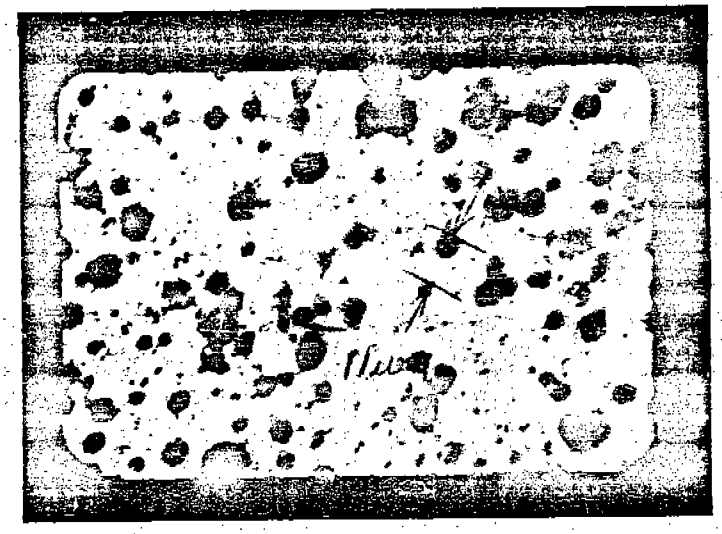

Figure 7. Particles collected on the membrane filter. 450X.

Data tabulation and reduction was done after all samples were analyzed. Variables of interest were: (1) weight gain by the membrane

filter, (2) weight gain by the train ahead of the membrane filter, (3) percent ash in the particulate, (4) average temperature of the gas during the sampling period, (5) particulate emission per unit volume of exhaust gas, (6) draft ratio (actual measured draft: theoretical draft) which indicated the amount of leakage through the burner shell, (7) size analysis of particulate on the membrane filter, and (8) size analysis of particulate in the sampling train ahead of the membrane filter.

RESULTS

Since 19 different burners were tested, it was desirable to determine if significant differences existed between the various burners. An analysis of variance was run and the results are indicated in Table 1.

Variable of Interest	Significant @ 5% Level (Burners significantly different)
Ash content of particulate	Yes
Average gas temperature	Yes
Particulate emission	Yes
Draft ratio	No
Mean particle size collected ahead of membrane filter	Yes
Mean particle size collected by membrane filter	Yes

Table 1. Analysis of variance of data from 19 burners.

Except for the draft ratio, it appears that each burner is significantly different from the average and they must be considered as individual sources (rather than identical sources).

The average draft ratio for all 100 tests was 0.49 which indicates that about 1/2 the theoretical draft can be expected from a wigwam burner. This is reasonable considering the size of the overfire air ports, leakiness of the shell, gaps at the point where the shell meets the ground, etc.

The mean values of the significantly different variables are presented in Table 2. The overall averages would be the values to use to describe a "typical" waste burner. Some values would be significantly higher than the average, and some values significantly lower, as indicated by the analysis of variance.

Number	Ash Content %	Average Gas Temp. °F	Particluate Emission grain/ft^3	Mean Particle Size Ahead of Filter, μ	Particle Geo. Deviation Ahead of Filter	Mean Particle Size on Filter, μ	Particle Geo. Deviation on Filter
1	50	389	0.171	6.29	2.25	0.70	1.42
2	21	539	0.105	2.06	2.86	0.90	1.42
3	30	400	0.080	1.92	2.38	0.96	1.45
4	25	455	0.120	2.09	3.48	1.26	1.56
5	31	291	0.312	2.42	3.64	1.10	1.42
6	44	544	0.155	2.98	4.00	1.19	1.42
7	24	525	0.129	2.57	3.25	1.08	1.43
8	32	598	0.224	2.71	3.96	1.07	1.43
9	56	866	0.130	3.70	3.60	1.03	1.46
10	28	435	0.284	3.92	2.63	1.01	1.45
11	56	405	0.191	2.85	2.84	0.99	1.49
12	*	379	0.163	3.03	2.73	0.96	1.40
13	*	338	0.252	3.41	2.87	1.02	1.55
14	*	208	0.194	3.38	2.38	1.06	1.61
15	*	166	0.132	3.68	3.18	1.03	1.57
16	45	519	0.021	3.29	4.12	1.10	1.57
17	13	791	0.128	3.44	3.31	1.04	1.59
18	22	230	0.160	3.41	3.74	0.96	1.47
19	23	308	0.252	3.79	3.01	0.92	1.56
Overall Average	37	485	0.168	3.28	3.25	1.02	1.49

*Indicates samples lost

Table 2. Significant Variables: Wigwam Waste Burners.

The particulate emitted from the "typical" waste burner would be about 37% ash. This indicates they would be about 1/3 combusted (100% ash would be complete combustion; the wood has about 1% ash originally).

The emission temperature would be 485° F which is considerably below the 600° F - 900° F temperature range recommended for smoke-free operation [3, 4].

The loading to the atmosphere is 0.168 grains per cubic foot of gas corrected to 12% CO_2 and standard temperature (60° F) and pressure (30.00 inches of mercury). This value is considerably below the value used by many control agencies of 0.3 grains per cubic foot for allowable incinerator emissions. Converted to metric units, the average particulate emission is 384 mg/m^3 (corrected to 12% CO_2 and STP). If the air/fuel ratio for a typical wood is assumed, 12% CO_2 [5], is approximately equivalent to 9.5 pounds of air per pound of fuel, the average emission can be calculated 10.7 pounds of particulate per ton of fuel consumed. This is considerably below the value of 22 pounds of particulate per ton of fuel which has been used for years when calculating the emission inventory [6]. An emission of 22 pounds per ton of fuel is roughly equivalent to 0.345 grains per cubic foot. This high a value was measured at times on some of the burners tested (see appendix for data on individual burners). Twenty-two pounds per ton of fuel can still be used as a high value but a more realistic value for an area survey would be the 10.7 pounds per ton figure. Possibly it would be easier to remember, as well as being simpler, if it were rounded to 11 pounds per ton.

The particle size distributions measured showed a significant difference for that material collected in the train ahead of the filter and for that material on the filter itself. This is to be expected because the train was designed to remove the large material before it reached the membrane filter.

The large geometrical deviation ahead of the filter also indicates the wide range of particle size collected by this portion of the train. If an attempt is made to convert the distribution to a weight mean, rather than a count mean, using the formula suggested by Hatch and Choate [7]:

$$\ln M'g = \ln Mg + 3(\ln \sigma g)^2$$

where:

$M'g$ = weight mean

Mg = count mean

σg = geometric deviation

the weight mean size becomes unreasonably large. This formula should not be used therefore because the distributions encountered

were not truly log-normal but a compromise between log-normal and normal. The reason for this was that the particulate emitted could not be considered as being generated by one single source. It was a combination of particles from different processes (sawing, planing, barking, etc.) which had undergone a chemical reaction (combustion) to varying degrees of completeness. A count mean therefore appears to be the best way to describe the size distribution of the material emitted by a wigwam waste burner.

Two distinct size distributions were noted upon microscopic examination of the collected material. One size distribution was noted for a larger particulate which was capable of settling to the ground as dustfall. Another distribution was noted for the smaller sized particles which are seen as "smoke" and are referred to as suspended particulate. An average value of 24% for the weight of the particulate collected on the membrane filter indicated that about one quarter of the mass of the particulate is emitted as "smoke" or suspended particulate.

A brief experiment was conducted in the laboratory to determine the settling velocity of the larger particulate. The time required for the particles to fall 10 feet was observed. The averages of several trails are presented as Table 3.

Particle Size, mm	Measured Settling Time, sec/305 cm	Stokes Diameter Assuming S. G. = 0. 67, mm
3	3. 33	0. 4
5	2. 33	0. 7
9	1. 67	0. 9

Table 3. Settling velocities for large waste burner emissions.

It appears that the larger material emitted by a waste burner, which is certainly a nuisance to nearby property owners, has a stokes diameter about 1/10 its measured diamter. The slow settling is primarily a function of the shape of the particles which is far from spherical. These particles will carry a great deal farther on a wind than would normally be expected if settling velocity were calculated from their measured size. Using a stokes diameter of 1/10 the actual, a 1 mm particle starting from an emitted height of 75 feet can be expected to travel about 1/5 mile on a 5 mph wind before reaching the ground. This assumes laminar flow which of course is never the case. It does give some idea of how far a relatively large particle (considering the size distribution) can travel on a light wind before reaching the ground and adding to the pollution burden as dustfall.

A correlation matrix of variables was run on a computer to see if there was a significant relationship between variables measured during this study. Only three significant correlations were found but they were very interesting as they indicate how a burner might be operated to reduce air pollution:

1. The particulate emission correlates inversely with the emission temperature. The higher the temperature, the lower the emissions.

2. The draft ratio (actual/theoretical) correlates directly with temperature. Higher temperature, and hence lower emission, is achieved with a tighter burner (better maintenance and the doors closed!).

3. The percent of ash in the emission correlates directly with temperature. Higher emission temperature indicates more complete combusion with less material to be emitted as an air pollutant.

The size of the particulate emitted did not correlate significantly with temperature which would indicate that it was more of a function of the material being fed to the burner than how the burner was operated.

CONCLUSION

Until the day of complete wood utilization at all mills comes, we will be using the wigwam burner for residue disposal. The information gathered during the extensive testing of several representative burners is both valid and useful. It can be used by the mill operators to reduce emissions to the minimum so that they might be observed as better industrial citizens. It can be used by control officials to evaluate these burners for particulate emission quantities, size distribution, and transport characteristics of the emissions.

ACKNOWLEDGEMENTS

The cooperation of the 19 mills is greatly appreciated. They are not named as this would not add to the value of this particular study. The lumber industry, as typified by these cooperating mills, has been very helpful in trying to solve their own air pollution problems.

The Oregon State Sanitary Authority Staff has cooperated on many of the studies reported here. Their continued efforts with the wood industries will result in a better environment for the entire Pacific Northwest.

The crews who did the work of testing and analysis deserve special mention. They performed their work well and cheerfully. All were students at Oregon State University: John Kellogg and Larry Thornburgh handled the field collection of the samples, Robert Morrison and Robert Black performed the laboratory analyses.

REFERENCES

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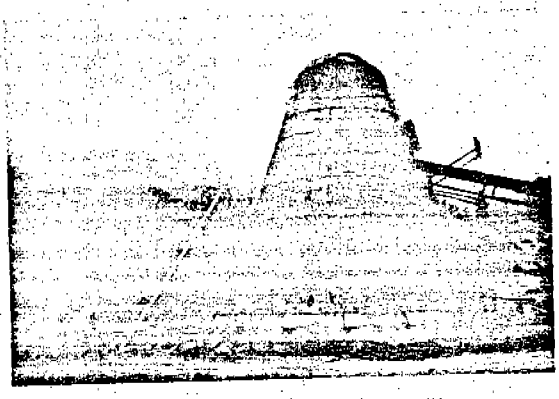
APPENDIX

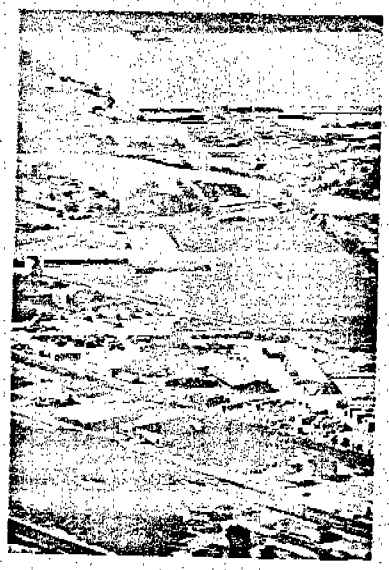
Mill No. - 1
Burner Height - 40 ft.
Burner Base Dia. - 30 ft.
Burner Top Dia. - 15 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, adjustable
Relief Vents - None
Burner Condition - Good
Fuel Type - Douglas Fir bark

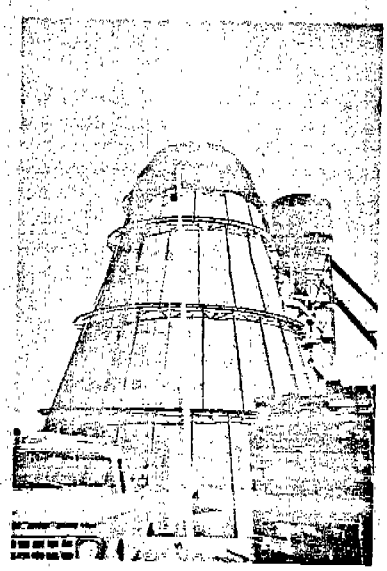


RESULTS OF 4 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0450	0.0770	0.0059	0.1605
% Ash of Particulate	50.17	31.05	9.52	81.16
Average Temp. During Test, °F	388.75	62.77	300.00	440.00
Particulate Emission, Corrected grains / ft^3	0.171	0.245	0.024	0.453
Draft Ratio, Actual / Theoretical	0.39	0.11	0.24	0.48
Sampling Train Mean Diameter (Count Basis), μ	6.29	4.14	2.80	11.90
Sampling Train Geometrical Deviation	2.25	1.04	1.39	3.66
Membrane Filter Mean Diameter (Count Basis), μ	0.70	0.09	0.61	0.82
Membrane Filter Geometrical Deviation	1.42	0.02	1.39	1.44

Mill No. - 2
Burner Height - 35 ft.
Burner Base Dia. - 30 ft.
Burner Top Dia. - 15 ft.
Forced Draft System - Centrifigal Fan
Grate System - Elbow Grates
Overfire Air - Tangential, adjustable
Relief Vents - None
Burner Condition - Fair - Good
Fuel Type - White Fir sawdust, rough stock, planer shavings

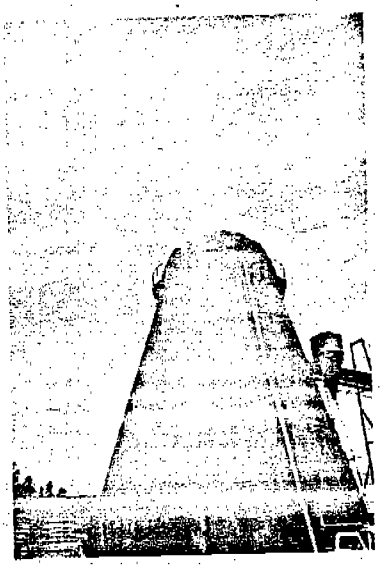




RESULTS OF 4 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0355	0.0158	0.0164	0.0552
% Ash of Particulate	21.35	0.52	20.73	21.97
Average Temp. During Test, °F	538.75	72.15	470.00	635.00
Particulate Emission, Corrected grains / ft^3	0.105	0.047	0.061	0.167
Draft Ratio, Actual / Theoretical	0.92	0.10	0.79	1.00
Sampling Train Mean Diameter (Count Basis), μ	2.06	0.48	1.46	2.61
Sampling Train Geometrical Deviation	2.86	0.55	2.29	3.60
Membrane Filter Mean Diameter (Count Basis), μ	0.90	0.03	0.87	0.95
Membrane Filter Geometrical Deviation	1.42	0.02	1.40	1.45

Mill No. - 3
Burner Height - 50 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 25 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, Adjustable
Relief Vents - None
Burner Condition - Fair
Fuel Type - Cedar sawdust, bark, rough stock

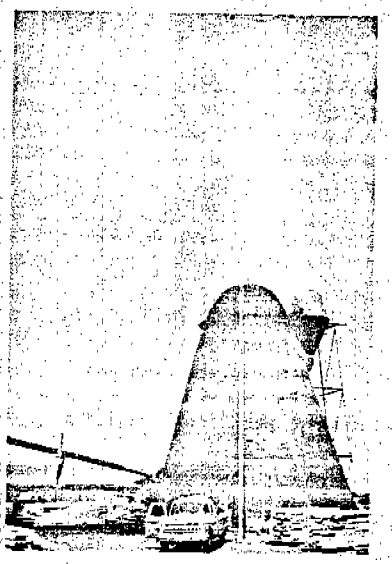


RESULTS OF 2 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0159	0.0008	0.0154	0.0165
% Ash of Particulate	29.82	2.02	28.40	31.25
Average Temp. During Test, °F	400.00	*	*	*
Particulate Emission, Corrected grains / ft^3	0.080	*	*	*
Draft Ratio, Actual / Theoretical	0.68	*	*	*
Sampling Train Mean Diameter (Count Basis), μ	1.92	0.66	1.45	2.39
Sampling Train Geometrical Deviation	2.38	0.23	2.22	2.55
Membrane Filter Mean Diameter (Count Basis), μ	0.96	0.05	0.92	0.99
Membrane Filter Geometrical Deviation	1.45	0.06	1.41	1.50

* Only one value

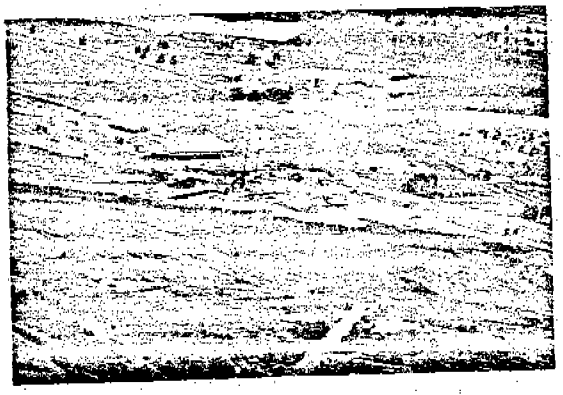
Mill No. - 4
Burner Height - 40 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 20 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, adjustable
Relief Vents - Yes
Burner Condition - Good
Fuel Type - Hemlock rough stock

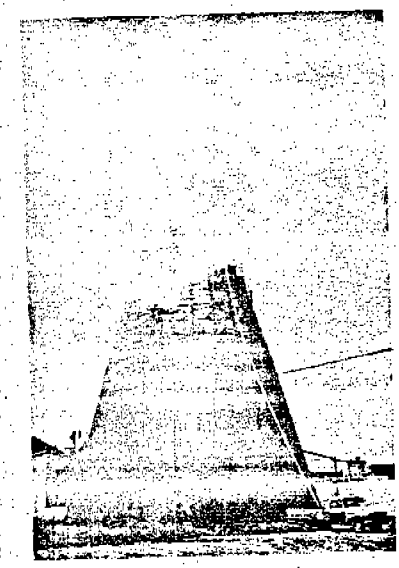


RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0173	0.0039	0.0130	0.0232
% Ash of Particulate	25.29	11.96	16.59	46.15
Average Temp. During Test, °F	455.00	50.74	390.00	510.00
Particulate Emission, Corrected grains / ft^3	0.120	0.032	0.082	0.156
Draft Ratio, Actual / Theoretical	0.43	0.08	0.33	0.54
Sampling Train Mean Diameter (Count Basis), μ	2.09	0.50	1.47	2.58
Sampling Train Geometrical Deviation	3.48	0.67	2.76	4.42
Membrane Filter Mean Diameter (Count Basis), μ	1.26	0.25	1.03	1.61
Membrane Filter Geometrical Deviation	1.56	0.24	1.28	1.86

Mill No. - 5
Burner Height - 60 ft.
Burner Base Dia. - 60 ft.
Burner Top Dia. - 30 ft.
Forced Air System - Centrifigal Fans
Grate System - None
Overfire Air - Tangential, Fixed
Relief Vents - None
Burner Condition - Fair - Good
Fuel Type - Ponderosa Pine sawdust, shavings, rough stock

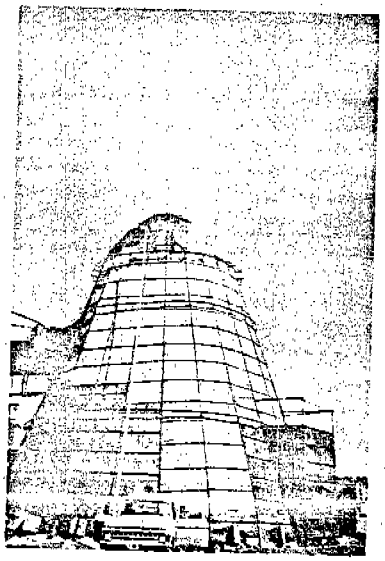




RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0180	0.0079	0.0050	0.0260
% Ash of Particulate	30.67	8.32	20.22	37.96
Average Temp. During Test, °F	291.00	133.15	190.00	525.00
Particulate Emission, Corrected grains / ft^3	0.312	0.184	0.103	0.539
Draft Ratio, Actual / Theoretical	0.38	0.19	0.22	0.71
Sampling Train Mean Diameter (Count Basis), μ	0.42	1.08	1.00	3.65
Sampling Train Geometrical Deviation	3.64	0.92	2.70	5.15
Membrane Filter Mean Diameter (Count Basis), μ	1.10	0.17	0.90	1.24
Membrane Filter Geometrical Deviation	1.42	0.05	1.36	1.49

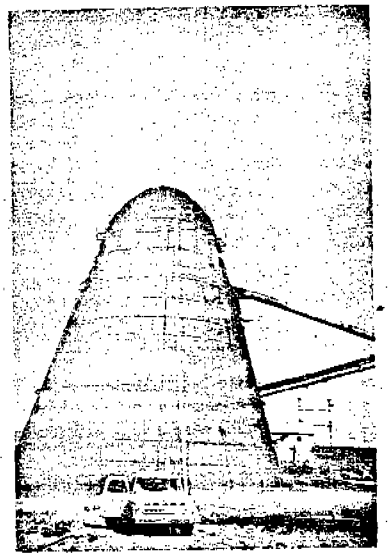
Mill No. - 6
Burner Height - 50 ft.
Burner Base Dia. - 50 ft.
Burner Top Dia. - 25 ft.
Forced Draft System - Axial & Centrifigal Fans
Grate System - Flat Grates
Overfire Air - Tangential, Fixed
Relief Vents - None
Burner Condition - Good
Fuel Type - White and Red Fir, Lodgepole Pine sawdust, shavings, rough stock



RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0350	0.0133	0.0121	0.0488
% Ash of Particulate	44.26	7.09	34.67	53.79
Average Temp. During Test, °F	544.00	22.75	525.00	580.00
Particulate Emission, Corrected grains / ft^3	0.154	0.063	0.060	0.232
Draft Ratio, Actual / Theoretical	0.74	0.04	0.68	0.77
Sampling Train Mean Diameter (Count Basis), μ	2.98	1.44	1.80	5.02
Sampling Train Geometrical Deviation	4.00	1.12	2.93	5.78
Membrane Filter Mean Diameter (Count Basis), μ	1.19	0.08	1.10	1.27
Membrane Filter Geometrical Deviation	1.42	0.11	1.32	1.59

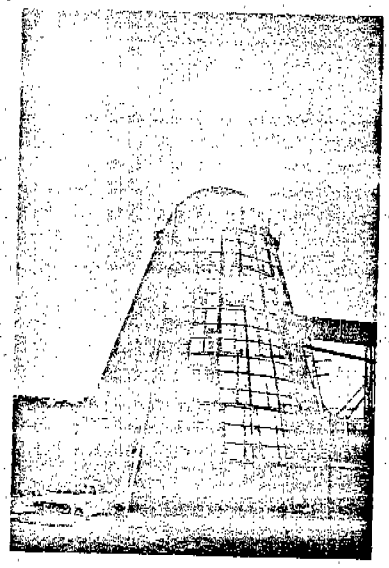
Mill No. - 7
Burner Height - 50 ft.
Burner Base Dia. - 50 ft.
Burner Top Dia. - 25 ft.
Forced Draft System - Centrifigal Fan
Grate System - None
Overfire Air - Window, Fixed
Relief Vents - None
Burner Condition - Fair
Fuel Type - Fir and Pine sawdust, bark, rough stock



RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0253	0.0124	0.0090	0.0426
% Ash of Particulate	23.69	4.59	16.39	27.53
Average Temp. During Test, °F	525.00	72.80	410.00	590.00
Particulate Emission, Corrected grains / ft^3	0.129	0.063	0.041	0.190
Draft Ratio, Actual / Theoretical	0.72	0.08	0.63	0.85
Sampling Train Mean Diameter (Count Basis), μ	2.57	0.66	1.92	3.64
Sampling Train Geometrical Deviation	3.25	0.43	2.67	3.82
Membrane Filter Mean Diameter (Count Basis), μ	1.08	0.06	0.98	1.14
Membrane Filter Geometrical Deviation	1.43	0.06	1.34	1.49

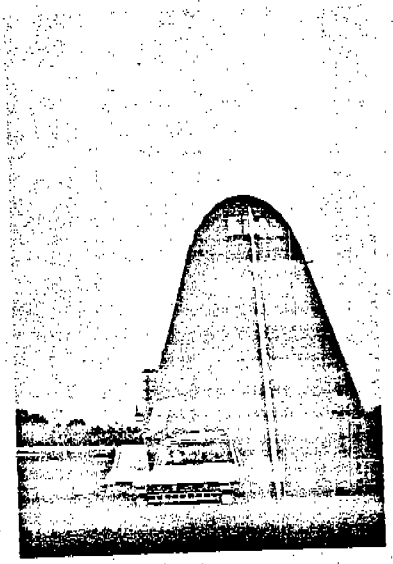
Mill No. - 8
Burner Height - 60 ft.
Burner Base Dia. - 50 ft.
Burner Top Dia. - 25 ft.
Forced Draft System - Centrifigal fan
Grate System - None
Overfire Air - Tangential, adjustable
Relief Vents - None
Burner Condition - Good
Fuel Type - Pine, some Fir sawdust, shavings, Fir bark



RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0395	0.0178	0.0133	0.0615
% Ash of Particulate	31.61	8.23	25.09	45.36
Average Temp. During Test, °F	598.00	49.32	525.00	650.00
Particulate Emission, Corrected grains / ft^3	0.224	0.096	0.096	0.358
Draft Ratio, Actual / Theoretical	0.68	0.15	0.55	0.90
Sampling Train Mean Diameter (Count Basis), μ	2.71	0.71	2.07	3.88
Sampling Train Geometrical Deviation	3.96	0.94	3.04	5.33
Membrane Filter Mean Diameter (Count Basis), μ	1.07	0.06	1.01	1.17
Membrane Filter Geometrical Deviation	1.43	0.03	1.42	1.48

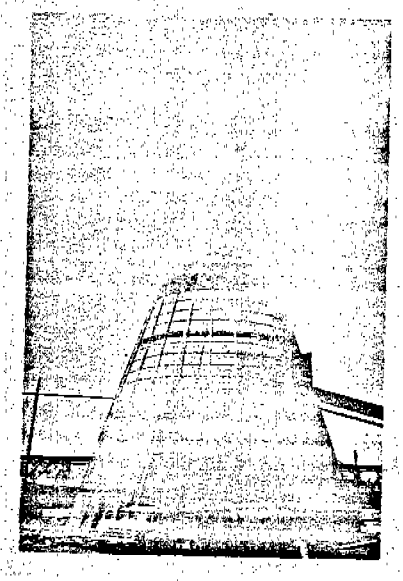
Mill No. - 9
Burner Height - 50 ft.
Burner Base Dia. - 25 ft.
Burner Top Dia. - 15 ft.
Forced Draft System - Centrifigal
Grate System - flat
Overfire Air - Tangential, adjustable
Relief Vents - None
Burner Condition - Good
Fuel Type - Fir shavings, bark



RESULTS OF 15 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.1054	0.0665	0.0064	0.2104
% Ash of Particulate	56.48	14.78	22.81	79.98
Average Temp. During Test, °F	866.33	323.58	150.00	1500.00
Particulate Emission, Corrected grains / ft^3	0.130	0.087	0.027	0.362
Draft Ratio, Actual / Theoretical	0.79	0.16	0.56	1.20
Sampling Train Mean Diameter (Count Basis), μ	3.70	1.30	2.05	6.45
Sampling Train Geometrical Deviation	3.60	0.84	2.62	5.61
Membrane Filter Mean Diameter (Count Basis), μ	1.03	0.08	0.91	1.19
Membrane Filter Geometrical Deviation	1.46	0.07	1.33	1.65

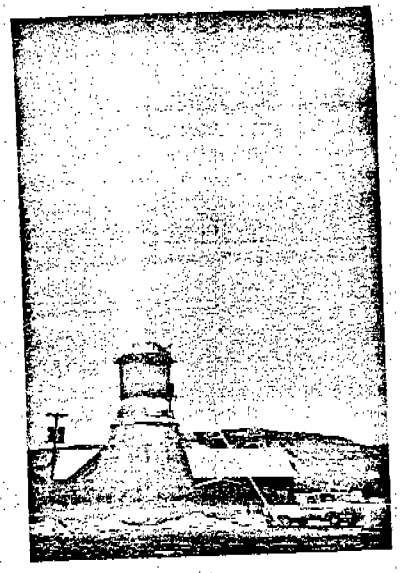
Mill No. - 10
Burner Height - 50 ft.
Burner Base Dia. - 50 ft.
Burner Top Dia. - 25 ft.
Forced Draft System - Centrifigal
Grate System - flat
Overfire Air - Tangential, fixed
Relief Vents - Yes
Burner Condition - Good
Fuel Type - Fir, Pine, Larch, Spruce sawdust, bark



RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0356	0.0186	0.0045	0.0510
% Ash of Particulate	27.78	14.63	3.22	38.94
Average Temp. During Test, °F	435.00	94.54	300.00	525.00
Particulate Emission, Corrected grains / ft^3	0.283	0.211	0.019	0.605
Draft Ratio, Actual / Theoretical	0.37	0.20	0.06	0.61
Sampling Train Mean Diameter (Count Basis), μ	3.92	0.76	2.71	4.45
Sampling Train Geometrical Deviation	2.63	0.68	1.80	3.46
Membrane Filter Mean Diameter (Count Basis), μ	1.01	0.05	0.96	1.09
Membrane Filter Geometrical Deviation	1.45	0.04	1.39	1.50

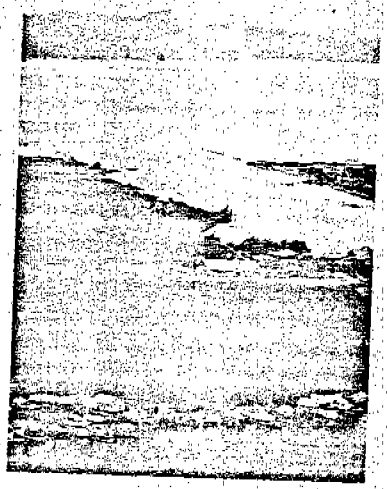
Mill No. - II
Burner Height - 35 ft.
Burner Base Dia. - 25 ft.
Burner Top Dia. - 15 ft.
Forced Draft System - Centrifugal
Grate System - None
Overfire Air - Window, fixed
Relief Vents - None
Burner Condition - poor
Fuel Type - Fir, Pine, Spruce sawdust, shavings, bark, rough stock

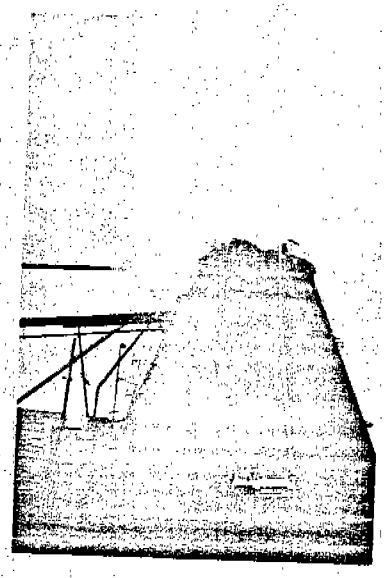


RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0308	0.0094	0.0198	0.0453
% Ash of Particulate	55.83	16.82	32.57	73.58
Average Temp. During Test, °F	405.00	59.58	340.00	500.00
Particulate Emission, Corrected grains / ft^3	0.190	0.042	0.132	0.246
Draft Ratio, Actual / Theoretical	0.29	0.06	0.22	0.33
Sampling Train Mean Diameter (Count Basis), μ	2.85	0.69	2.00	3.52
Sampling Train Geometrical Deviation	2.84	0.88	1.81	3.63
Membrane Filter Mean Diameter (Count Basis), μ	0.99	0.08	0.88	1.10
Membrane Filter Geometrical Deviation	1.49	0.04	1.43	1.53

Mill No. - 12
Burner Height - 60 ft.
Burner Base Dia. - 50 ft.
Burner Top Dia. - 25 ft.
Force Draft System - Centrifugal
Grate System - Flat
Overfire Air - Tangential, adjustable
Relief Vents - None
Burner Condition - Fair
Fuel Type - Hemlock sawdust, shavings, rough stock

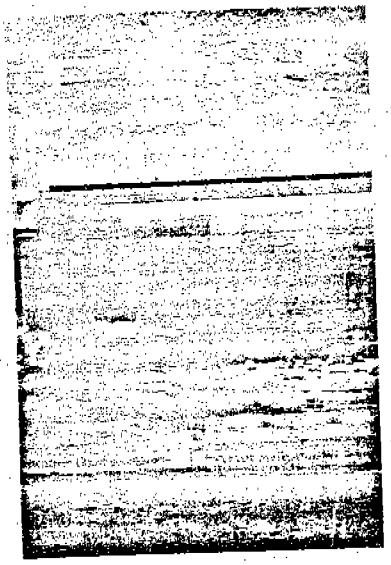


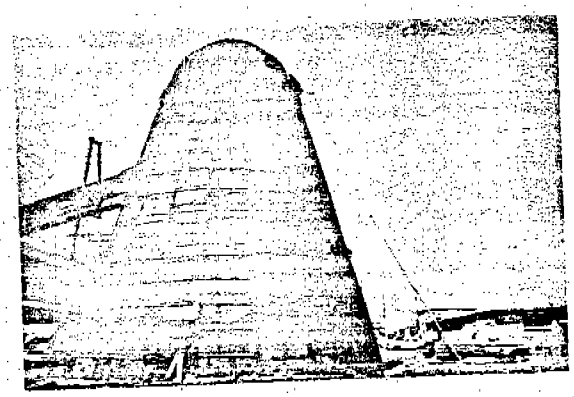


RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0195	0.0076	0.0090	0.0275
% Ash of Particulate	----------	----- No Data ---	----------	----------
Average Temp. During Test, °F	379.00	163.72	90.00	490.00
Particulate Emission, Corrected grains / ft^3	0.163	0.152	0.045	0.429
Draft Ratio, Actual / Theoretical	0.70	1.05	0.17	2.57
Sampling Train Mean Diameter (Count Basis), μ	3.03	0.79	2.00	4.12
Sampling Train Geometrical Deviation	2.73	0.69	1.91	3.52
Membrane Filter Mean Diameter (Count Basis), μ	0.96	0.05	0.88	1.00
Membrane Filter Geometrical Deviation	1.40	0.06	1.31	1.47

Mill No. - 13
Burner Height - 45 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 20 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, fixed
Relief Vents - None
Burner Condition - Poor
Fuel Type - Veneer (fir, hemlock, spruce, cedar) rough stock

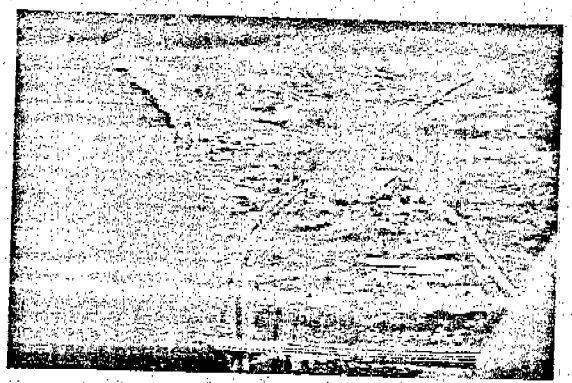


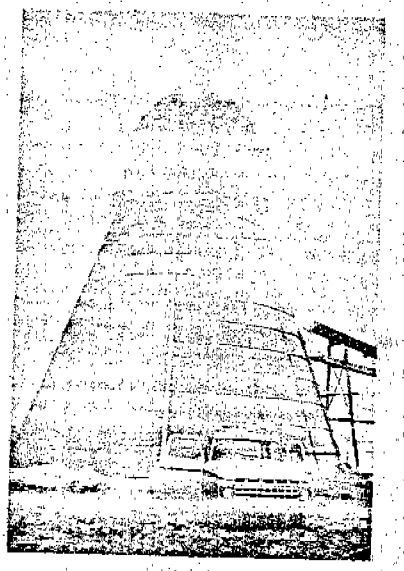


RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0224	0.0195	0.0045	0.0522
% Ash of Particulate	----------	-------- No Data	----------	----------
Average Temp. During Test, °F	388.00	66.86	290.00	450.00
Particulate Emission, Corrected grains / ft^3	0.252	0.242	0.028	0.607
Draft Ratio, Actual / Theoretical	0.70	0.42	0.11	1.26
Sampling Train Mean Diameter (Count Basis), μ	3.41	0.98	2.52	4.95
Sampling Train Geometrical Deviation	2.87	0.46	2.13	3.33
Membrane Filter Mean Diameter (Count Basis), μ	1.02	0.08	0.92	1.13
Membrane Filter Geometrical Deviation	1.55	0.18	1.32	1.75

Mill No. - 14
Burner Height - 50 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 20 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, None
Relief Vents - Yes
Burner Condition - Fair
Fuel Type - Alder, Maple, Oak sawdust, bark, rough stock

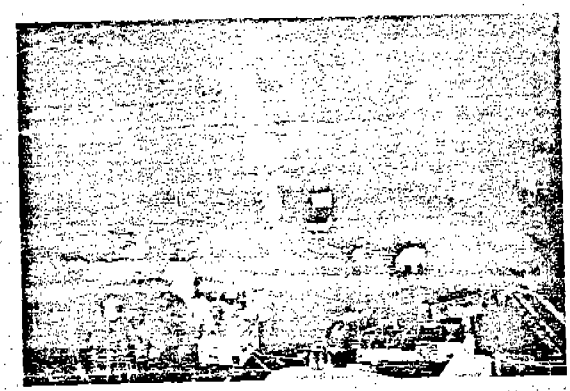


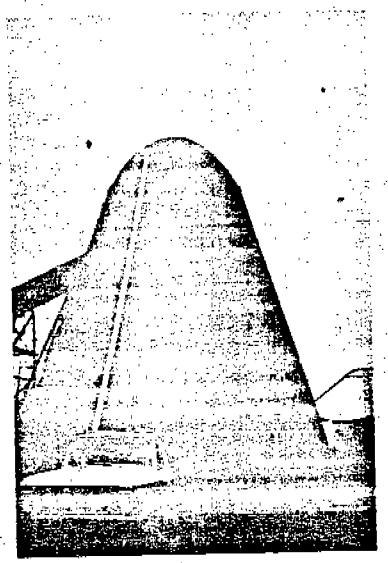


RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0139	0.0080	0.0060	0.0253
% Ash of Particulate	----------	------ No Data ---	----------	----------
Average Temp. During Test, °F	208.00	60.89	130.00	290.00
Particulate Emission, Corrected grains / ft^3	0.194	0.069	0.123	0.287
Draft Ratio, Actual / Theoretical	0.31	0.15	0.14	0.49
Sampling Train Mean Diameter (Count Basis), μ	3.38	0.79	2.90	4.78
Sampling Train Geometrical Deviation	2.38	1.30	1.26	3.99
Membrane Filter Mean Diameter (Count Basis), μ	1.06	0.13	0.92	1.19
Membrane Filter Geometrical Deviation	1.61	0.09	1.50	1.72

Mill No. - 15
Burner Height - 40 ft.
Burner Base Dia. - 30 ft.
Burner Top Dia. - 15 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, fixed
Relief Vents - None
Burner Condition - Poor
Fuel Type - Fir, Hemlock, Spruce sawdust, bark, rough stock

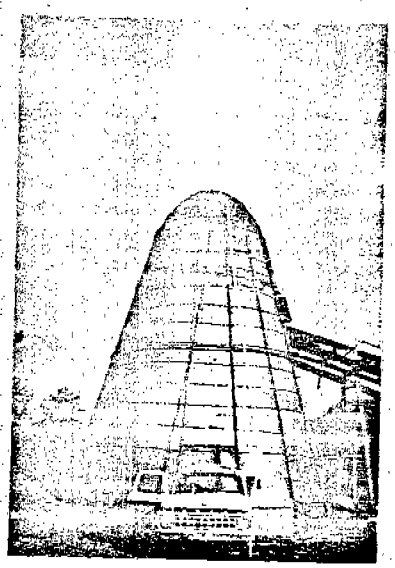




RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0101	0.0050	0.0054	0.0184
% Ash of Particulate	----------	-------- No Data --	----------	----------
Average Temp. During Test, °F	166.00	73.09	100.00	275.00
Particulate Emission, Corrected grains / ft^3	0.132	0.081	0.069	0.271
Draft Ratio, Actual / Theoretical	0.12	0.08	0.00	0.24
Sampling Train Mean Diameter (Count Basis), μ	3.68	1.01	2.44	5.06
Sampling Train Geometrical Deviation	3.18	0.53	2.51	3.70
Membrane Filter Mean Diameter (Count Basis), μ	1.03	0.04	1.00	1.08
Membrane Filter Geometrical Deviation	1.57	0.12	1.41	1.72

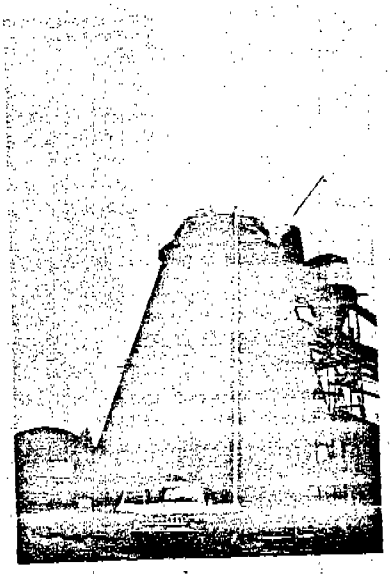
Mill No. - 16
Burner Height - 45 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 20 ft.
Forced Draft System - Axial
Grate System - Mushroom
Overfire Air - Tangential, fixed
Relief Vents - None
Burner Condition - Good
Fuel Type - Redwood bark



RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0113	0.0044	0.0071	0.0166
% Ash of Particulate	44.84	28.97	15.09	93.22
Average Temp. During Test, °F	519.00	22.75	480.00	540.00
Particulate Emission, Corrected grains / ft^3	0.020	0.008	0.012	0.032
Draft Ratio, Actual / Theoretical	0.31	0.17	0.00	0.44
Sampling Train Mean Diameter (Count Basis), μ	3.29	0.75	2.60	4.28
Sampling Train Geometrical Deviation	4.12	1.46	2.57	6.38
Membrane Filter Mean Diameter (Count Basis), μ	1.10	0.09	0.98	1.17
Membrane Filter Geometrical Deviation	1.57	0.20	1.40	1.81

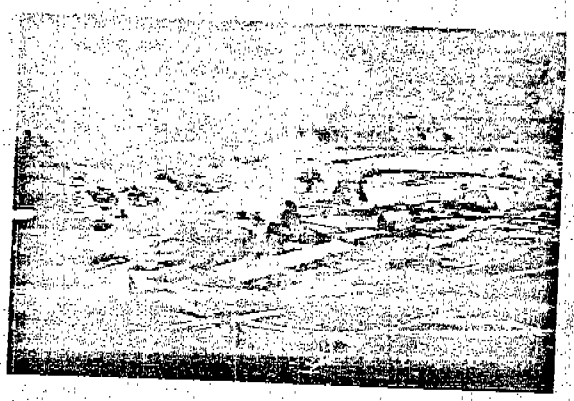
Mill No. - 17
Burner Height - 50 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 20 ft.
Forced Draft System - Centrifigal, Axial
Grate System - Mushroom
Overfire Air - Tangential, fixed
Relief Vents - None
Burner Condition - Good
Fuel Type - Redwood shavings

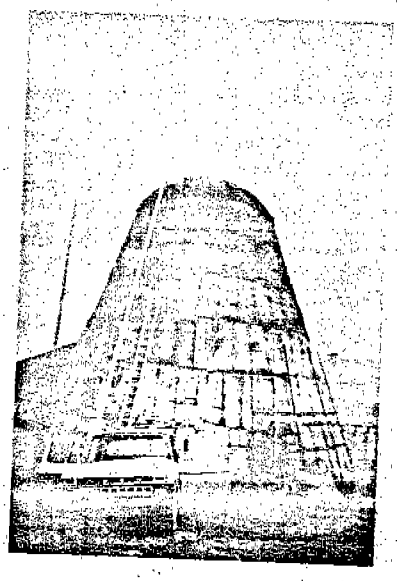


RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0449	0.0067	0.0353	0.0519
% Ash of Particulate	12.84	5.16	6.81	19.19
Average Temp. During Test, °F	791.00	248.93	450.00	1075.00
Particulate Emission, Corrected grains / ft^3	0.128	0.074	0.055	0.228
Draft Ratio, Actual / Theoretical	0.41	0.14	0.24	0.60
Sampling Train Mean Diameter (Count Basis), μ	3.44	0.96	2.23	4.55
Sampling Train Geometrical Deviation	3.31	0.60	2.83	4.35
Membrane Filter Mean Diameter (Count Basis), μ	1.04	0.09	0.96	1.17
Membrane Filter Geometrical Deviation	1.59	0.18	1.38	1.79

Mill No. - 18
Burner Height - 40 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 20 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, fixed
Relief Vents - None
Burner Condition - Poor
Fuel Type - Douglas Fir sawdust, rough stock

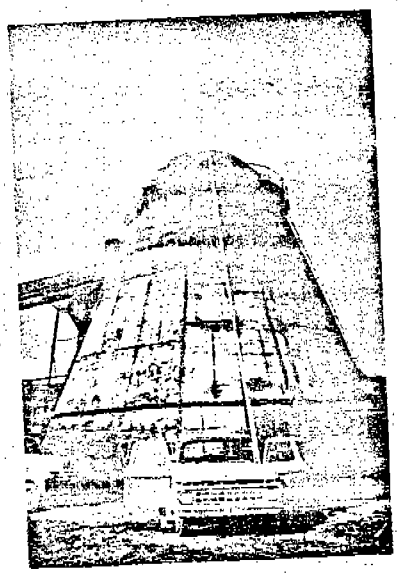




RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0088	0.0057	0.0014	0.0143
% Ash of Particulate	22.17	0.07	0.00	22.22
Average Temp. During Test, °F	230.00	183.20	100.00	550.00
Particulate Emission, Corrected grains / ft^3	0.160	0.133	0.004	0.302
Draft Ratio, Actual / Theoretical	0.15	0.09	0.00	0.25
Sampling Train Mean Diameter (Count Basis), μ	3.41	0.77	2.86	4.75
Sampling Train Geometrical Deviation	3.74	1.22	1.77	4.97
Membrane Filter Mean Diameter (Count Basis), μ	0.96	0.13	0.78	1.09
Membrane Filter Geometrical Deviation	1.47	0.04	1.43	1.54

Mill No. - 19
Burner Height - 40 ft.
Burner Base Dia. - 40 ft.
Burner Top Dia. - 20 ft.
Forced Draft System - None
Grate System - None
Overfire Air - Tangential, fixed
Relief Vents - Yes
Burner Condition - Poor
Fuel Type - Douglas Fir sawdust, rough stock, sander dust, shavings



RESULTS OF 5 TESTS

Variable of Interest	Mean	Standard Deviation	Low Value	High Value
Total Particulate Collected, grams	0.0233	0.0127	0.0087	0.0347
% Ash of Particulate	23.18	5.18	14.52	27.35
Average Temp. During Test, °F	308.00	208.28	100.00	540.00
Particulate Emission, Corrected grains / ft^3	0.252	0.194	0.028	0.465
Draft Ratio, Actual / Theoretical	0.22	0.12	0.00	0.40
Sampling Train Mean Diameter (Count Basis), μ	3.79	1.75	2.34	6.15
Sampling Train Geometrical Deviation	3.01	0.75	2.35	4.30
Membrane Filter Mean Diameter (Count Basis), μ	0.92	0.05	0.83	0.96
Membrane Filter Geometrical Deviation	1.56	0.14	1.43	1.74