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EMISSION FACTOR DEVELOPMENT FOR LEAF BURNING

by

Ellis F. Darley

Statewide Air Pollution Research Center
University of California
Riverside, California 92502

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EPA Project Officer: Thomas F. Lahre

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Abstract

In order to develop emission factors for particulates, carbon monoxide and hydrocarbons from the burning of street tree leaves, leaf samples from 15 species were burned in the tower at the University of California, Riverside; a total of 131 fires was conducted. Leaves at two moisture levels, approximately 10 and 20% (dry weight basis), were arranged in conical piles and ignited either around the periphery at the bottom or at a single spot at the top. A few samples were arranged in windrows and ignited from one end. For one species, American sycamore, the opportunity was presented to compare the effect of different bulk densities on the amount of pollutants emitted.

Catalpa, magnolia, American sycamore, and California sycamore were consistently low in yields of all three pollutants at the low moisture level. Averaging the four species together, the yields for particulate, CO and hydrocarbon in pounds per ton of fuel burned were about 11, 85 and 8 pounds, respectively. Magnolia was the cleanest at about 9, 51 and 8 pounds, respectively, although for hydrocarbons alone, the yield from California sycamore was the lowest at 2.7 pounds. The highest yields were from black locust which produced about 68, 117 and 49 pounds of the three pollutants, respectively.

Raising the fuel moisture level generally increased the production of all three pollutants. The increase was greatest for particulate (up to four times) and hydrocarbon (up to three times), and the least for CO (up to 29%).

In one sample of silver maple, green leaves had fallen among the dry leaves. The average moisture of the mix was a little higher than the high moisture level of the standard fires, but pollutant yields were increased dramatically.

Top ignition generally reduced the pollutant emissions. In many cases this reduction was so great that yields from the high moisture level was less than from the bottom ignition at the low moisture level.

An increase in bulk density of American sycamore as the result of physically compressing the leaves resulted in an increase in pollutant emissions.

There was relatively little variation in the proportion of individual or groups of hydrocarbons within grab samples taken for hydrocarbon analysis. Averaging all fuels at both moisture levels, the ratio of olefins to methane, other saturates, and acetylene was 42:32:13:8.

The majority of particles from all fires sampled were submicron in size. Mass median diameter averaged .28μ and ranged from .05μ (catalpa) to .60μ (black locust). An increase in moisture consistently resulted in particles of larger diameter, ranging from a few percent change in cottonwood to a six-fold change in catalpa. Top ignition gave no real benefit in altering particle size distribution. Increasing the bulk density of American sycamore caused the particles to be larger.

Emission Factor Development for Leaf Burning

Introduction

In order to determine the emissions from burning leaves from a number of street tree species, arrangements were made between the National Data Branch, Environmental Protection Agency, and the University of California, Riverside. This project was an outgrowth of one carried out for the State of Illinois where leaves from only three tree species were burned. The leaves were burned in a special tower that had been developed for the purpose of determining pollutant emissions from burning wastes of agricultural and forest operations. One hundred thirty one fires were completed using 15 species of leaf samples collected in the Riverside-Los Angeles area. One series of fires included leaves from the previous Illinois study.

Facilities

Experimental procedures for burning fuels and sampling emissions were carried out in an out-of-doors burning tower and adjacent instrument building which has been described earlier by Darley *et al*. (1). Some important modifications have since been made and are given in some detail in a recent publication of the National Academy of Sciences (2). A brief description of the tower is presented here.

The facility simulates open burning but channels the combustion products so that representative samples of gas and particles can be taken. The tower is in the form of an inverted funnel, 16 feet in diameter at the base, decreasing to 28 inches in a length of 20 feet, and topped with a stack 8 feet in length. The tower is erected above a table 8 feet in diameter, which is positioned in a scale with a maximum capacity of 125 pounds. The sample site for gases, particulate, and for recording temperature and airflow is in the stack about two feet below the top. Stack gases for analysis of total hydrocarbon, CO, and CO_2, are drawn through sample lines into the appropriate analyzers in the instrument building to give a continuous millivolt equivalent recording of concentrations. Taps on the gas sampling system lead to bottles which were used to take grab samples at two points during the fire--the temperature peak and the hydrocarbon peak. Grab samples were taken from 34 fires, representing 11 of the 15 species and analyzed for individual hydrocarbons.

Airflow is monitored with a 4-cup anemometer mounted in the stack. A shaft encoder is positioned on the end of the anemometer shaft, just outside of the stack. The encoder generates a millivolt signal by making and breaking a light beam through an 800-slot disc. One revolution of the shaft creates 800 pulses, and 3000 pulses per second generates the full-scale 50 mv signal. The maximum airflow encountered during the peak of the hottest agricultural fires is between 40-45 mv, or approximately 10,000 cubic feet per minute. A transducer was adapted to the actuating mechanism of the scale so that a change in weight generated a millivolt signal; 1 mv is equivalent to 1 pound and full range is 50 mv.

All recording instruments are connected to a data acquisition system which in turn is connected to the campus computer. The computer polls each recorder every 2.6 seconds and stores the millivolt response of each instrument on tape or discs. A computer program has been written from which the yield of pollutants in pounds per ton of fuel burned can be calculated using the data collected on temperature, gas concentration, and airflow.

Particulates are collected isokinetically on standard Type A glass fiber filters held in two modified HIVOL samplers positioned in series in the sample line and outside of the tower. A pneumatic controller senses differences in airflow in the stack and continuously adjusts a globe valve in the sample line so that isokinetic sampling is achieved. The sample volume is approximately 1/776th of the total flow through the stack. The principal use made of the isokinetic collection system has been to determine the total weight of particulate from given fuels to establish emission factors. In addition, for the present project a Sierra Instrument Company HIVOL 5-stage cascade impactor was used to determine particle size distribution from 36 fires, representing all but one of the species. The impactor was set up near the top of the tower so that samples were taken just above the opening of the stack. Particle cut-off sizes were determined for each stage by calculations based on the theory developed by Marple (3). A correction was made for a 50 cfm flow and a mass density of 0.9 g/cc was selected as a reasonable approximation.

Leaf Samples and Burning Procedures

Samples of leaves from the following 15 following tree species were collected from the Riverside Campus, City parks, and from the Los Angeles State and County Arboretum in Arcadia:

Black ash
Modesto ash
White ash
Catalpa
Horse chestnut
Cottonwood
American elm
Eucalyptus
Sweet gum
Black locust
Magnolia
Silver maple
American sycamore
California sycamore
Tulip

Great care was taken in all stages of collecting, transporting, and subsequent handling of the leaves so as not to alter their bulk density from what might have existed if the leaves had been raked into a pile on site and burned.

Leaves were burned at two moisture levels determined on a dry weight basis. The low level was the air-dry moisture existing in the leaves at the time the leaves were burned and was generally between 7 and 10 percent. The high level of moisture used was approximately 20 percent. Once the moisture content of the air-dry leaves had been determined, the amount of water to be added to a given weight of leaves to bring the moisture to approximately 20 percent could be calculated. Leaves to be moistened were placed in a large polyethylene bag and the desired amount of water was added in a fine spray in 3 to 5 aliquots, stirring the leaves between each spraying. The bag was sealed and allowed to equilibrate for about 16 hours; the leaves were rolled gently around within the bag a few times during that interval. Just before the leaves were placed on the table, a sample was taken for moisture determination.

From the previous Illinois study, it was found that a 6-pound sample of leaves was the best quantity to use for each fire. In most cases leaves were arranged in a conical pile; windrows were occasionally used. Piles were ignited with small laboratory-type propane torches either around the entire periphery at the bottom or at a single spot at the top. Windrows were lighted across the bottom of one end. At least two fires were conducted at each moisture level and ignition method for each of the species.

Some special fires were conducted comparing the emissions from leaves of American sycamore collected in Riverside with those sent to us from Illinois. The latter leaves had become quite compressed during shipping so that their bulk density was somewhat greater than that of leaves raked into piles on site. Piles of Riverside leaves burned quickly and completely within a few minutes, whereas the piles of Illinois leaves had to be stirred several times to accomplish similar burning rates.

Results and Discussion

Emissions of Particulates, Carbon Monoxide, and Hydrocarbons

The emissions of particulate, CO, and hydrocarbons at the two moisture levels and two ignition methods are given in terms of pounds per ton of leaves burned in Table 1. In addition, the bulk density in pounds per cubic foot is also given.

Particulates.--Bottom ignition is probably the most common method of lighting piles of combustible plant material. When particulate emissions were compared between species at the low moisture level using bottom ignition, it was found that catalpa, magnolia, and both American and California sycamore produced less than 15 pounds per ton of fuel burned, the low value being 9.4 pounds for magnolia. White ash and tulip produced a little less than 20 pounds while the emission value for all other species was over 25 pounds. Those producing nearly 40 or more pounds were Modesto ash (40.4), cottonwood (39.1), sweet gum (40.9), black locust (68.0), and silver maple (74.2).

Increasing the moisture generally increased the particulate yield, in some cases by a factor of two and in one case (white ash) by a factor of almost 4. Moistened horse chestnut leaves gave the highest yield at 76.3 pounds. In four species, black ash, cottonwood, silver maple, and California sycamore, there was a slight reduction in the yield of particulate matter with an increase in moisture. At first one might think that the reversal could be associated with bulk density *per se*, since three of the species had a bulk density of less than .80 pounds per cubic foot. But Modesto ash, American elm, sweet gum, and tulip leaves have a similar range of bulk densities and in all of these cases there was a considerable increase in particulate yield with increase in moisture.

Table 1. Emissions of Particulate, Carbon Monoxide, and Hydrocarbon from Burning Street Tree Leaves at Two Moisture Levels and Three Ignition Patterns

Leaf Species	Ignition Method[a/]	Bulk den. lbs/cu.ft.[b/]	% Moisture dry wt. basis	Emissions, lbs./ton of leaves burned Part.	CO	HC
Black ash	B	1.50	8.2	36.2	111.0	29.6
			16.6	35.8	143.6	52.0
Modesto ash	B	.89	8.4	40.4	139.0	27.1
			17.7	71.1	166.6	64.1
	T		6.7	19.5	190.1	13.2
			21.9	15.2	122.1	13.3
	WR		8.1	22.5	178.4	16.7
White ash	B	1.40	9.8	17.4	103.3	10.0
			21.0	68.2	122.6	32.5
Catalpa	B	--	9.6	13.8	85.6	12.0
			17.3	28.2	99.0	28.1
	T		9.5	12.2	87.5	7.5
			18.3	16.3	88.5	16.1
	WR		9.5	12.5	85.3	8.5
			19.2	16.5	86.1	14.5
Horse chestnut	B	--	8.1	31.9	145.9	26.7
			21.5	76.3	148.2	51.0
Cottonwood	B	.77	9.7	39.1	93.0	29.4
			20.0	35.9	86.2	34.2

a/ Ignition of conical piles; B, complete circle at bottom of pile, and T, single spot at top of pile. WR; leaves piled in a window and ignited across the bottom at one end.

b/ Bulk density was determined when the leaves were at the low moisture content.

Table 1. (continued)

Leaf Species	Ignition Method	Bulk den. lbs/cu.ft.	% Moisture dry wt. basis	Emissions, lbs./ton of leaves burned		
				Part.	CO	HC
American elm	B	.82	10.7[c]	26.1	102.9	26.3
			17.4	52.7	126.0	58.2
	T		9.8[d]	12.8	128.7	15.5
			17.5	10.8	120.1	18.8
	WR		8.1[c]	15.1	122.2	17.2
			16.5	39.4	115.4	40.0
Eucalyptus	B	2.45	7.3	33.9	85.4	18.8
			19.5	37.7	94.1	32.9
Sweet gum	B	.77	10.3[c]	40.9	151.2	29.9
			20.1	61.5	144.9	44.8
	T		6.4	7.1	113.0	8.0
			17.5	19.1	131.6	24.5
	WR		7.5	14.3	135.6	14.5
			25.0	56.8	163.6	42.0
Black locust	B	3.00	7.2	68.0	116.7	49.0
			19.4	72.4	142.7	74.6
Magnolia	B	1.09	8.2	9.4	51.1	7.7
			19.9	16.4	59.4	12.5
Silver maple	B	.78	8.9[e]	74.2	98.7	27.3
			19.4	63.9	105.7	35.6
			24.1[f]	164.7	143.3	45.9
	T		9.1	25.6	86.8	11.9
			22.5	39.6	74.8	16.6
	WR		7.1	37.5	98.2	15.9
			20.6	56.8	105.5	24.1

c/ Average of 4 fires

d/ Average of 3 fires

e/ Average of 7 fires

f/ This single fire was composed of a mix of dry leaves and some that were still quite green, all of which had fallen from the tree. The proportion of each leaf type in the mix and the moisture content was as follows: Dry - 61% at 19.1% moisture
Green - 38% at 41.9% moisture

Table 1. (continued)

Leaf Species	Ignition Method	Bulk den. lbs/cu.ft.	% Moisture dry wt. basis	Emissions, lbs./ton of leaves burned		
				Part.	CO	HC
American sycamore	B	.38	9.0	11.8	97.6	7.5
			17.1	24.5	117.9	16.3
	T		8.7	14.3	139.5	3.1
			22.8	10.3	104.1	3.3
California sycamore	B	.28	10.7	10.2	106.3	2.7
			17.4	9.8	101.3	6.8
	-- Special Bulk Density Series --					
American sycamore						
River.	B	.38	9.3	11.9	106.9	5.7
	T		8.9	11.9	124.7	2.6
Ill.	B	1.78	10.0	34.5	118.5	30.6
	T		9.7	20.6	98.6	20.5
Tulip	B	.65	10.5	19.1	74.0	16.8
			16.6	31.4	81.5	29.5
	T		7.2	12.5	78.5	8.6
			26.6	19.1	61.8	15.5
	WR		11.0	13.3	86.1	8.6
			18.4	23.1	78.5	19.3

One of the silver maple leaf fires should be mentioned. We noted that the fallen leaves under one tree near the campus included a fairly high proportion of green leaves. Such a mix could have been burned by the property owner had our laws permitted burning. These leaves gave us an opportunity to compare emissions of remoistened dry leaves with a mix of leaves, some of which had not yet dried naturally. A random sample of the dry-green mix was separated and weighed. Sixty-one percent of the sample was classed as the dry type having a moisture content of 19.1% and 38% of the leaves were classed as the green type having a moisture content of 41.9%. Since the leaves had been held for a few days in a plastic collection bag, it was obvious that the dry leaves had absorbed some moisture from the green leaves. But, fortunately, the dry leaves in the mix were at almost the same moisture content as the remoistened leaves with which they were being compared (19.1 and 19.4%, respectively) and the moisture content of the dry-green mix was only a little higher than that of the remoistened sample (24.1 and 19.4%, respectively). The green leaves alone had 41.9% moisture. The particulate yield of the dry-green mix was more than 2.5 times (164.7 vs. 63.9 pounds) that of the dry leaves that had been moistened. This indicates the sheer folly of trying to burn leaves in the green state.

Top ignition was employed with seven of the leaf species. In all cases but one (American sycamore-low moisture), both at the high and low moisture levels, the yield of particulate was reduced when compared with yields from bottom ignition. In some instances, the reduction was more than 60%. It was interesting to note also that in most cases, yield of particulate from top ignition at high moisture was less than the yield from bottom ignition at low moisture.

The windrow arrangement for ignition was used with six of the leaf species. At both low and high moisture levels, the yield of particulate was intermediate between bottom and top ignition for a given species.

These results indicate that for particulate emissions, the leaves should be as dry as feasible, preferably less than 12% on a dry weight basis. Top ignition is by far the most desirable ignition method. Bottom ignition is the least desirable, even when the leaves are quite dry.

The leaf species varied a great deal in bulk density, due mostly to differences in leaf (or leaflet) size and degree of curling upon drying. The largest and most curled leaves were the American and California sycamores, having a bulk density of .28 and .38 pounds per cubic foot, respectively. The most dense species were eucalyptus and black locust at 2.45 and 3.00 pounds, respectively. The former leaf does not curl at all, and the latter, being a compound leaf, included relatively large petioles in the collected leaf sample. Whereas the lowest particulate yields with dry leaves were obtained from the two sycamores with the lowest bulk density and nearly the highest yield came from black locust which had the highest bulk density, this relationship did not occur consistently. Eucalyptus, the second most dense leaf sample, had a yield of particulate about half that of black locust. Further, silver maple at a density of .78 yielded more particulate than did black locust at a density of 3.00 pounds.

Within American sycamore, where the bulk density was altered by physical manipulation of the samples, the density did have an effect on particulate emissions. The Illinois sample had been compressed to a density of 1.78 pounds as compared to a normal Riverside sample of .38, and the particulate yield of the former was almost 3 times that of the latter with bottom ignition and twice as much with top ignition.

Carbon monoxide.--Using bottom ignition, seven species (cottonwood, eucalyptus, magnolia, silver maple, American sycamore, and tulip) yielded less than 100 pounds of CO per ton of fuel burned at the low moisture level. Magnolia leaf fires produced the least at 51.1 pounds. The three species yielding the least amount of particulate (catalpa, magnolia, and American sycamore) were among the group yielding the least CO. Sweet gum at low moisture gave the highest yield at 151.2 pounds.

An increase in fuel moisture resulted in an increase in CO yield in all but three species (cottonwood, sweet gum, and California sycamore); the increase, however, was not nearly as dramatic as had occurred with particulates. The greatest increase of CO due to moisture was 29% (black ash) whereas particulate increases were often by a factor of two and even 4 in one case.

With the normal silver maple leaves, an increase in moisture resulted in only a 7% increase in CO. However, burning the dry-green mix resulted in a 45% increase of CO over the dry leaves and a 24% increase over the nearly comparable wet leaves. This again illustrates the folly of burning green leaves.

Igniting the leaves at the top of the pile was not quite as beneficial as it had been with particulate emissions. At the low moisture level, top ignition increased CO yields in five of the seven species where this method was employed; only with sweet gum and maple was the yield decreased. However, at the high moisture level top ignition was always an improvement over bottom ignition.

Again, yields of CO from windrow ignition were intermediate between bottom and top ignition.

The effect of bulk density alteration of the American sycamore leaves had a variable effect on CO emissions. Yields from the higher density Illinois sample were increased by 11% over the Riverside sample with bottom ignition and were decreased by 21% with top ignition.

Hydrocarbons.--Bottom ignition at low moisture levels resulted in a range of total emissions of hydrocarbons from a low of 2.7 pounds from California sycamore to a high of 49.0 pounds from black ash. Catalpa, magnolia, and American sycamore were again among the species lowest in yield as they had been with particulates and CO; white ash was also quite low, the yield being 10.0 pounds. The yield from the remaining species was between 16.8 and 29.9 pounds. Increasing the moisture always resulted in an increase in hydrocarbon, at times as much as by a factor of 3.

Burning the dry-green mix of silver maple followed the same pattern as was evident with particulates and CO. The mix produced 68% more hydrocarbon (27.3 vs. 45.9 pounds) than did the normal dry leaves and 26% more (35.6 vs. 45.9 pounds) than dry leaves that had been brought to nearly the same moisture.

The effect of top ignition was about as striking in reducing hydrocarbon emissions as the method had been in reducing particules. In every instance, at both low and high moisture levels, the yields of hydrocarbon were lower than from bottom ignition. Further, in all species except catalpa, the top-wet combination gave a lower yield than the bottom-dry combination.

As had been the case with particulates and CO, windrow ignition had no particular advantage since the yields of hydrocarbon were intermediate between those from bottom and top ignition.

The physical alteration of bulk density of American sycamore caused a greater increase in hydrocarbon emissions than it did with particulates. Emission of hydrocarbon from the compressed Illinois sample was increased by a factor of 5.5 (5.7 vs. 30.6 pounds) over the normal Riverside sample using bottom ignition, and by a factor of 7.9 (2.6 vs. 20.5 pounds) using top ignition.

The above results on emission factors from burning of several species of street tree leaves suggest that the factors will vary from species to species, but that the emissions from some species are consistently low for the three pollutants examined. Moisture content of the leaves is an important variable and letting them dry down will keep the emission factors low. The type of ignition should also be given serious consideration because where there is a choice between lighting piles at the bottom or top, the latter method results in further benefits. Limited studies on variable bulk density within a given species strongly suggests that leaves should not be broken, stomped on, or otherwise compressed when burning is to be the ultimate disposal method.

Yields of Methane, Other Saturates, Olefins, and Acetylene

Gas grab samples were taken from one fire at each moisture level from 11 of the tree species as well as from fires in the special bulk density group. Analysis of the grab samples gives the concentration of some 23 individual hydrocarbons. For convenience these have been grouped as methane, other saturates, olefins, and acetylene. The percent yield of these four groups were averaged for the two samples taken within one fire at each moisture level. The results are given in Table 2. Also shown is the amount of carbon in the grab sample expressed as a percent of the total carbon in the peaks at the time of sampling.

By averaging all of the fires with bottom ignition only, the photochemically reactive olefins constituted about 42% of the hydrocarbons in the grab samples. In decreasing order of occurrence, methane, other saturates, and acetylene constituted about 32, 13, and 8%, respectively.

In general, the yields of a given hydrocarbon or groups of hydrocarbons from the several leaf species did not vary greatly from the above averages.

Table 2. Percent Yield of Methane, Other Saturates, Olefins, and Acetylene in Grab Samples Taken During the Burning of Street Tree Leaves at Two Moisture Levels and Two Ignition Methods

Leaf Species	Ignition Method[a]	% Moisture Dry Wt. Basis	% of Total Carbon in Grab Sample	Percent of Hydrocarbons in Grab Sample: Methane	Other Sat.	Olefins	Acetylene
Black ash	B	8.2	32.0	38.9	14.0	38.5	8.5
		16.6	52.0	37.7	12.4	42.4	7.3
Modesto ash	B	8.4	27.0	38.0	14.2	40.5	7.2
		17.5	50.5	34.6	15.4	43.5	6.4
Catalpa	B	9.6	50.5	39.5	10.3	39.0	11.2
		17.2	50.5	34.3	15.3	41.1	9.4
Horse chestnut	B	8.1	33.0	39.1	11.7	43.0	6.2
		21.0	30.5	36.9	10.5	45.0	7.6
Cottonwood	B	9.7	33.0	39.7	13.5	38.9	7.9
		19.3	47.5	34.7	12.7	42.9	10.0
American elm	B	9.1	29.0	36.7	19.1	37.4	6.9
		17.7	38.0	32.3	13.9	45.8	8.1
	T	8.5	65.5	49.2	8.7	34.3	7.6
		17.7	37.5	46.0	9.5	36.7	8.1
Eucalyptus	B	7.3	49.0	37.5	7.8	41.5	13.3
		19.6	48.0	33.3	10.8	44.3	11.6
Sweet gum	B	10.3	32.0	39.6	8.5	41.4	10.5
		20.8	46.0	47.7	14.7	59.0	7.1
	T	6.4	39.5	55.2	6.9	29.2	8.5
		17.8	45.0	42.3	6.6	43.7	7.3
Black locust	B	7.2	49.5	43.2	17.8	30.5	8.4
		19.2	53.5	39.5	16.0	40.5	4.1
Silver maple	B	7.5	34.0	32.2	9.4	49.3	9.3
		18.9	44.0	28.9	16.7	45.2	9.3
	T	9.1	40.0	48.3	5.2	32.5	13.5
		24.6	36.0	48.5	9.8	35.7	6.0

a. Ignition of conical piles; B, complete circle at bottom of pile, and T, single spot at top of pile.

Table 2 (continued)

Leaf Species	Ignition Method[a/]	% Moisture Dry Wt. Basis	% of Total Carbon in Grab Sample	Percent of Hydrocarbons in Grab Sample: Methane	Other Sat.	Olefins	Acetylene
American sycamore	B	9.0	51.5	41.2	5.3	40.0	13.4
		16.6	50.5	42.8	6.8	43.3	7.1
	T	8.7	51.0	49.1	4.2	39.9	6.8
		22.7	48.0	49.4	4.9	29.9	16.2
(bulk den. series)							
River.	B	9.3	67.5	45.6	14.8	29.5	10.0
Ill.	B	10.0	59.0	42.0	9.0	41.4	7.6
River.	T	8.9	58.5	52.7	4.6	27.1	15.5
Ill.	T	9.7	51.5	48.2	13.0	36.0	5.6

The notable exceptions were the lower yields of other saturates from low moisture fires of eucalyptus, sweet gum, silver maple, and American sycamore, and the somewhat higher yield of acetylene from eucalyptus and American sycamore.

In most cases, increasing the moisture had the effect of slightly decreasing yield of methane and increasing the yield of olefins. For other saturates and acetylene, increased moisture had no consistent effect on yield, increasing in some cases and decreasing in others. It is apparent that moisture did not have the marked influence on the varying proportion of hydrocarbons within the sample as it did on total hydrocarbon yield as discussed in an earlier section.

While top ignition did not have as great an influence on varying the proportion of groups of hydrocarbons within the sample as it did in reducing total hydrocarbon yield, there was a consistent reduction in the yield of olefins as compared to bottom ignition. This again demonstrates top ignition to be a better method of lighting piles of leaves.

Similarly, the physically imposed alteration on the bulk density of American sycamore leaves did not have the effect on proportion of hydrocarbons within the sample as it did on the yield of total hydrocarbons. Nevertheless, the yield of the important olefins was increased by more than 30% by burning the compressed Illinois leaves.

Particle Size Distribution

Particle size distribution was determined for one fire at both moisture levels for all tree species except California sycamore. In addition, this determination was also made for the bulk density fires with American sycamore. Mass median diameter and percent of particles less than 1 and 2 microns are given in Table 3. The particle diameters plotted

Table 3. Particle Mass Median Diameter and Percent of Particles Less than 1μ and 2μ from Burning Street Tree Leaves at Two Moisture Levels and Two Ignition Methods

Leaf Species	Ignition Method [a]	% Moisture dry wt. basis	Mass median Diameter, Microns	Percent of Particles less than 1μ	2μ
Black ash	B	8.2	.30	84	94
		16.6	.44	76	91
Modesto ash	B	8.4	.34	82	94
		17.5	.45	75	90
White ash	B	9.8	.13	93	98
		21.5	.47	79	94
Catalpa	B	9.6	.05	93	97
		17.2	.32	84	94
Horse chestnut	B	8.1	.41	78	92
		21.0	.58	71	89
Cottonwood	B	9.7	.52	72	89
		19.3	.54	73	90
American elm	B	10.6	.33	84	95
		17.7	.56	72	90
	T	12.4	.32	84	95
		17.5	.36	83	94
Eucalyptus	B	7.3	.14	90	96
		19.6	.44	77	91
Sweet gum	B	10.3	.33	82	93
		20.8	.63	68	88
	T	17.8	.25	87	96
Black locust	B	7.2	.60	68	87
		19.2	.75	61	82

[a] Ignition of conical piles; B, complete circle at bottom of pile, and T, single spot at top of pile.

References

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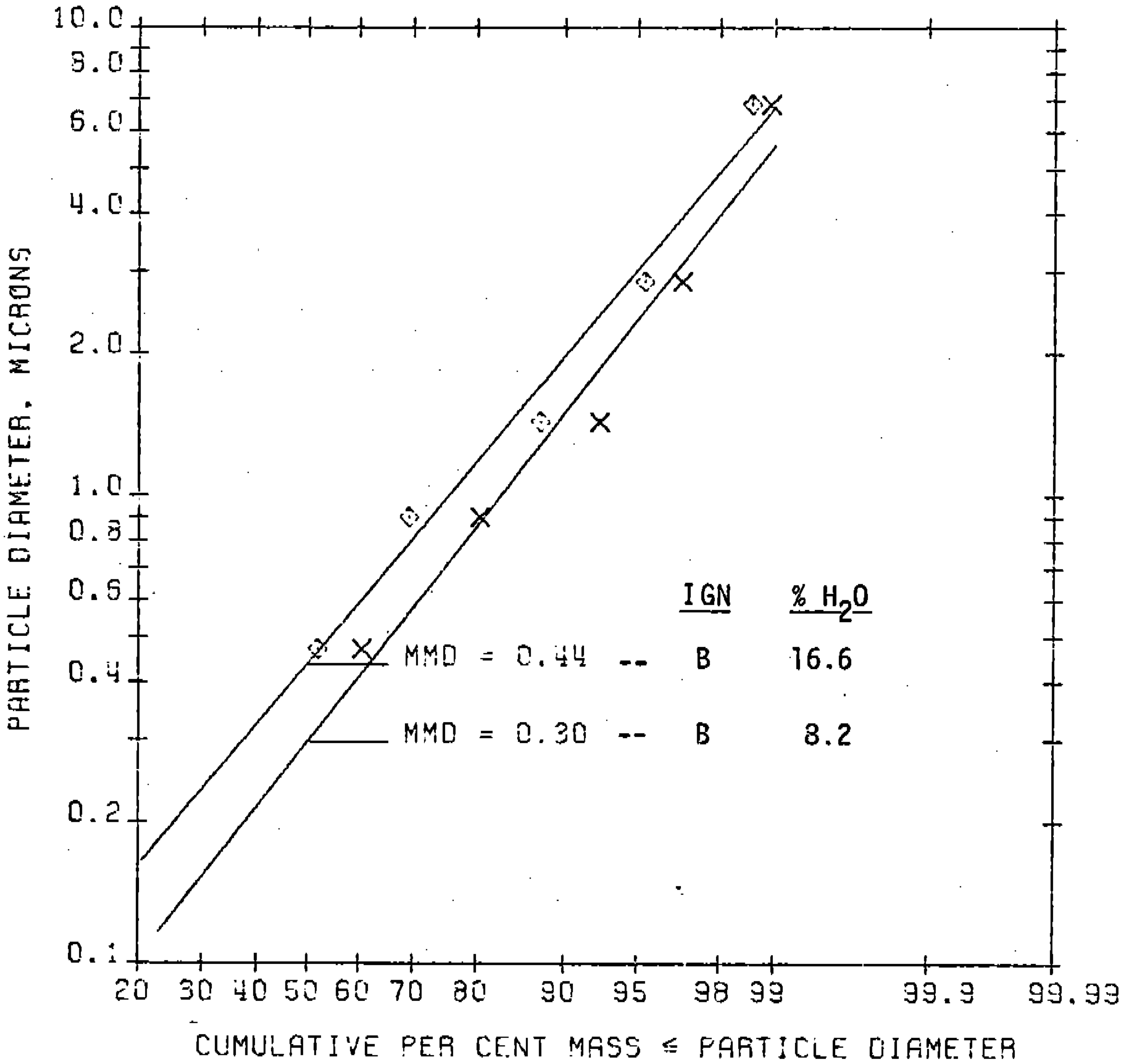
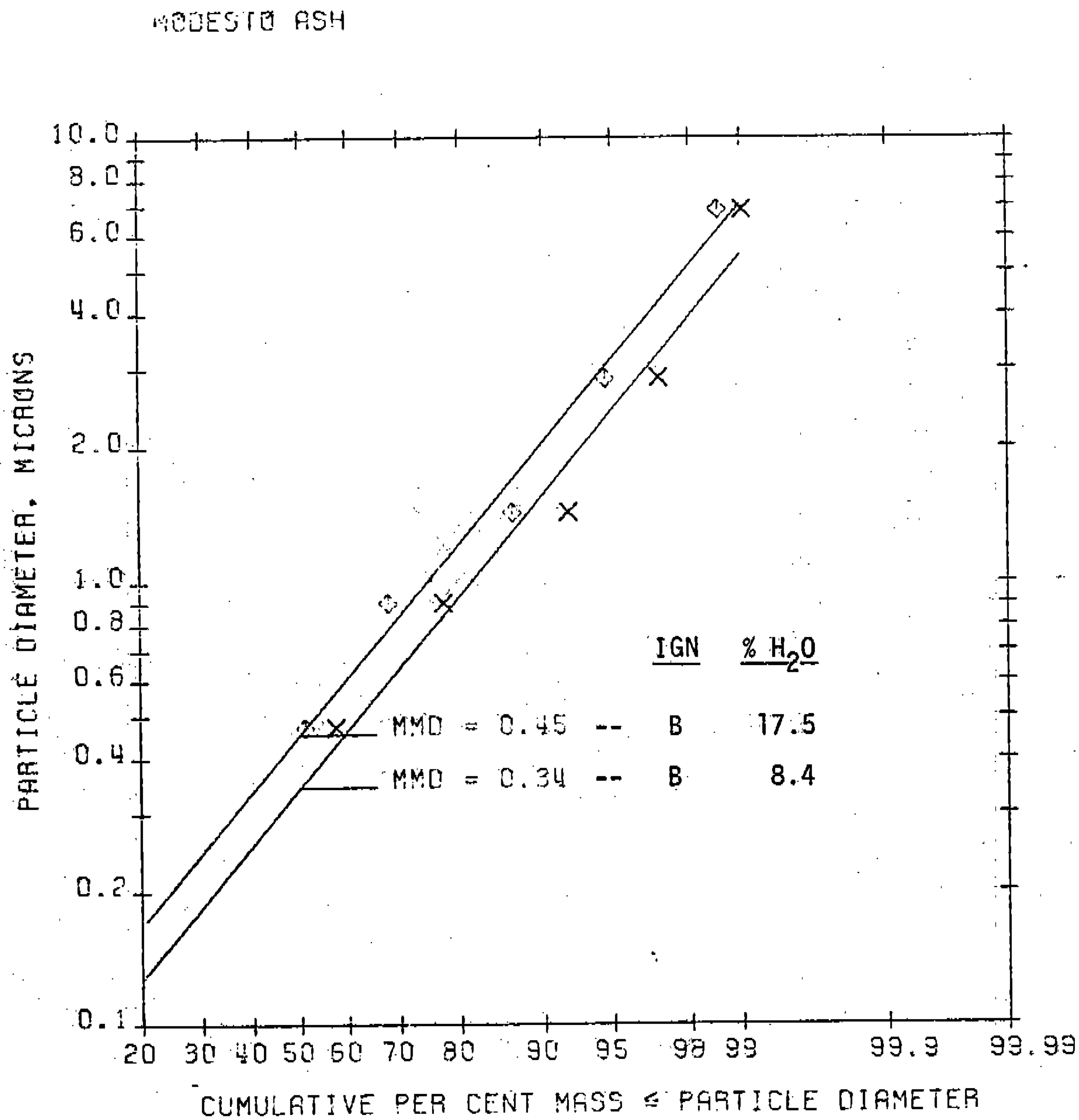
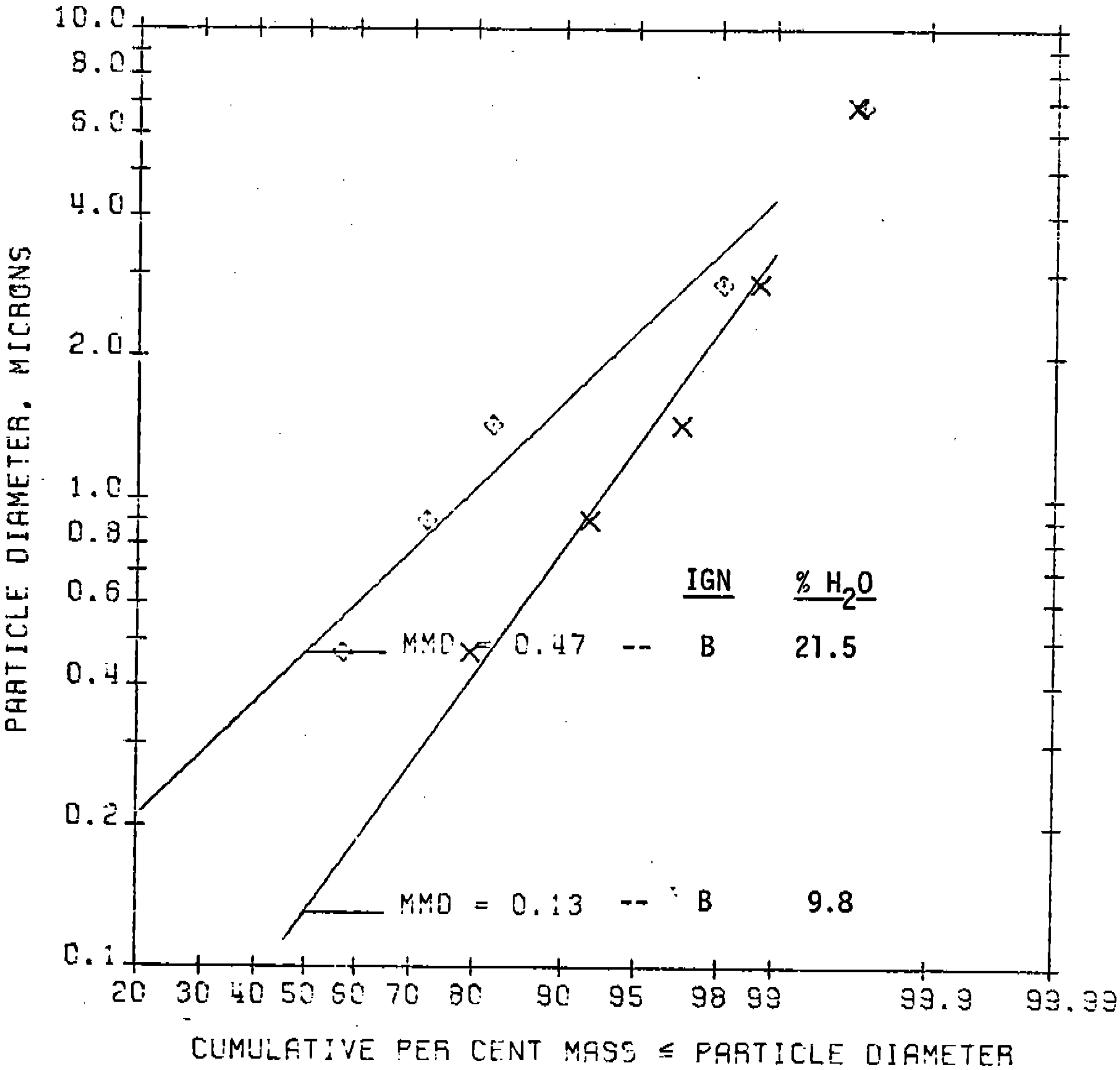
3. Marple, V. A. A fundamental study of inertial impactors. Ph.D. Thesis, Mechanical Eng. Dept., Univ. of Minnesota, December, 1970.

BLACK ASH


10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H_2O
MMD = 0.44 -- B 16.6
MMD = 0.30 -- B 8.2
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER


MODESTO ASH
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
20
30
40
50
60
70
80
90
95
98
99
99.9
99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER
IGN
% H_2O
MMD = 0.45 -- B 17.5
MMD = 0.34 -- B 8.4

WHITE ASH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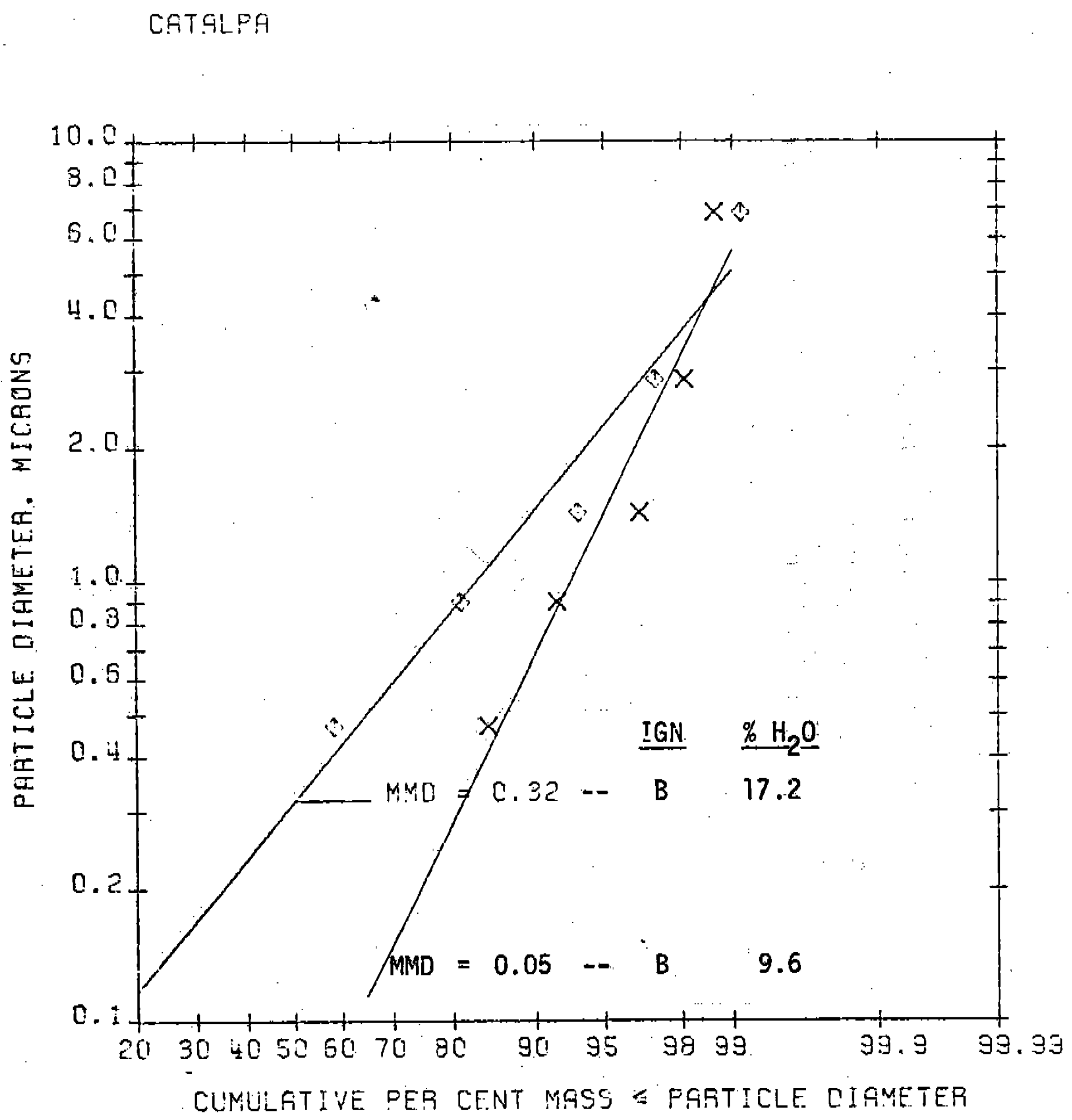
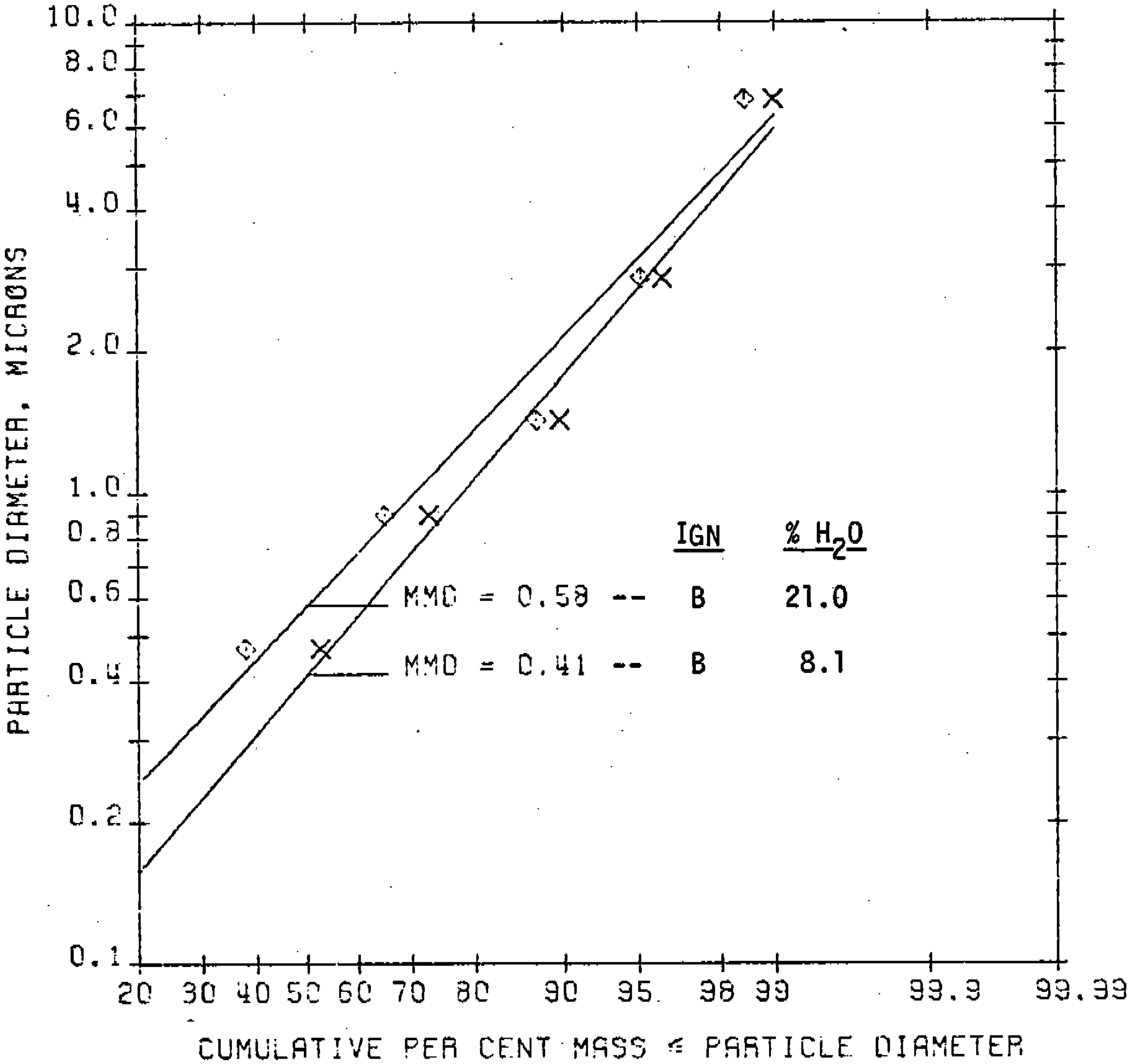
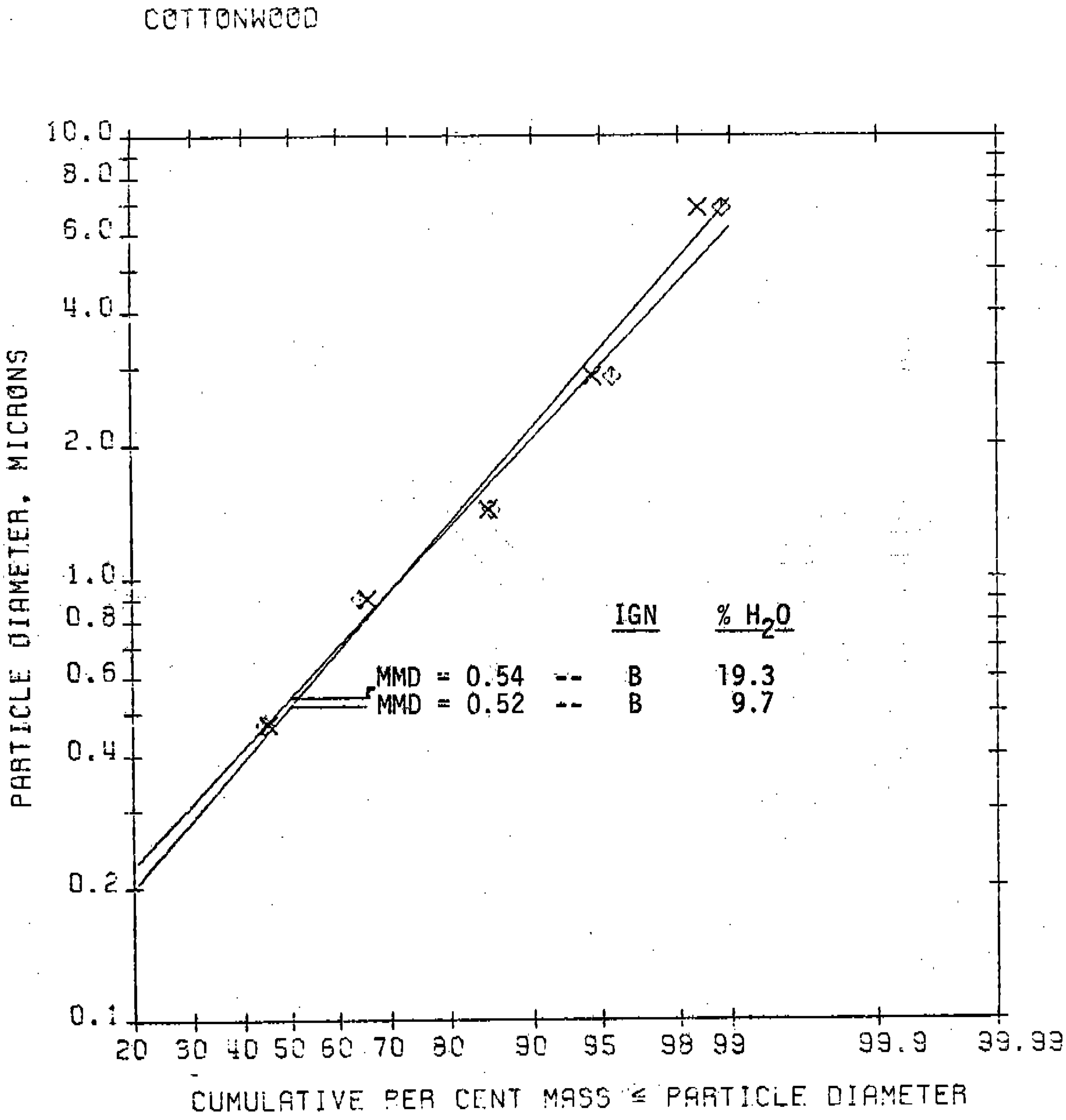
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H_2O
MMD = 0.47 -- B 21.5
MMD = 0.13 -- B 9.8
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER

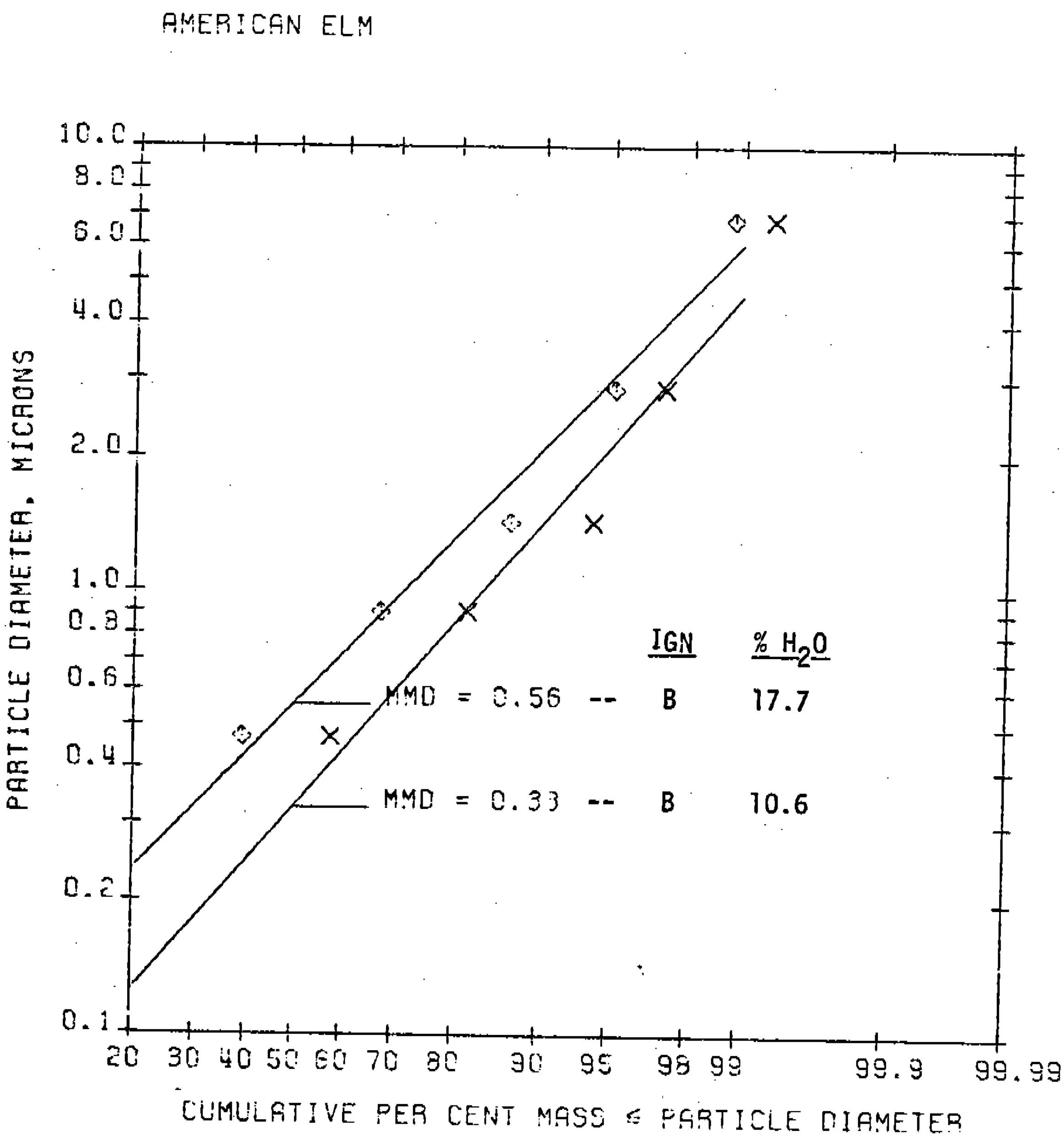

CATALPA
PARTICLE DIAMETER, MICRONS
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
IGN
% H_2O
MMD = 0.32 -- B 17.2
MMD = 0.05 -- B 9.6
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER

HORSE CHESTNUT

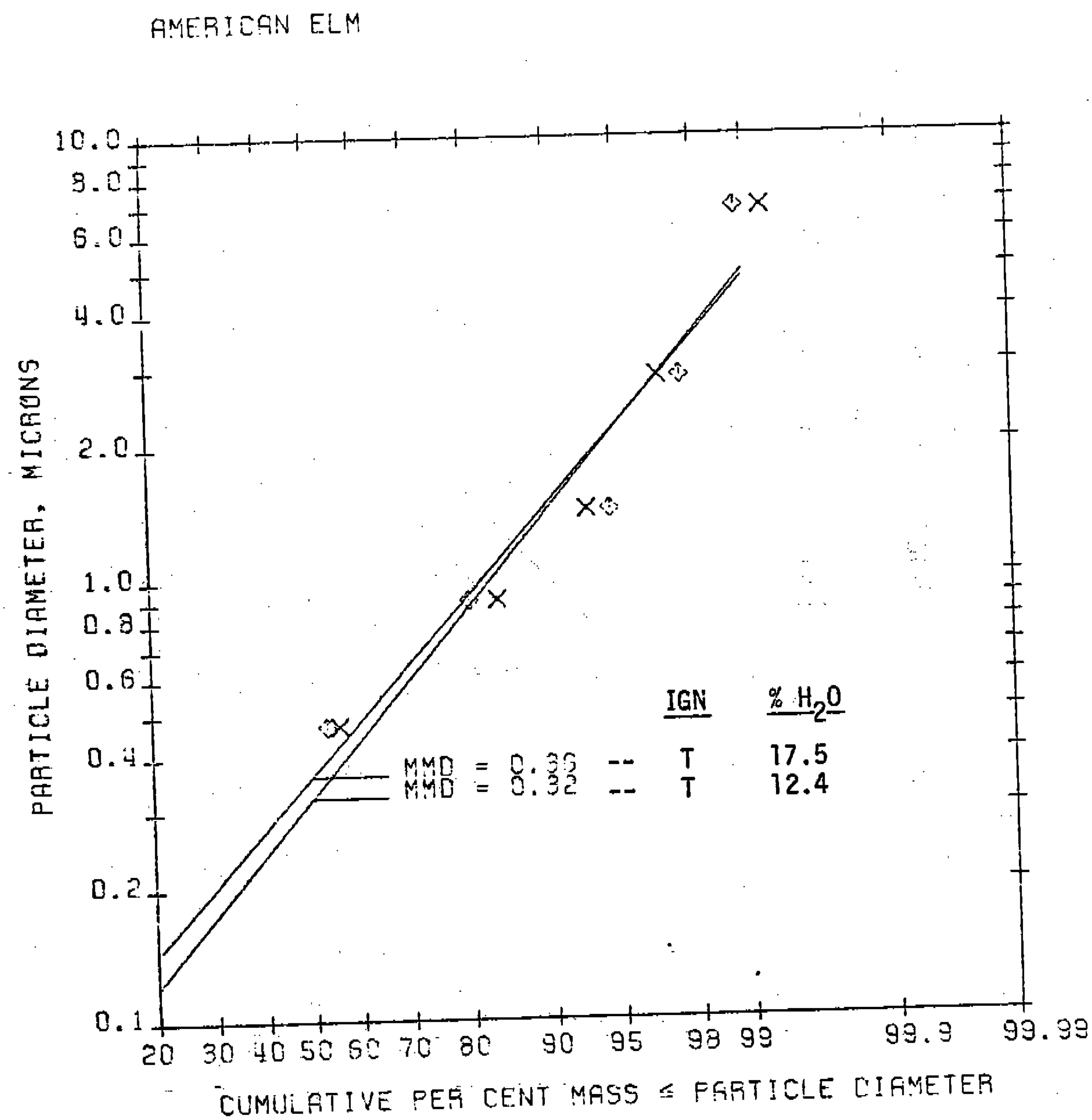


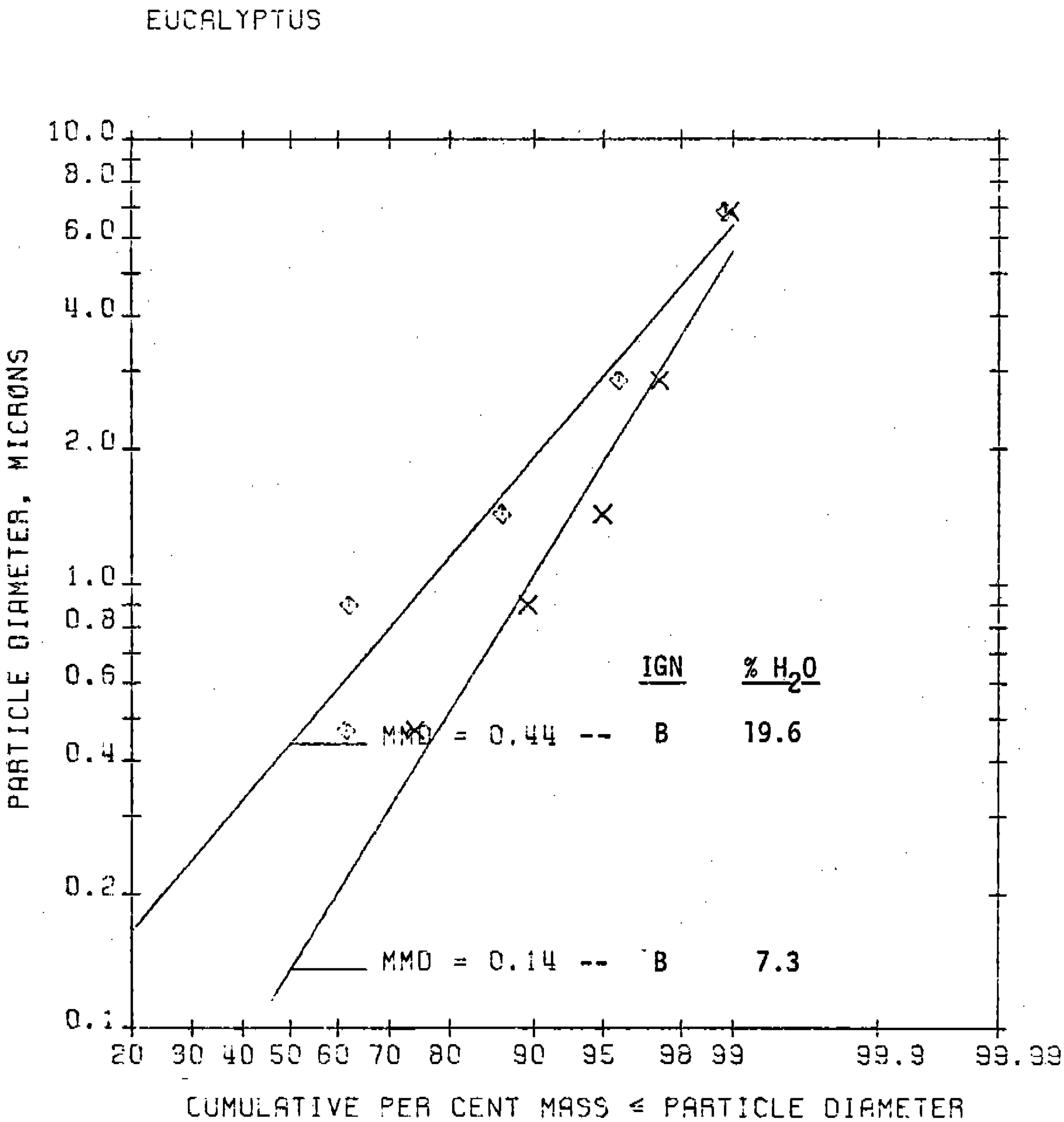


COTTONWOOD
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H2O
MMD = 0.54 -- B 19.3
MMD = 0.52 -- B 9.7
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER



AMERICAN ELM
PARTICLE DIAMETER, MICRONS
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
IGN
% H_2O
MMD = 0.56 -- B 17.7
MMD = 0.33 -- B 10.6


AMERICAN ELM
PARTICLE DIAMETER, MICRONS
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
IGN
% H_2O
MMD = 0.36 -- T 17.5
MMD = 0.32 -- T 12.4
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER


EUCALYPTUS
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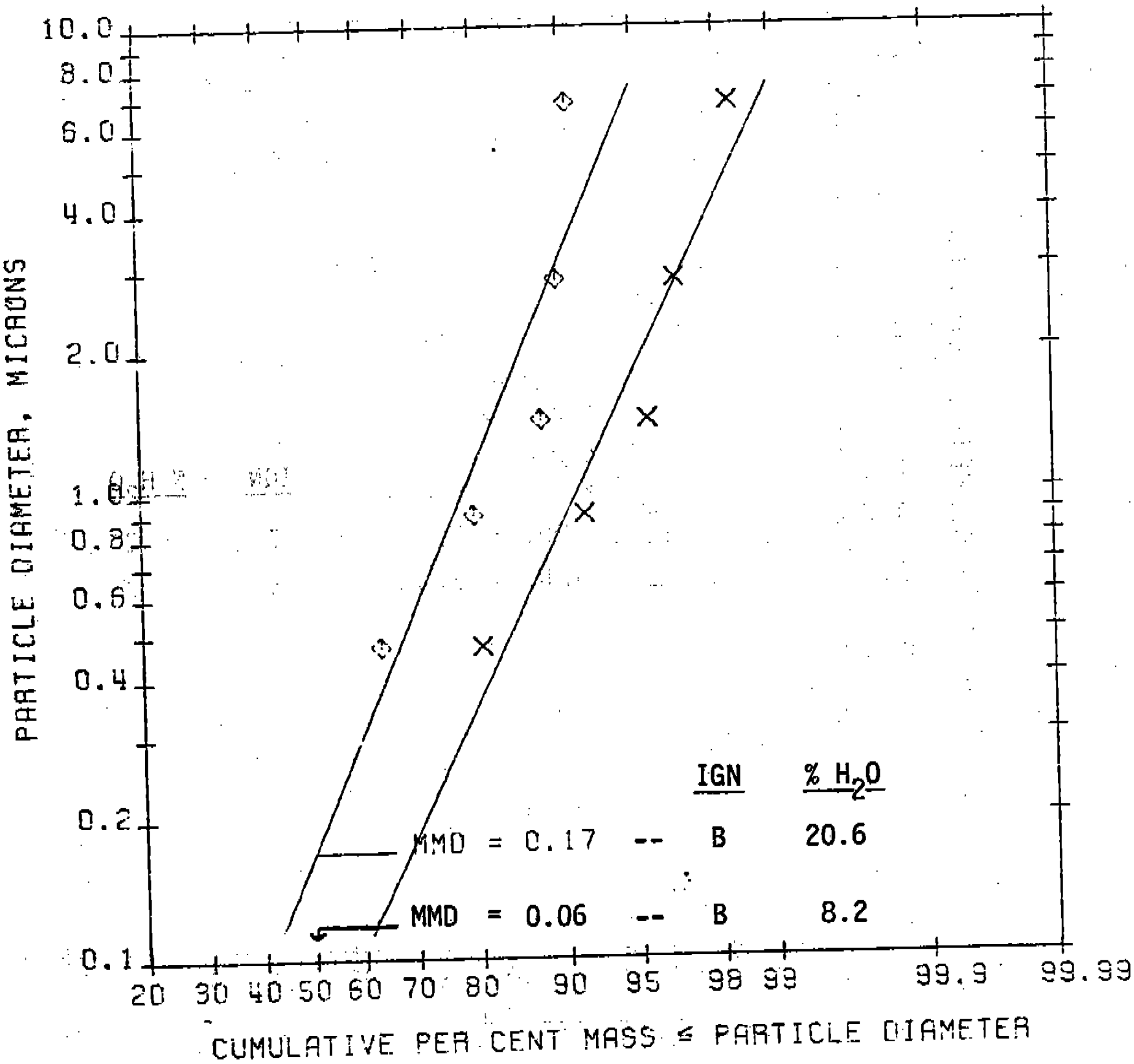
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H2O
MMD = 0.44 -- B 19.6
MMD = 0.14 -- B 7.3
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER

MAGNOLIA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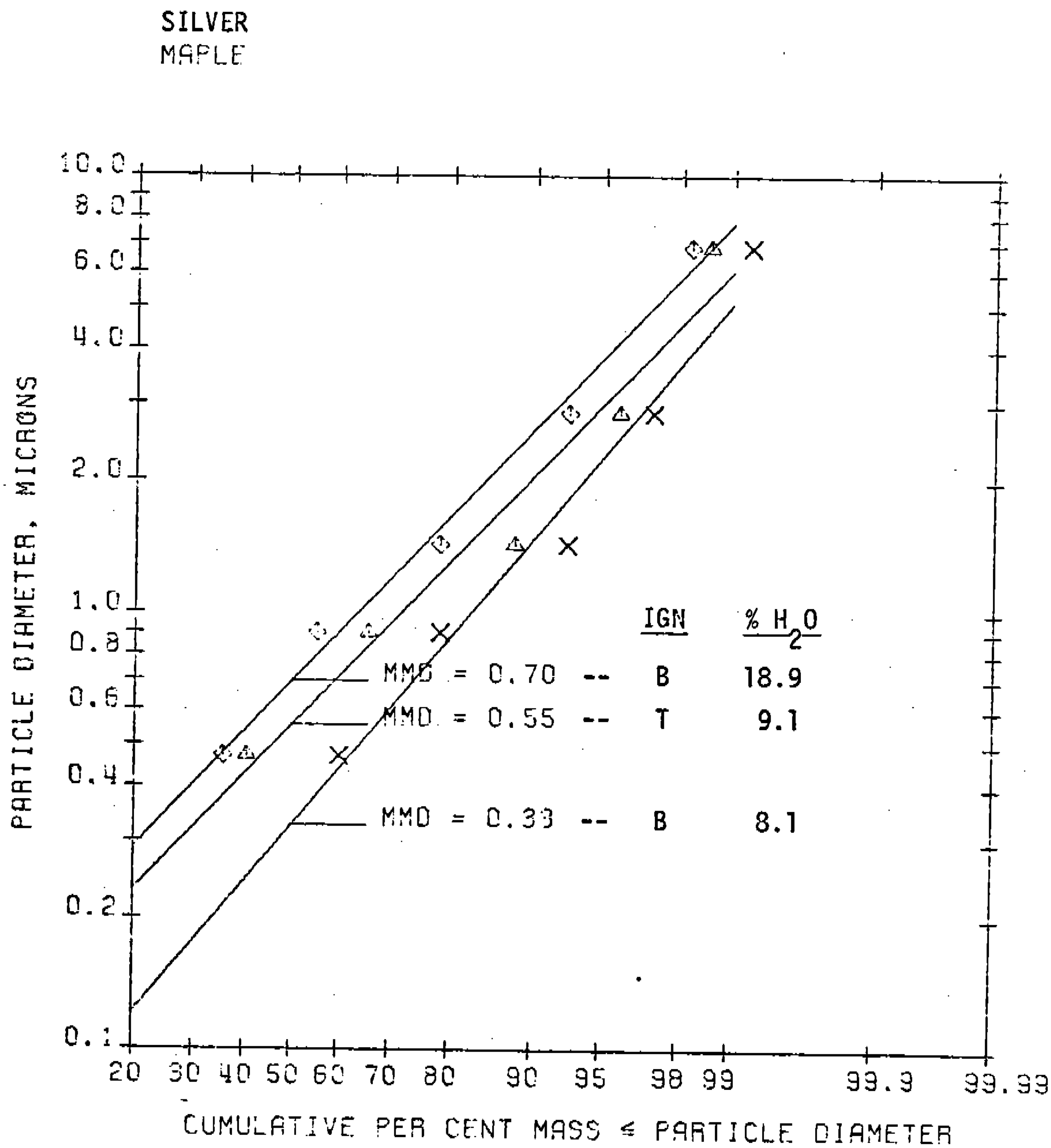
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H_2O
MMD = 0.17 -- B 20.6
MMD = 0.06 -- B 8.2
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER


SILVER
MAPLE
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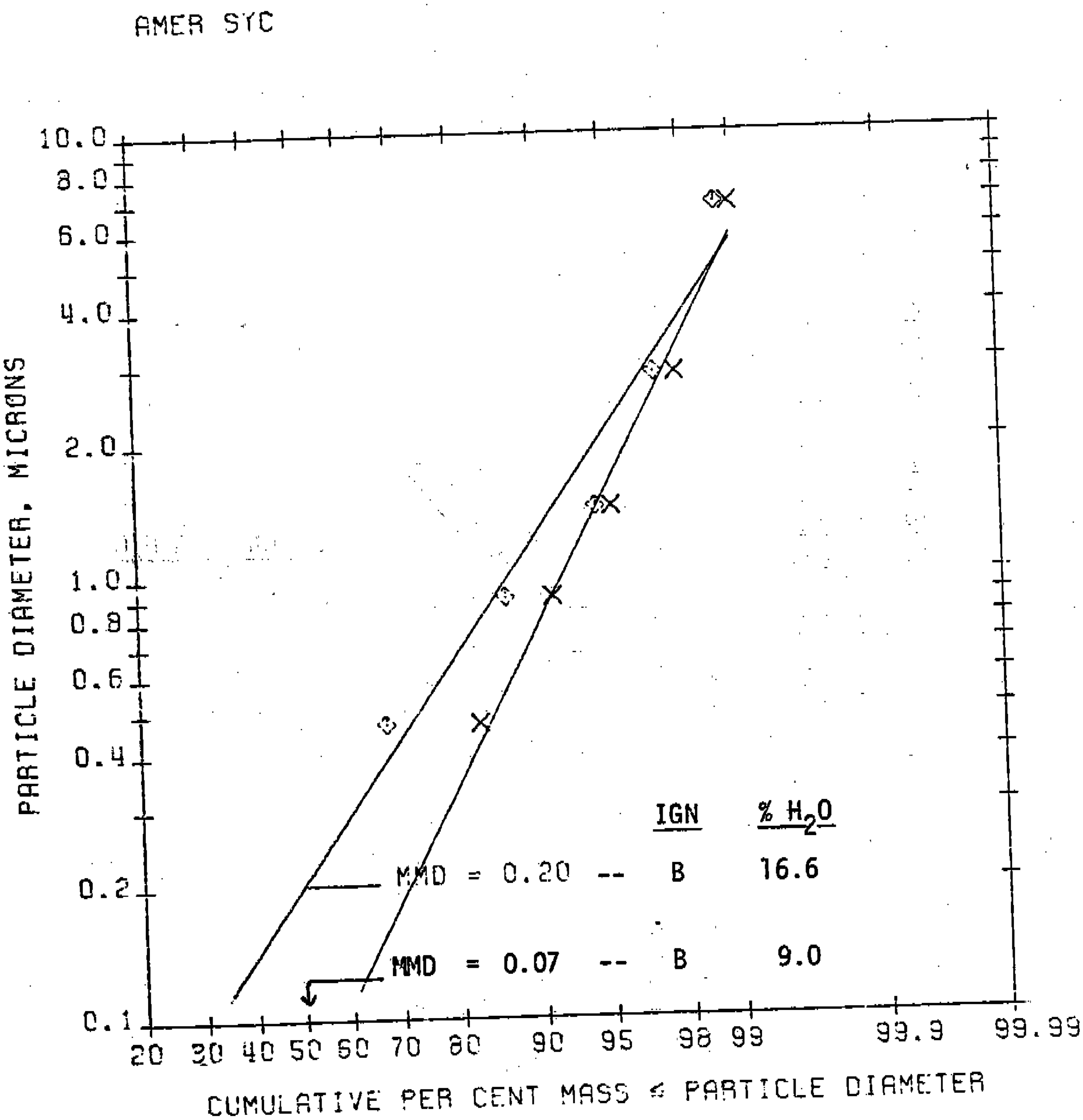
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H_2O
MMD = 0.70 -- B 18.9
MMD = 0.55 -- T 9.1
MMD = 0.33 -- B 8.1
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER


AMER SYC
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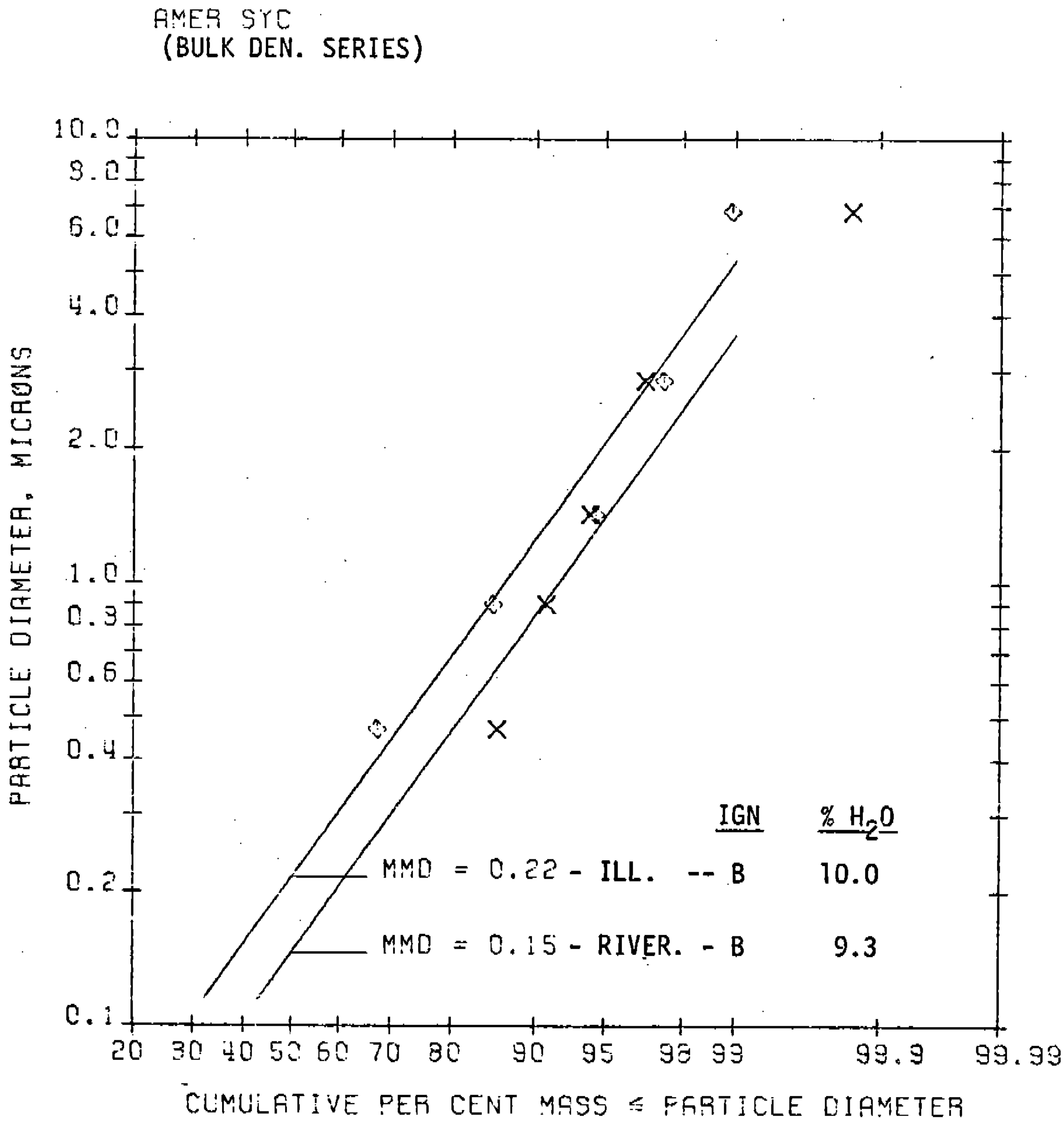
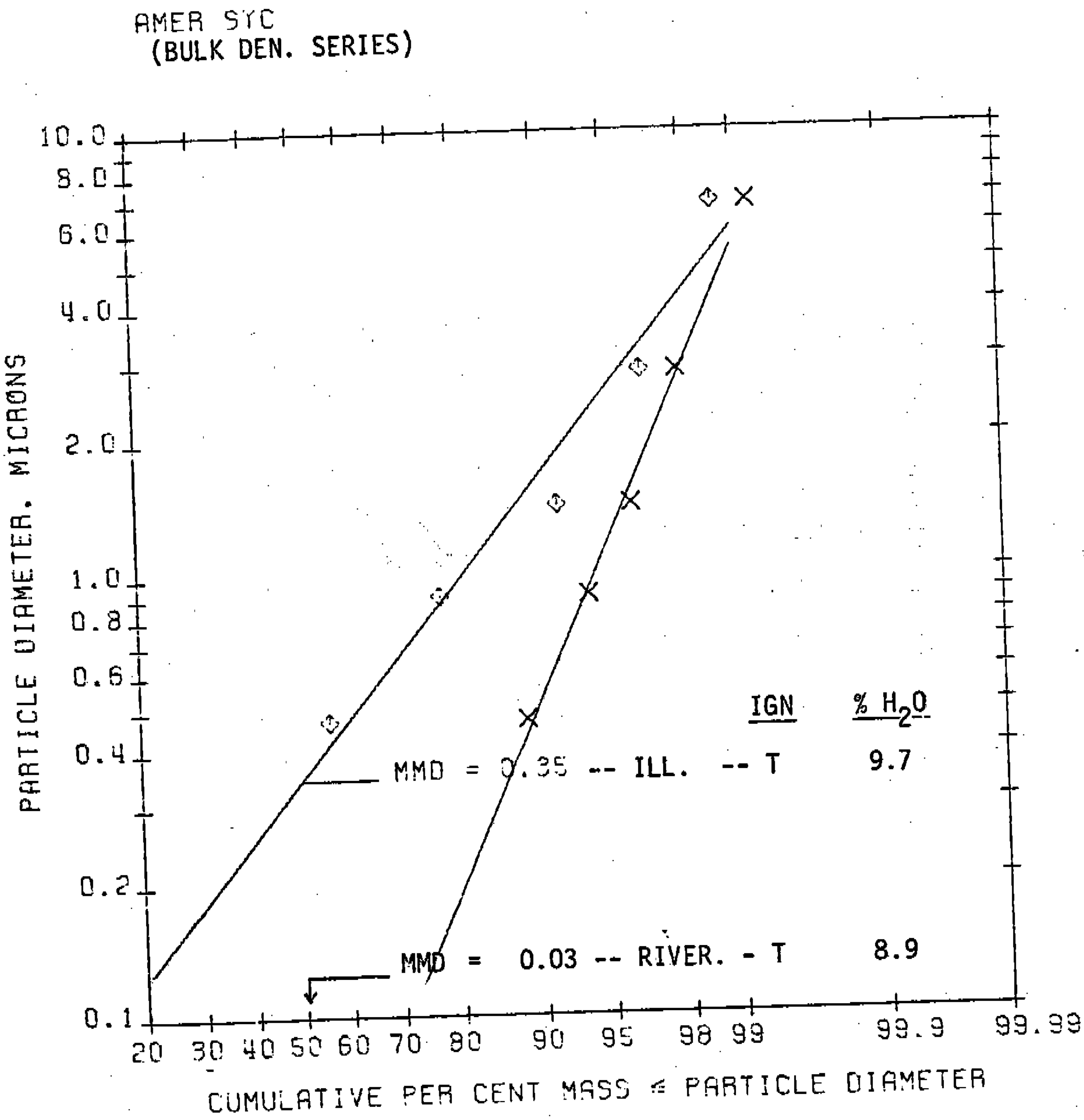
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H2O
MMD = 0.20 -- B 16.6
MMD = 0.07 -- B 9.0
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER


AMER SYC
(BULK DEN. SERIES)
PARTICLE DIAMETER, MICRONS
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
IGN
% H_2O
MMD = 0.22 - ILL. -- B
10.0
MMD = 0.15 - RIVER. - B
9.3
20
30
40
50
60
70
80
90
95
98
99
99.9
99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER


AMER SYC
(BULK DEN. SERIES)
PARTICLE DIAMETER, MICRONS
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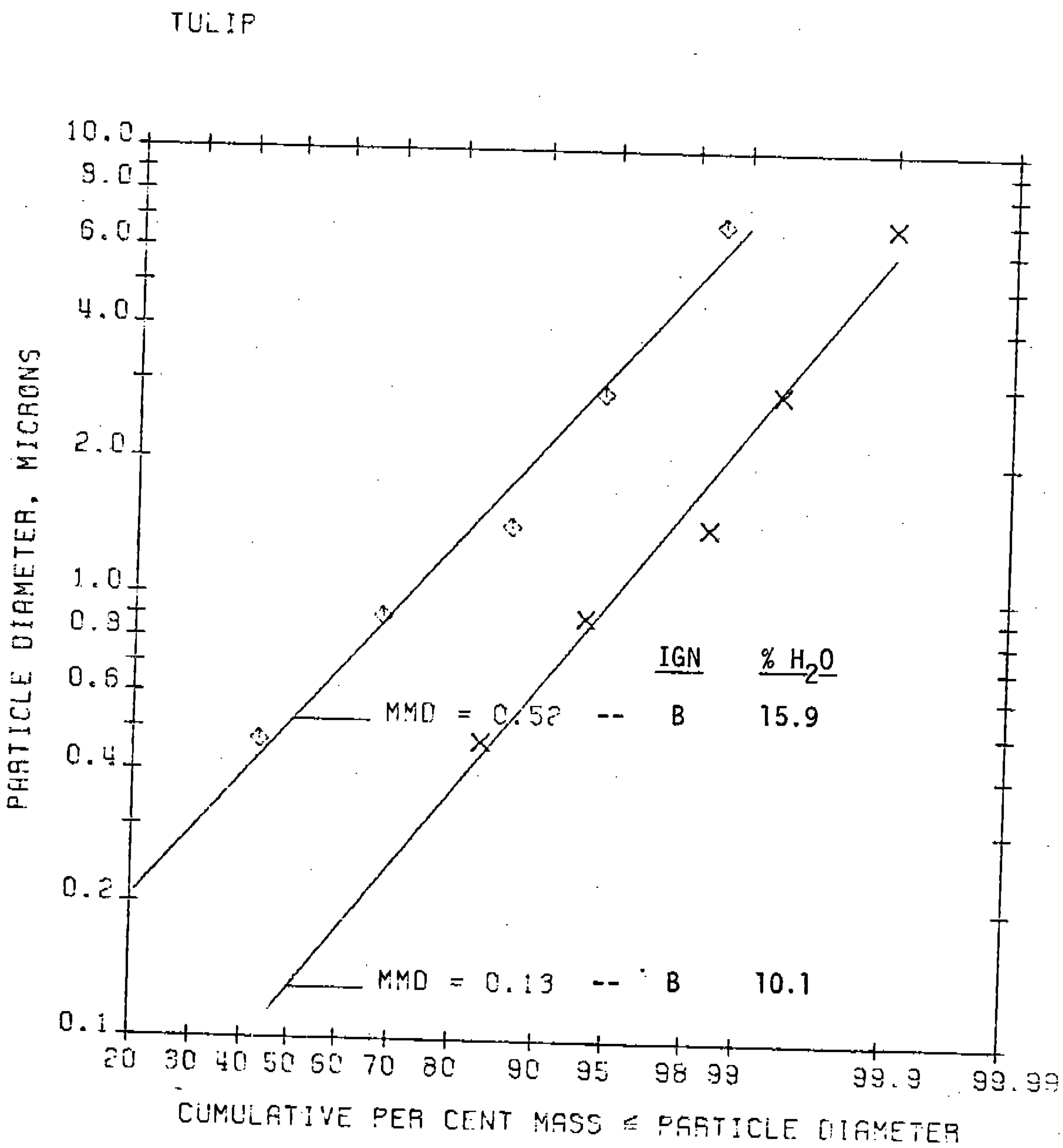
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
IGN
% H_2O
MMD = 0.35 -- ILL. -- T
9.7
MMD = 0.03 -- RIVER. - T
8.9
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER


TULIP
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6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
PARTICLE DIAMETER, MICRONS
IGN
% H_2O
MMD = 0.52 -- B 15.9
MMD = 0.13 -- B 10.1
20 30 40 50 60 70 80 90 95 98 99 99.9 99.99
CUMULATIVE PER CENT MASS ≤ PARTICLE DIAMETER

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(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-76-044	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Emission Factor Development For Leaf Burning		5. REPORT DATE December 1976
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Ellis F. Darley		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Statewide Air Pollution Research Center University of California Riverside, California		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. Project No. 5-02-6876-1
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air and Waste Management Office of Air Quality Planning and Standards Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This report describes the methodology used to develop emission factors for particulates, carbon monoxide and hydrocarbons from the burning of street tree leaves. This project was an outgrowth of one carried out for the State of Illinois where leaves from only three tree species were burned. The leaves were burned in a special tower that had been developed for the purpose of determining pollutant emissions from burning wastes of agricultural and forest operations. One hundred thirty one fires were completed using 15 species of leaf samples collected in the Riverside-Los Angeles area. One series of fires included leaves from the previous Illinois study.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Emissions Particulates Carbon Monoxide Hydrocarbons Methane Olefins Saturates Acetylene		

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	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

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Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

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