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THE DETERMINATION OF SEED SOURCE BY THE IGNITIBILITY OF TREE SEED

by

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Approved by:

Chairman, Board of Examiners

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INTRODUCTION

Nurserymen, foresters, and planters have found that trees of poor quality or complete failures may result in forest planting, if seed from a corresponding site is not used. Trees require a long period of time to produce a marketable crop, therefore it is important to prevent any costly mistakes in the initial selection of seed for planting stock (Rudolf, 1945 and 1949, and Isaac, 1949).

In 1939 the U. S. Department of Agriculture established a "Forest Policy" for the Forest Service and the Soil Conservation Service. It requires that only seed of known locality or origin be used. The lot number, year of collection, species, locality including county and state, elevation of origin, and proof of origin should be furnished when purchasing seed. Local seed to be used should be collected within 100 miles and under 1,000 feet difference in elevation from the planting site. When local seed is unavailable, purchased seed was to be obtained from an environment as similar as possible (Anon. Jour. For., 1939).

New York, Georgia, Michigan, Massachusetts, and Pennsylvania have provisions in their state seed laws to protect the buyer of tree seeds (Heit, 1960). Efforts are being made toward obtaining certified tree seeds, but no official state or government certification of seed origin is now required. Because of this, seed collectors do not always provide forest tree seed from precisely known sources and of desirable quality. Until officially certified tree seed is required, a reliable method of determining the site and elevation from which the seed was collected is needed in the United States.

The combined influence of site factors (climatic, edaphic, physiographic, and biotic) determines site quality for a particular species (Korstian and Toumey, 1947). It also expresses what chemicals are available for a certain species in the given soil. These available chemicals are utilized by the tree and stored in its vegetative tissues. A variation in site quality therefore may produce differences in the chemical composition of the vegetative tissues, which in turn may alter the phenotype of a tree.

Deichmann (1959) found ignitibility differences in spruce needles collected from two separate localities in Germany with the Jentzsch Ignition Tester in his ground fuel experiments. He explained this phenomenon with the fact that a site has a great influence on the chemical make-up of plant tissues. Because of their higher chemical concentration, seeds should be superior to needles or leaves for ignition tests (Baldwin, 1942). For this reason, preliminary studies on the ignitibility of seed were initiated in the fall of 1959.

Objectives. The primary objectives were to:

1. Establish a suitable procedure for testing the ignitibility of seeds.
2. Determine by ignition tests whether differences in the elevation of seed source could be measured.
3. Investigate whether or not any relationship expressed in a burning process could be used to differentiate site classes.

Scope. The Jentzsch Ignition Tester was used by the author in his seed ignition studies. Twenty-eight samples of four species of certified German tree seed, collected from sites of known elevation, exposure, precipitation, and locality were tested. The species comprising the twenty-eight samples were Norway spruce (*Picea excelsa*), Scotch pine (*Pinus sylvestris*), European larch (*Larix europaea*), and Douglas fir (*Pseudotsuga menziesii*). All experiments were conducted in a small laboratory set up for ignition tests at Montana State University School of Forestry.

DESCRIPTION OF THE JENTZSCH IGNITION TESTER

The Jentzsch Ignition Tester is a hot plate-type ignition measuring device developed by Jentzsch to evaluate fuels (Gilmer and Calcote, 1951). Two significant features of the tester are: the amount of oxygen supplied to the test material can be regulated, and the exact temperature in the ignition chambers can be controlled.

The Jentzsch Ignition Tester (Figure 1) has a stainless steel ignition unit consisting of four symmetrically arranged chambers, each 15 mm. wide and 40 mm. deep. The ignition unit is located in the center of an electric furnace. Oxygen is supplied through a passageway in the middle of the ignition unit to the three ignition chambers, and a thermometer is installed in the rear chamber to measure temperature in the ignition chambers. Temperatures ranging from 200 to 600° C. can be read from the thermometer. A rheostat is used to control the temperature in the ignition chambers by regulating the current to the electric furnace (Gilmer and Calcote, 1951).

The quantity of oxygen supplied to the ignition unit is regulated by a fine control needle valve. If the desired rate of oxygen feed is less than 100 bubbles per minute, the number is determined by counting the bubbles that appear from the nozzle in the distilled water of the bubble counter during a measured time interval.

When 100 or more bubbles are supplied to the ignition unit, a three way petcock from the bubble counter is closed and the rate of water

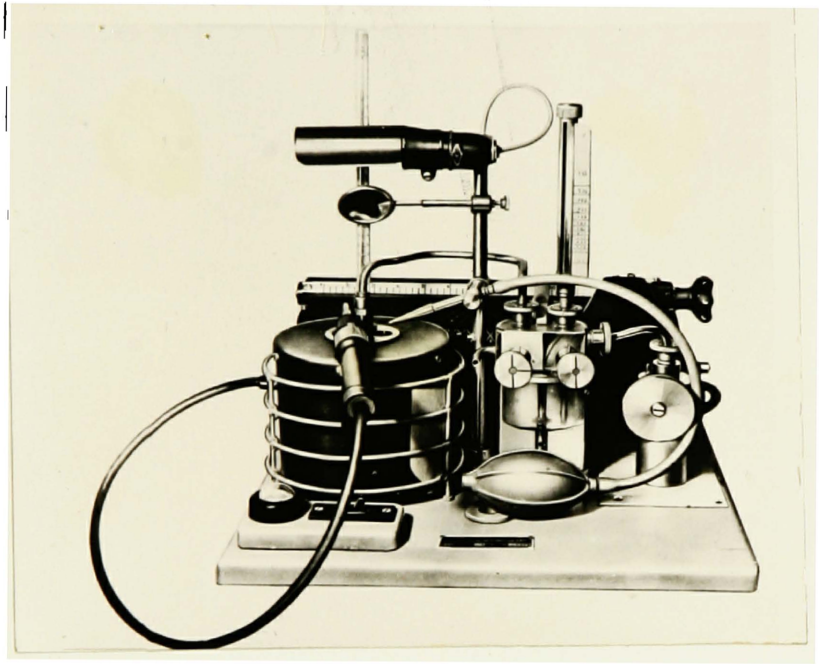


Figure 1. The Jentzsch Ignition Tester.

rise is observed in a calibrated measuring tube. The rate of water rise in five seconds is equivalent to the number of bubbles per minute which can be read directly from the measuring tube.

Oxygen is fed to the ignition unit by opening the three way petcock. The oxygen is preheated to remove any moisture that it might have taken on in the bubble counter and to adapt its temperature to that of the sample in the ignition chamber (Deichmann, 1958). Sixty bubbles of oxygen per minute supplied to the ignition chamber are equal to 5 cc. of oxygen per minute.

Stainless steel evaporating dishes are used to place samples in the ignition chambers. A mirror enables the observer to watch the burning process in the front ignition chamber. The ignition chambers are cleaned by squeezing a rubber ball (blower) which forces air into the ignition chambers.

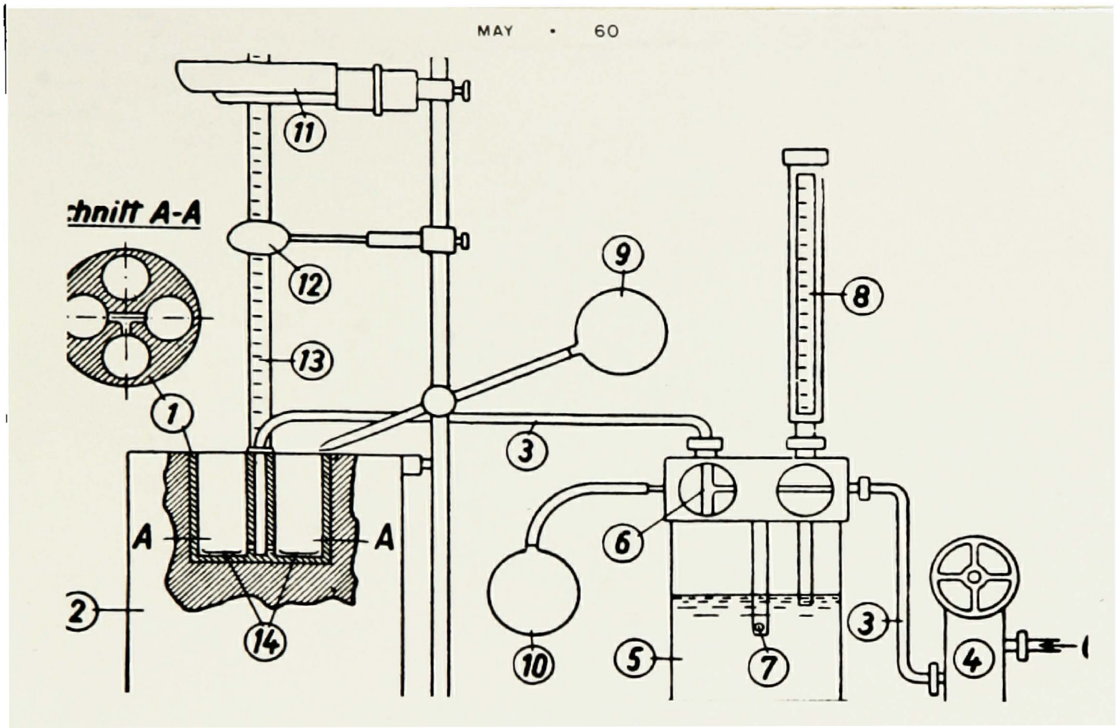


Figure 2. A cross section of the ignition unit and the essential parts of the Jentzsch Ignition Tester.

1) Ignition unit
2) Electric furnace
3) Oxygen pipe
4) Fine control needle valve
5) Bubble counter
6) Three way pet cock
7) Nozzle
8) Calibrated measuring tube
9) Blower
10) Blower
11) Light
12) Mirror
13) Thermometer
14) Evaporating dish
A) Ignition chambers (only two visible)

METHODS

Seed storage. All the certified tree seed was stored at 32° to 34° F. in the cooler of the forestry school greenhouse until it was needed for testing. The German tree seed data are summarized by species in Table I. The seeds were collected during the fall of 1958 and 1959.

Sample size. Only one cylindrical weighing bottle (30 mm. high and 50 mm. inside diameter) of seed from each seed batch was necessary to constitute a large enough sample for completing the ignition tests. When testing a material as expensive as tree seed, the advantage of using the Jentzsch Ignition Tester over other ignition devices is that only a small quantity of test material is required. Metz (1936) points out that in studies of heterogeneous materials, the variability of the results is diminished because of the small volume of samples and consequent increase of the possible number of tests.

Sample preparation. Samples with a relatively greater surface area ignite more readily than samples with relatively less surface because of the greater working surface available for oxygen. Deichmann (1958) and others found that the moisture content of the material and the composition of the volatile components influence ignition. The method of seed analysis adopted by the Association of Official Agricultural Chemists (Methods of Analysis, 1950) recommends drying at the boiling point of water (95 - 100° C.) to remove the moisture from seeds. The seed samples

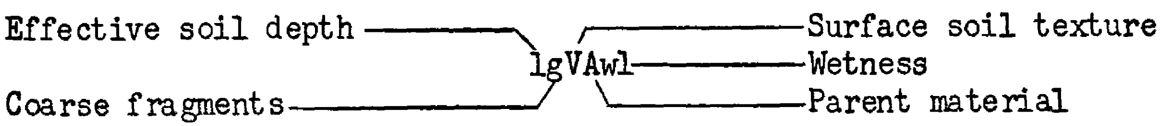
TABLE I

GERMAN TREE SEED DATA

Species	Sample No.	Site[1/] class	Elevation (meters)	Exposure	Slope[2/]	Growing season		Ave. age stand (yrs.)	Soil[2/]	Locality
						Temp. (°C.)	Ppt. (mm.)			
Spruce	1	I	0-100							Ratzeburg
	2	I	960-1300	S-SW	G-S	14	800	135	34SLwl-w3	Oberammergau
	3	I	400-500							Rödgen
	4	I	220	NW	G	12.5	440	140	2 DF	Westerhof
	5	II	720	N&W	M	11		95	23SK	Stryck
	6	I	500	E	M	13.7	825	112	2HVK	Rothenkirchen
	7	I	1000-1150	S-SE	M-S	11.4	550	135	3SAwl	Schluchsee
	8	I	760		L	14-15	550	121	2Swl	Denklingen
Pine	1	I	31-61		L	14.7	326	140	Dw2-w3	Erdmannshausen
	2	I	700							Sigmaringen
	3	I	305-335	N,NW,S	G-M	14-15	270	110	grCFwl	Burgebrach
	4	II/III	200-500	NW		13.7	350		F	Breitenbach
	5	I	200-400							Bitburg
	6	I/II	300-400							Altengronau
	7	I	0-100							Wolfgang
Larch	1	I/II	225-350	all	L-M	14.7	256	116		Schlitz
	2	I	400-500							Schweckhausen
	3	II	450							Czechoslavakia
	4	II	200-300							Bad Homburg
	5	II	100-200							Helmstedt
	6	I/II	300-400							Nastätten
	7	I/II	500			16.2	370	130	SLwl	Salem

TABLE I (Continued)

Species	Sample No.	Site[1] class	Elevation (meters)	Exposure	Slope[2]	Growing season Temp. (°C.)	Growing season Ppt. (mm.)	Ave age stand (yrs.)	Soil[2]	Locality
Fir	1	I	300-400							Stockach
	2	I/II	31-61			14.7	326	75	23gSKw2	Erdmannshausen
	3	I	420-460	all	L-S	13.6	395	45		Daun
	4	I/II	370-510	all	L-S	14.4	293	50	3gSIKw2	Kirchberg
	5	I	300-400							Obereimer
	6	I	200-300							Bad Homburg



<u>Effective soil depth</u>
1 - Very deep (over 60")
2 - Deep (36" to 60")
3 - Mod. deep (20" to 36")
4 - Shallow (less than 10")

<u>Coarse fragments</u>
g - gravelly
r - very stony

<u>Surface soil texture</u>
V - Very heavy (clay)
H - Heavy (light & silty clay)
F - Mod. heavy (silty clay loam, clay, & sandy clay)
S - Mod. light (sandy loam & fine sandy loam)
C - Very light (coarse & medium sands)

<u>Parent material</u>
A - Acid igneous rocks
D - Loess or aeolian material
F - Sandstone
I - Schist
K - Shale or slate
L - Limestone

<u>Slope</u>
L - Level
G - Gentle
M - Moderate
S - Steep

<u>Wetness</u>
w1 - slightly wet
w2 - moderately wet
w3 - very wet

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[1] The site class of larch is determined according to Schober. The site classes for the other species are determined according to Wiedemann.

[2] Soil Conservation Survey Guide

were dried to constant weight in an electric oven regulated between 100 and 102° C. to obtain a comparable moisture content in all samples.

Drying and grinding. First, the whole seeds were dried in the oven for twelve hours to facilitate crushing them. After this preliminary drying, a porcelain crucible and pedestal was used to crush the seeds so they would dry and grind more easily. The mashed seed was then dried again in the electric oven for forty-eight hours. Next, the seed was ground in a Fisher Scientific Soil Grinder until it could be sifted through a screen with forty holes per inch. This screened material was dried for an additional twelve hours to remove any moisture acquired while being ground and screened. A cylindrical weighing bottle filled with screened seed was then placed in a desiccator until the material was needed for ignition tests. Figure 3 shows the laboratory arrangement and some of the equipment used.

Ignition tests. Jentzsch and Jellitto (1953) describe the self ignition point, the upper ignition value, and ignition delay as three values which constitute sound criteria in determining the ignition and combustion properties of wood and other substances.

The pressure and relative humidity of the surrounding air also influence ignition. According to Jentzsch (1941) a five per cent difference in relative humidity either higher or lower will not affect ignitibility results with his ignition tester. For this reason, all ignition tests were made when the relative humidity was between twenty-five and thirty-five per cent.

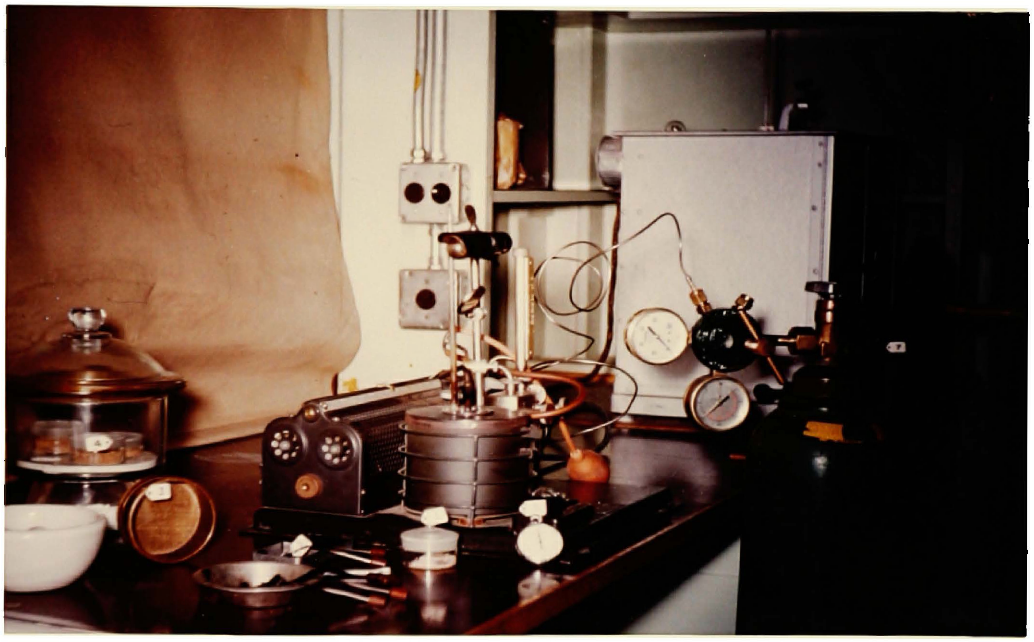


Figure 3. Laboratory arrangement

and some of the equipment used.

1) Cylindrical weighing bottle containing prepared seed sample
2) Evaporating dish with handle
3) Screen with 40 holes/inch
4) Desiccator
5) Stopwatch
6) Crucible and pedestal
7) Fisher Scientific Soil Grinder
8) Electric drying oven

A hair hygrometer and sling psychrometer (Figure 4) were used to measure the relative humidity. The hygrometer was used to determine whether conditions were favorable for testing, while the more accurate sling psychrometer was used to determine the relative humidity and room temperature after each ignition point was established.

By making tests a various air pressures, no difference in ignition could be found between 29.75 and 30.50 inches of mercury. These operable limits were marked on record paper which was attached to a barograph cylinder. Weekly air pressure checks were made with the United States Weather Bureau in Missoula.

Autogeneous ignition curves. Jentzsch says that the self ignition point and the upper ignition value, together with some intermediate ignition points can be graphically connected to form an autogeneous ignition curve (According to Deichmann, 1958).

In the author's experiments, graph paper (20 squares to the inch) was prepared for making ignition curves by plotting bubbles of oxygen per minute on the ordinate and temperatures in degrees centigrade on the abscissa. Bubbles of oxygen per minute ranged from 0 to 400 on the plus axis of the ordinate, while temperatures ranged from 200 to 600° C. on the plus axis of the abscissa.

Self ignition point. The self ignition point is the lowest temperature at which a material in an abundant stream of oxygen (300 to 400 bubbles per minute) ignites and burns visibily without an ignition source (Jentzsch, 1952).

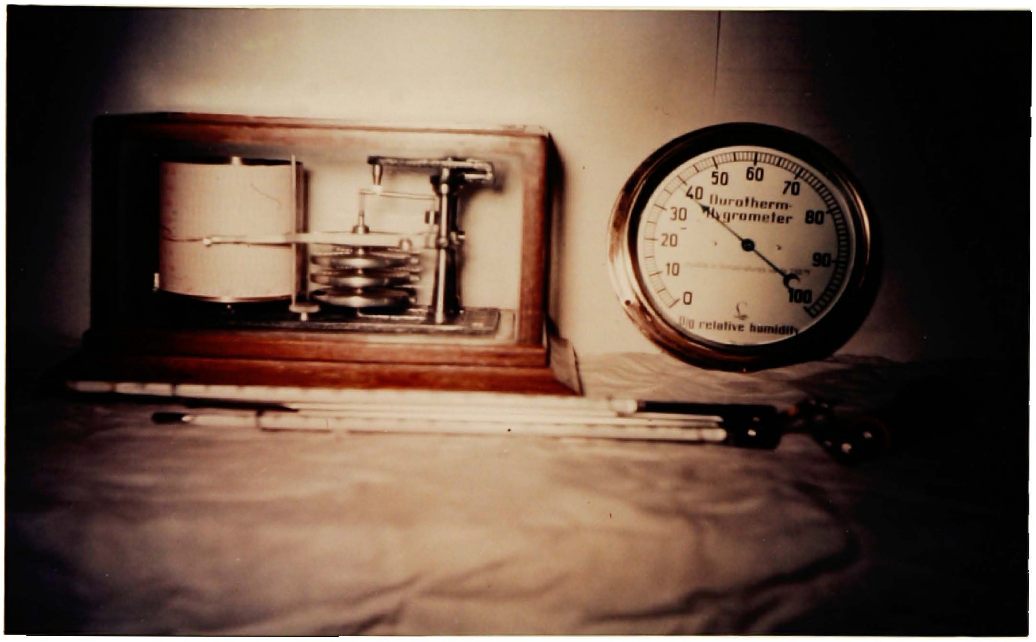


Figure 4. Hair hygrometer, sling psychrometer, and barograph.

First, the self ignition point for each sample was found by regulating the temperature to 250° C. and by fixing the rate of oxygen feed to the ignition chamber at 400 bubbles per minute. The passage of oxygen into the two side ignition chambers was blocked by inserting a steel cup into the bottom of each chamber, because only the front ignition chamber should be used for testing. Then an evaporating dish containing the ground seed was placed in the front ignition chamber. If the test material glowed within five minutes the temperature was lowered ten degrees. On the other hand, if glowing did not occur within five minutes the temperature was raised ten degrees. This trial method was repeated until the lowest temperature was found within a ten degree interval in which glowing occurred at the higher temperature and no glowing was observed at the lower temperature.

Immediately after the self ignition point was found and plotted, the relative humidity, air pressure, and room temperature were measured and recorded on the Individual Species Data Sheet (See Appendix). Between each test residues were removed from the ignition chamber and the evaporation dishes. The ignition chamber was cleaned with the blower and the evaporating dishes were scoured with a steel brush.

Intermediate ignition points. An intermediate ignition point is the lowest temperature at which glowing occurs at a fixed number of oxygen bubbles per minute (within the range between the self ignition point and the upper ignition value) and without an ignition source.

Intermediate ignition points were found at twenty-five bubble intervals in this study. The first intermediate ignition point determined for each sample was at 375 bubbles of oxygen per minute. The final ignition point was found at twenty-five bubbles per minute.

The procedure used for determining an intermediate ignition point was the same as that used for finding the self ignition point. Again the relative humidity, air pressure, and room temperature were measured and recorded after each intermediate ignition point was found.

As a result of the reduced oxygen supply, the temperatures found for intermediate ignition points were higher than those found for the self ignition point. The test material ignited more rapidly at higher temperatures than at lower temperatures with oxygen supply rates of less than 200 bubbles per minute. Because the burning process proceeded so rapidly at higher temperatures, tests for ignition points with temperatures exceeding 400° C. were made and observed in the dark.

<u>Upper ignition value</u>. The upper ignition value is the lowest temperature at which ignition takes place without an artificial inlet of oxygen and without an ignition source (Deichmann, 1958).

The upper ignition value was found in the same manner as the other ignition points, only the oxygen inlet to the ignition chamber was completely stopped. This was done by closing the two petcocks on the tester and the oxygen regulating valve on the oxygen tank.

Within an ignition region, the test material usually ignited spontaneously in less than one minute. The temperatures found for the upper ignition values were higher than those of the other ignition points, because no additional oxygen was supplied. According to Jentzsch (1941) the diffusion of oxygen from the surrounding air into the ignition chamber influences ignition by only one bubble per minute. When the upper ignition value was established, the atmospheric measurements were made and recorded.

After plotting the upper ignition value, an autogeneous ignition curve for the tested sample was formed by connecting the plotted self ignition point, the intermediate ignition points, and the upper ignition value.

Ignition delay. Ignition delay is the duration of temperature application until ignition occurs at a fixed inlet of oxygen per time unit (Deichmann, 1958).

Before a test was made, the temperature in the ignition chamber was regulated to 320° C. and oxygen inlet was set at 400 bubbles per minute (Jentzsch and Jellitto, 1953). The time between the introduction of the test material to the ignition chamber and ignition was measured with a stopwatch. Five individual tests were made for each sample. Ignition delay for a sample was calculated as the average value of the five tests.

Deichmann (1958) found that ignition delay was influenced by: 1) the amount of volatile components released, 2) the chemical composition of the volatile components, 3) the moisture content of the material, and 4) the particle size of the test material. Since all the samples were oven dried and ground to the same size for these tests, only the chemical composition and the quantity of volatile components influenced the differences in ignition delay.

Volatility tables. Volatility tables were used by Jentzsch (1952) to evaluate his ignition tests. Volatility tables, which Jentzsch developed on an empirical basis, permit the reading of comparative figures. They are based on the self ignition point, upper ignition value, and ignition delay of the individual material. These comparative figures allow easy and direct calculations concerning the flammability of the material. A comparison number of 100 indicates that a material is highly flammable, while a comparison number of zero indicates that the material does not burn well. The volatility tables for these experiments were developed by Jentzsch.

THE IGNITION PROCESS

Three factors that influence ignition of an oven dried sample are: 1) the temperature, 2) the nature and amount of volatile components released from a material at ignition temperature, and 3) the amount of oxygen available. For ignition to occur the mixture of the three elements must be in the correct proportions. Thus at low temperatures additional oxygen is required for ignition to take place. To compensate for an insufficient supply of oxygen, more heat is needed to ignite the material. The volatile components released can be either too rich or too lean for ignition. If they are too rich, oxygen must be added to thin the mixture; if the volatile components are too lean more volatile components have to be added by raising the temperature (Deichmann, 1958). Consequently, in a sufficient stream of oxygen and at a sufficient temperature the flammability of a material depends upon the chemical composition of the volatile components, and the amount of components released.

One of the difficulties in completely understanding the ignition process was brought out by testing the crude fat content of the four species tested. The methods outlined in Methods of Analysis (1950) were followed, with the exception of the drying process. Fir was found to have 14.0% crude fat, pine 13.1%, spruce 10.0%, and larch 5.2%. The comparative figures indicate opposite values than were expected from the above results. Fir with the highest amount of crude fats had the lowest comparison number, while larch with the smallest percentage of crude fats had the highest flammability rating.

Once the material is inflamed the burning process proceeds very rapidly. Jentzsch found that the gases released from a fuel ignite first. The burning gases then ignite the fuel (According to Deichmann, 1958).

Ignitions observed. Ignitions observed at the upper ignition value were of a different nature than those observed for the self ignition point and most of the other ignition points. At the ignition temperature of the upper ignition values, the tested samples ignited spontaneously and continued to burn with constant flame, while the ignitions observed for the other ignition points were identified by a deep red glowing of the test material. Occasionally ignition of the sample was accompanied by a sharp report. Apparently the mixture of the volatile components, the quantity of oxygen supplied, and the temperature in the ignition chamber were ideal for this small explosion. When the sharp report occurred it marked the beginning of the ignition process. Besides this, the only significance the sharp report had concerning ignition tests, was to startle the experimenter.

RESULTS OF IGNITION TESTS

Autogeneous ignition curves. Similar ignition curves were obtained for each species. The distinct form of a spruce, pine, larch, or fir curve can be seen by comparing the ignition curves included in the Appendix (Figures 6 - 33).

Every ignition curve separates a region of ignitions from a region of non-ignitions, because the curve was drawn through the lowest temperatures at which ignition occurred with a controlled oxygen supply. Therefore, at any point on the right hand side of a curve ignition took place, while on the left hand side no ignition was observed.

The autogeneous ignition curves show the ignition willingness of a flammable material. The steeper the slope of the curves between 200 and 400° C., the nearer the upper ignition value lies to the self ignition point, and the higher the flammability of the material (Deichmann, 1958). This was found to be true. Larch curves had the steepest slope, the highest flammability, and their self ignition points were located closer to their upper ignition values than any of the other species. Ranked in order following larch were spruce, pine, and fir. The difficulty of making ignition tests under the outlined procedures follows the same order. Larch and spruce samples with their higher flammability ratings were more easily tested than the poorer rated pine and fir samples.

Besides the larger differences in ignitibility found between species, smaller differences were found within a single species. These ignition differences can be seen by comparing the curves obtained from the tested samples for each species (See Appendix).

Ignition values. The results of the ignition tests summarized in Table II show that the greatest ignitibility differences within a species were found at the self ignition point and ignition delay of the samples tested.

When no oxygen was supplied for making the upper ignition value tests, only small differences in the temperature of the upper ignition values were found. Two outstanding exceptions to this were larch sample 3 from Janovice-Bedrichow, Czechoslavakia and larch sample 5 from Helmstedt, Germany. Other authors (Gilmer and Calcote, 1951) have stated that the temperature of the upper ignition value is essentially the same for diesel oil and similar highly flammable fuels.

An upper ignition value was found most easily after all the other ignition tests for the ignition curve had been completed. Then by extrapolation the experimenter had a good idea of where the upper ignition value should be sought. Much time was wasted otherwise when the upper ignition value was sought purely on a trial basis. The average time required for making a complete series of ignition tests for a single sample was approximately sixteen hours.

Comparison numbers. The comparison numbers which are an index of of a material's flammability were read from a volatility table that Jentzsch developed for this experiment. Four separate but identical volatility tables (Tables IV, V, VI, and VII) were copied from the table

TABLE II

SELF IGNITION POINTS, UPPER IGNITION VALUES, AND IGNITION DELAYS

Species	Sample No.	Self ignition point (°C.)	Upper ignition value (°C.)	Ignition delay (seconds)
Spruce	1	236	568	75
	2	236	570	54
	3	236	564	66
	4	242	574	70
	5	260	574	65
	6	230	554	70
	7	232	564	63
	8	234	568	69
Pine	1	272	558	101
	2	252	560	83
	3	262	556	98
	4	306	558	135
	5	278	558	94
	6	274	558	92
	7	278	566	102
Larch	1	234	470	44
	2	238	472	47
	3	240	530	49
	4	240	474	49
	5	238	506	48
	6	232	470	43
	7	234	474	44
Fir	1	256	550	117
	2	316	550	132
	3	286	550	119
	4	274	560	106
	5	296	554	120
	6	298	546	125

Jentzsch developed. The four tables were made to display the range of comparison numbers found for each species and to eliminate any overlapping of ranges that would have occurred if all the species were shown on one table.

Table III summarizes the three important ignition values and illustrates how they were incorporated into the volatility tables to obtain the comparison figures. According to Jentzsch (1960) the process of setting up a volatility table is simplified by rounding off the self ignition points and the upper ignition values to the nearest 10° C. Jentzsch recommended that a correction of minus 40° C. be taken from the upper ignition values to convert the experimental values to their corresponding sea level values. A correction of minus 40° C. was taken from each upper ignition value to correct from the altitude of Missoula (3,250 feet above mean sea level) to a sea level reading.

TABLE III

DERIVATION OF THE COMPARISON NUMBERS

Species	Sample No.	Self ignition point (°C.)	Upper ignition value (°C.)	Upper ignition value minus 40°C.	Upper ignition value minus Self ignition point (°C.)	Ignition delay (seconds)	Comparison number
Spruce	1	240	570	530	290	75	55
	2	240	570	530	290	54	68
	3	240	560	520	290	66	60
	4	240	570	530	290	70	58
	5	260	570	530	270	65	56
	6	230	550	510	280	70	58
	7	230	560	520	290	63	64
	8	230	570	530	300	69	61
Pine	1	270	560	520	250	101	30
	2	250	560	520	270	83	46
	3	260	560	520	260	98	34
	4	310	560	520	210	135	-2
	5	280	560	520	240	94	32
	6	270	560	520	250	92	35
	7	280	570	530	250	102	28

TABLE III (Continued)

Species	Sample No.	Self ignition point (°C.)	Upper ignition value (°C.)	Upper ignition value minus 40° C.	Upper ignition value minus self ignition point (°C.)	Ignition delay (seconds)	Comparison number
Larch	1	230	470	430	200	44	64
	2	240	470	430	190	47	61
	3	240	530	490	250	49	66
	4	240	470	430	190	49	59
	5	240	510	470	230	48	64
	6	230	470	430	200	43	66
	7	230	470	430	200	44	65
Fir	1	260	550	510	250	117	20
	2	320	550	510	200	132	0
	3	290	550	510	220	119	12
	4	270	560	520	250	106	26
	5	300	550	510	210	120	9
	6	300	550	510	210	125	7

TABLE IV

VOLATILITY TABLE FOR SPRUCE

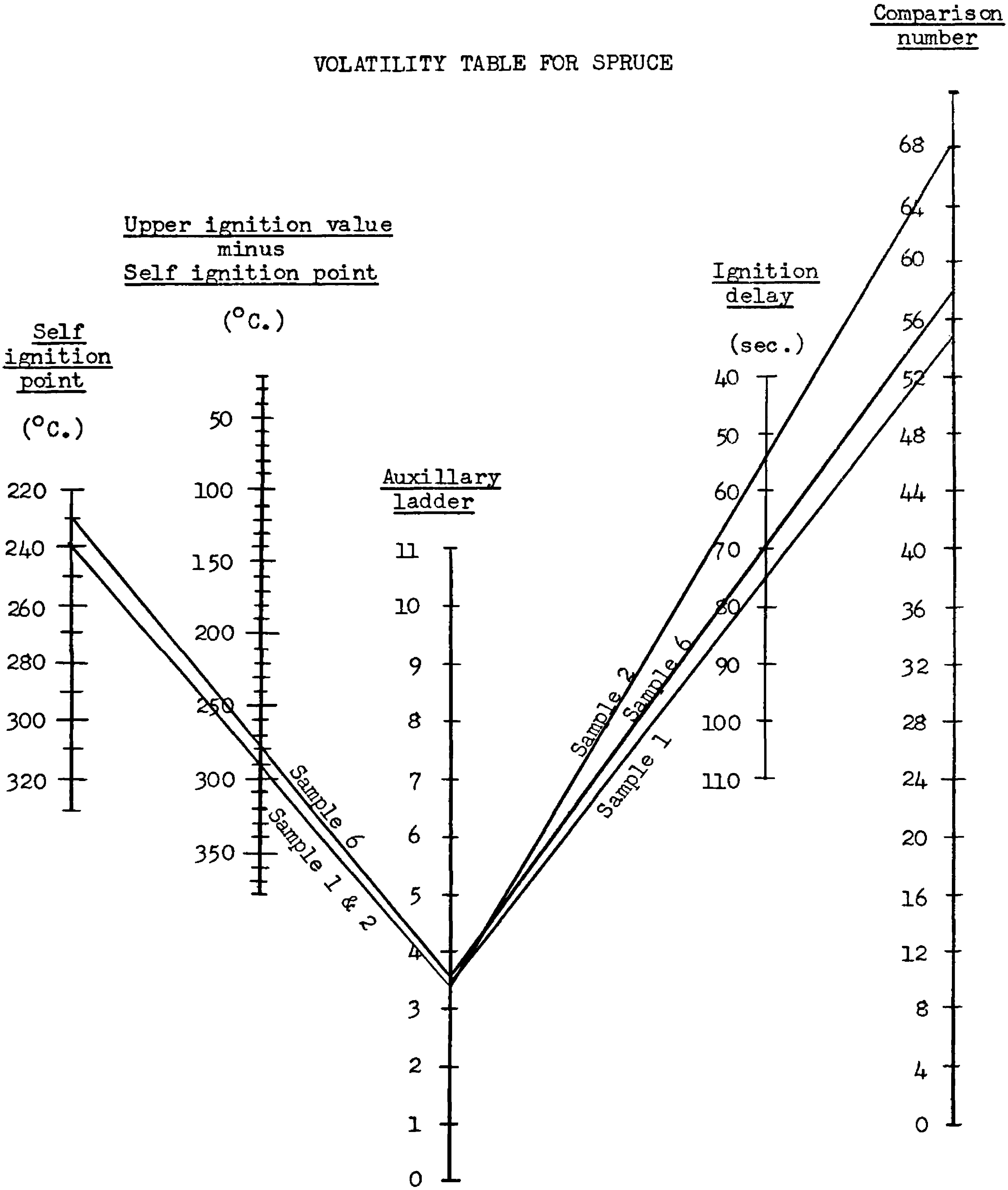


TABLE V

VOLATILITY TABLE FOR PINE

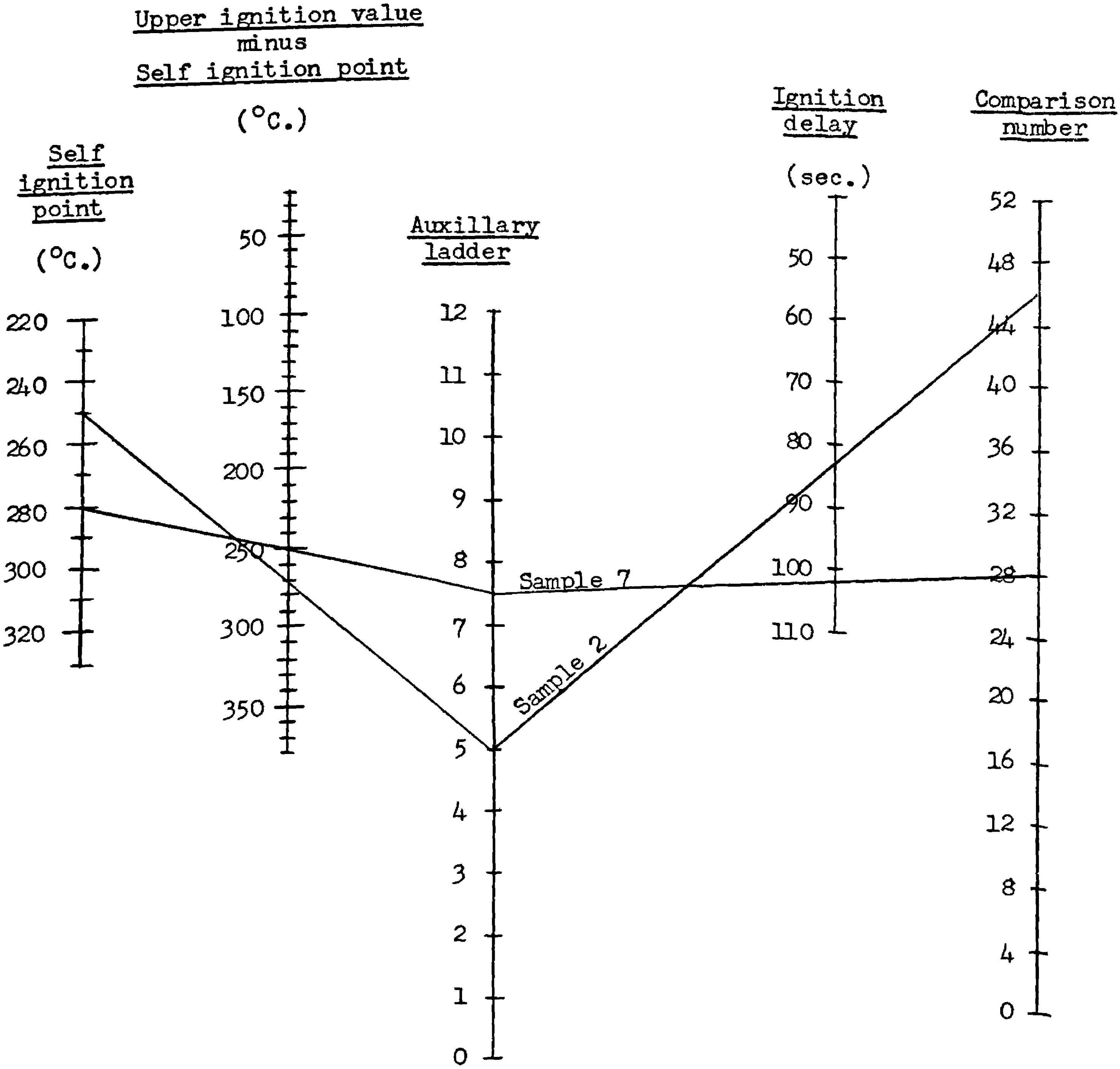


TABLE VI

VOLATILITY TABLE FOR LARCH

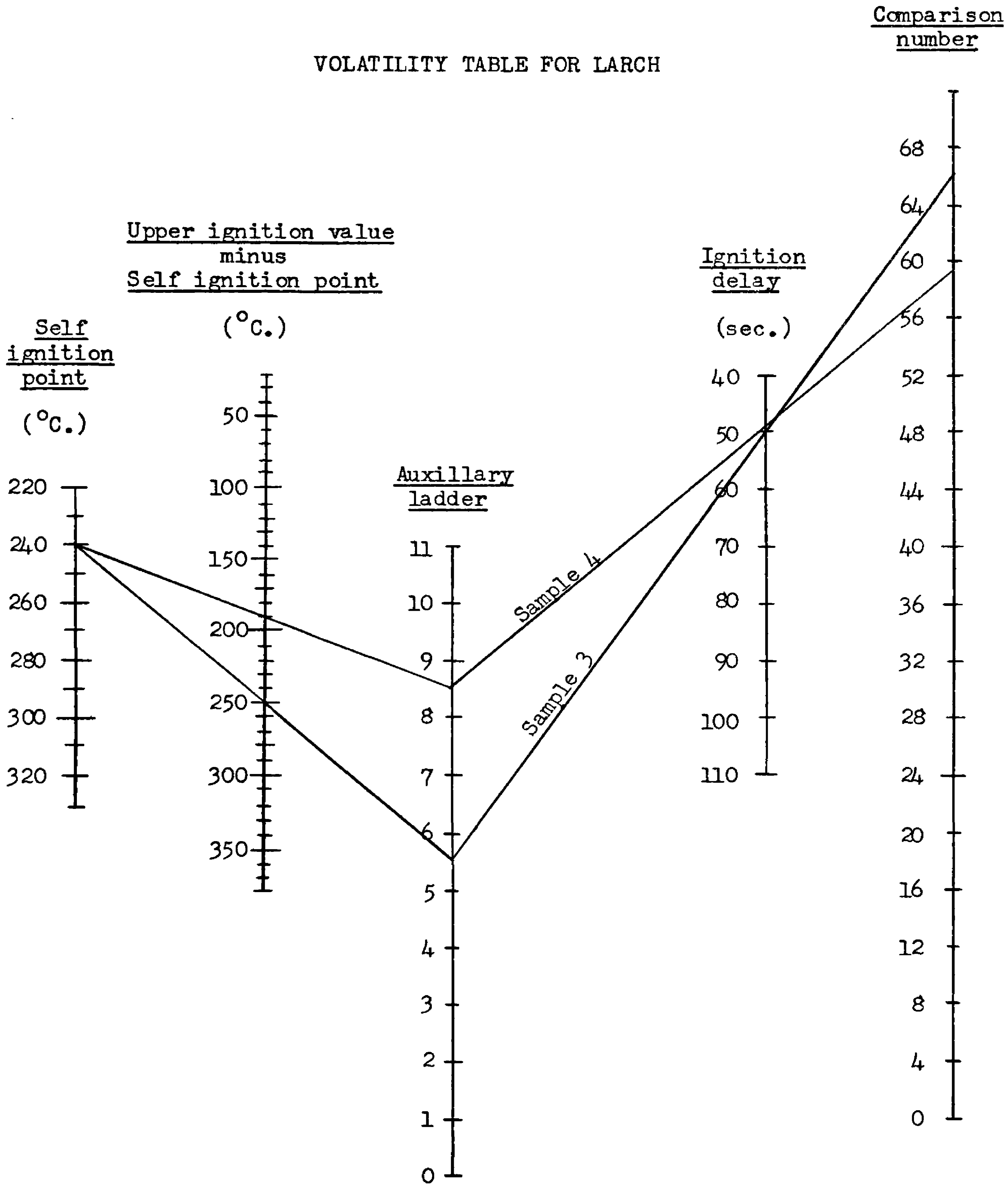
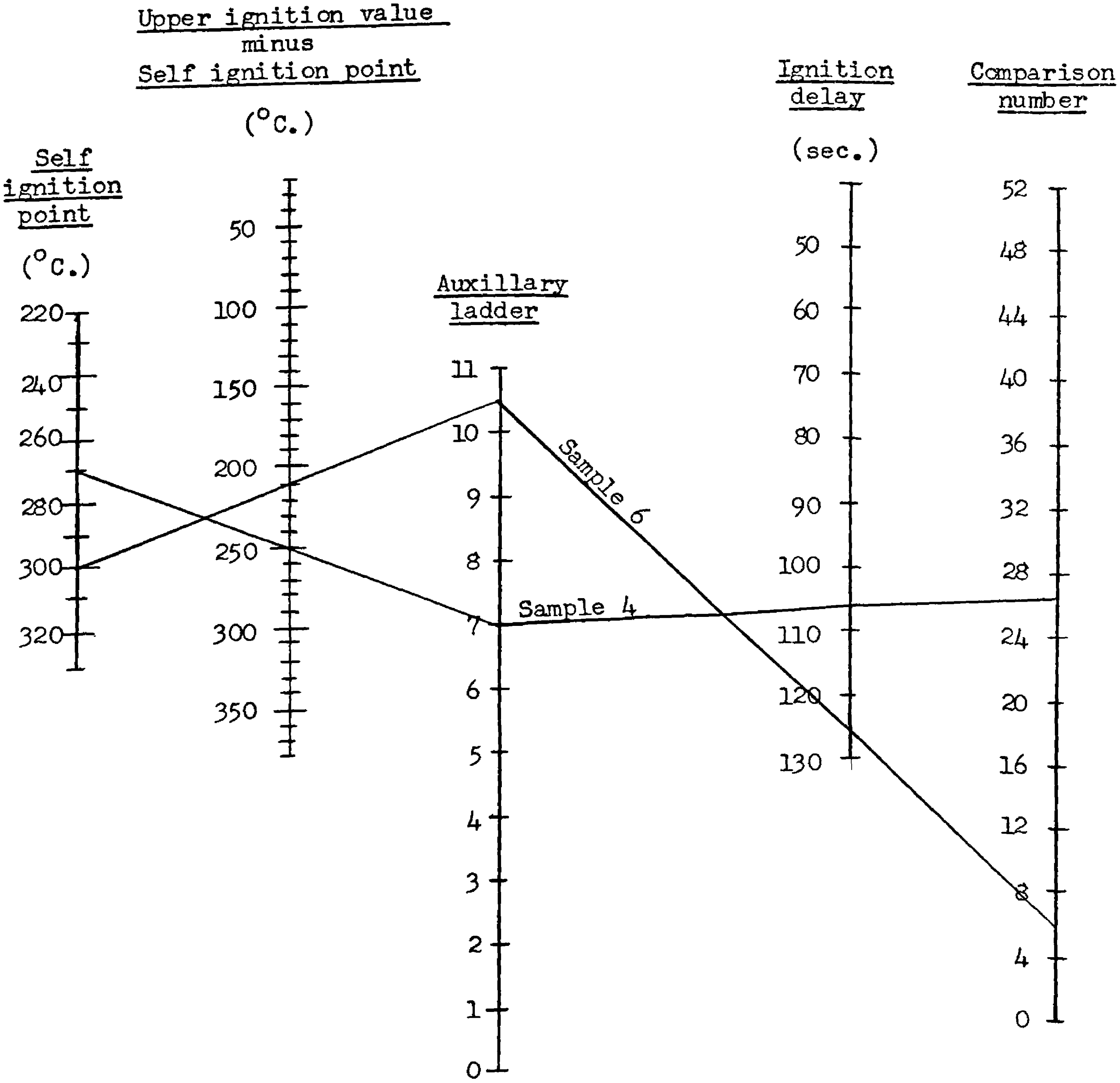


TABLE VII

VOLATILITY TABLE FOR FIR



ANALYSIS OF DATA AND CONCLUSIONS

In Table VIII the samples of each species are arranged according to the site classes and elevations from which the seeds were collected. The sample's index of flammability (comparison number) obtained from the ignition tests is also shown. A straight line relationship was indicated for all species by plotting a sample's comparison number over the mean elevation from which the sample was collected. The straight line relationship pointed to the use of linear regressions as being the best method of analyzing the data.

The data (Table VIII) permitted the development of four linear regressions: 1) spruce site class I, 2) pine site class I-I/II, 3) larch site class I/II-II, and 4) fir site class I-I/II. Insufficient data were available to determine the regressions for spruce site class II, pine site class II/III, and larch site class I.

The independent variable elevation upon which variations in comparison numbers seemed to depend was plotted on the X axis. Comparison numbers were plotted as the dependent variables on the Y axis. The coefficient of regression or (b) value is a measure of the slope of the regression line which describes the unit change in Y with a given change in X. The (b) value was calculated (See Appendix Table XI) for each of the four regression lines.

The (a) values computed are intercepts on the Y axis where X equals zero (Snedecor, 1956). Thus an intercept measures the distance

TABLE VIII

COMPARISON NUMBERS, ELEVATIONS, AND SITE CLASSES

Species	Sample No.	Comparison number	Elevation (meters)	Site class
Spruce	2	68	960-1300	I
	7	64	1000-1150	I
	8	61	760	I
	6	58	500	I
	3	60	400-500	I
	4	58	220	I
	1	55	0-100	I
	5	56	720	II
Pine	2	46	700	I
	3	34	305-335	I
	5	32	200-400	I
	7	28	0-100	I
	1	30	31-61	I
	6	35	300-400	I/II
	4	-2	200-500	II/III
Larch	2	61	400-500	I
	7	65	500	I/II
	6	66	300-400	I/II
	1	64	225-350	I/II
	3	66	450	II
	4	59	200-300	II
	5	64	100-200	II
Fir	3	12	420-460	I
	1	20	300-400	I
	5	9	300-400	I
	6	7	200-300	I
	4	26	370-510	I/II
	2	0	31-61	I/II

from the origin of measurements (zero) along the Y axis to the point where the regression line starts. The intercept (a) was calculated for each regression by, $\bar{Y} = a + b\bar{X}$.

Where:

$\bar{Y}$ = the mean of the comparison numbers for a given species

b = the coefficient of regression

$\bar{X}$ = the mean elevation

Three of the four correlation coefficients (r) calculated for the the regressions showed a high degree of association between comparison numbers and elevation. The computed (r) values are summarized in Table IX. Figure 5 shows the four regression lines, the plotted samples, and the formula used for calculating the expected values of Y ($\hat{Y}$) to plot the regression lines.

Two values also summarized in Table IX are the standard error of the estimate (SE_e) and the standard error of the regression (SE_b). The standard error of the estimate is a measure of the dispersion of the individual values from the regression line, while the standard error of the regression measures the error of the coefficient of regression or the (b) value.

The coefficient of regression and the standard error of the regression were used to calculate sample t in the following formula:

$$\text{Sample } t = \frac{b}{SE_b}$$

Tests of significance were made by taking the sample t value derived from the above formula and comparing them to Fisher's table of

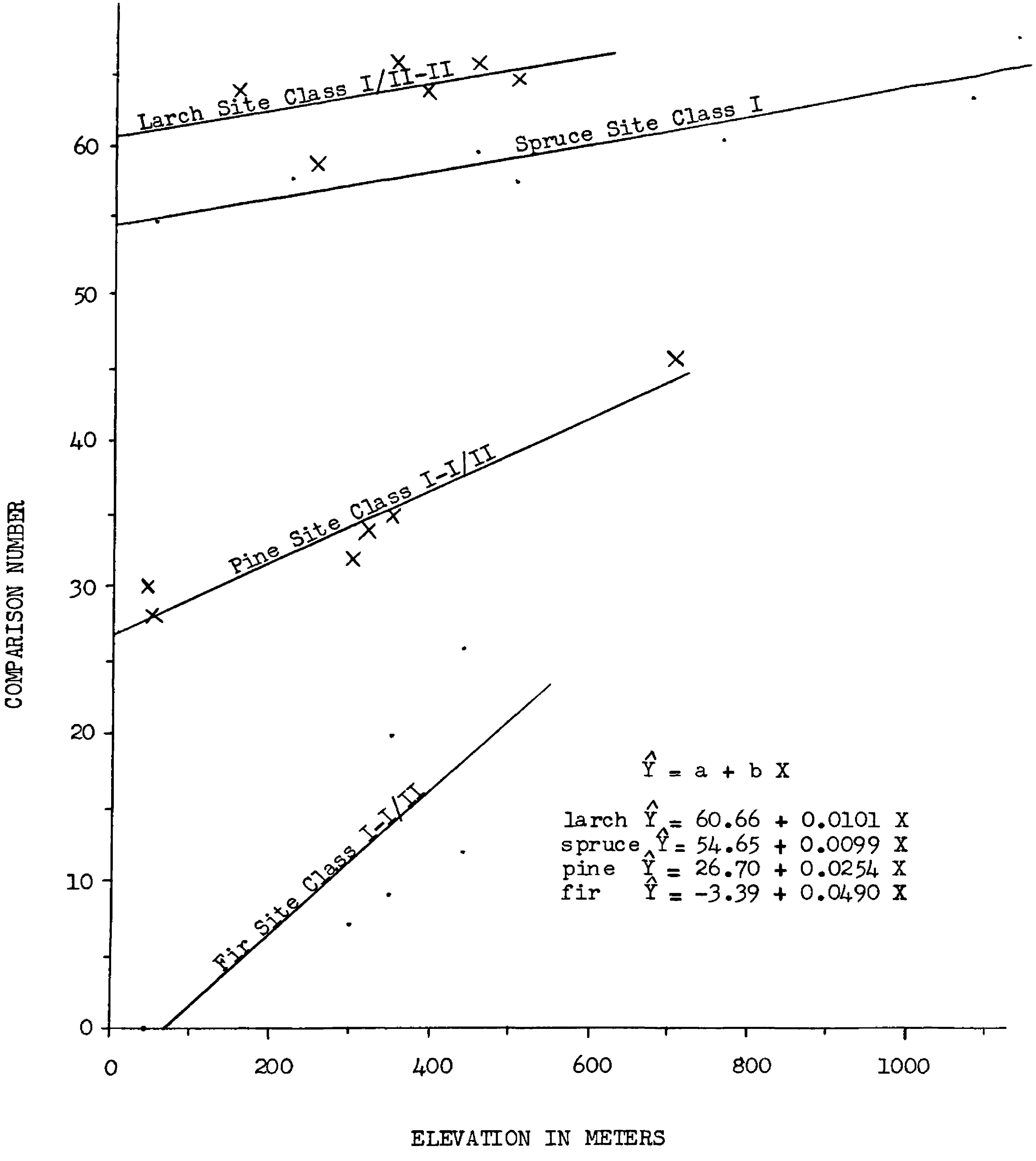


Figure 5. Regressions and the relationship of comparison numbers to elevation.

"t" values. The corresponding degrees of freedom used were n-2 because estimates were made from two reference points from Y. One of the degrees of freedom was already used for the mean, while the other was used for the regression (Snedecor, 1956). Snedecor's F test or the Variance Ratio Test as described by Moroney (1956) was applied to the results too. Table X illustrates that the results of the F test are essentially the same as those of the "t" test.

If the calculated value of t exceeds the 5% probability point in the table of "t", for the number of degrees of freedom in question, then the conclusion can be made that the result is probably significant. But both the t values calculated for spruce site class I and for pine site class I-I/II are definitely significant because they exceeded the 1% probability (Moroney, 1956). However, the calculated t value for fir site class I-I/II is only significant at the 90% level of confidence or the 10% probability point, and the sample t value for larch site class I/II-II is not significant.

Therefore the Null Hypothesis that there is no difference in the burning index with changes in elevation holds for larch site class I/II-II and fir site class I-I/II at the 95% level of confidence. But the Null Hypothesis breaks down for both spruce site class I and pine site class I-I/II at the 99% level of confidence. The differences found in a species flammability with variations in elevation must be a result of dissimilar storage of chemicals in tree seed at different elevations.

The reason for the positive and negative results can be attributed to the fact that insufficient samples were tested across the range of

TABLE IX

REGRESSION ANALYSIS OF THE RELATIONSHIP BETWEEN THE COMPARISON NUMBERS AND ELEVATION

Species	No. of items	Site	Range in elevation (meters)	Coefficient of regression (b)	Correlation coefficient (r)	Intercept (a)	Standard error of the estimate (SE_e)	Standard error of regression (SE_b)	Sample t
Spruce	7	I	50-1130	0.0099	0.9417	54.65	- 1.57	0.0016	6.19**
Pine	6	I-I/II	45-700	0.0254	0.9654	26.70	- 1.83	0.0034	7.47**
Larch	6	I/II-II	150-500	0.0101	0.5021	60.66	- 2.52	0.0087	1.16
Fir	6	I-I/II	45-440	0.0490	0.7654	-3.39	- 6.73	0.0206	2.38*

** Significant at the 1% point.
* Significant at the 10% point.
Not significant.

TABLE X

SNEDECOR'S F TEST

Species	Category	Degrees of Freedom	Sum of Squares	Variance	F	$F_{.05}$	$F_{.01}$
Spruce	Total	6	111.72	18.62			
	Regression	1	99.32	99.32	40.05**	6.61	16.26
	Standard error of the estimate	5	12.40	2.48			
Pine	Total	5	200.83	40.17			
	Regression	1	187.45	187.45	56.12**	7.71	21.20
	Standard error of the estimate	4	13.38	3.34			
Larch	Total	5	34.00	6.80			
	Regression	1	8.57	8.57	1.35	7.71	21.20
	Standard error of the estimate	4	25.43	6.36			
Fir	Total	5	437.33	87.47			
	Regression	1	256.38	256.38	5.67	7.71	21.20
	Standard error of the estimate	4	180.95	45.24			

** Significant at the 1% point.

elevations for larch and fir to obtain reliable regressions. Of all the species tested, spruce had the best range in elevation (50-1130 meters) followed by pine (45-700 meters), fir (45-440 meters), and larch (150-500 meters). This may mean that only the sampling was insufficient to detect more significant differences.

As was previously pointed out, spruce site class II and pine site class II/III were not used in the analysis of spruce site class I and pine site class I-I/II regressions. The reason they were not used is that they did not seem to belong to the same population as the site class I spruce and site class I-I/II pine. This can be clearly seen by referring to pine sample 4 and then plotting the sample's comparison number over the mean collection elevation on Figure 5. Therefore, a sample that has a comparatively high self ignition point temperature and/or a longer ignition delay (See spruce sample 5 and pine sample 4 Table II) appears to be from a poorer site class than site class I. The reason for this is that high self ignition temperatures as well as longer ignition delay periods result in lower comparison numbers. A regression analysis was made using the larch samples from site class I/II and site class II because there was only one sample for larch site class I.

SUMMARY

Methods outlined in this study appear to be suitable for tree seed ignition tests. However, drying samples under reduced pressure not exceeding 100 mm. of mercury for approximately five hours at 95 to 100° C. as recommended by the A.A.O.C., (1950) would probably be a better method of drying. This drying process would result in a smaller loss of crude fats and shorten the total drying time considerably. The seed drying temperature should be corrected to a standard temperature at sea level so that the results of ignition tests made at different elevations are comparable. This was not done in this preliminary study. Fresh seeds (not held over one year) should be used for ignition tests because the chemical composition of seeds may change in storage.

The Jentzsch Ignition Tester provided a simple and reliable method of appraising the flammability properties of tree seed. Four species comprising twenty-eight samples of certified German tree seed were tested.

Linear regression analysis of the data for each species were restricted to one site class with changing elevations. Other environmental or genetic factors that may influence a sample's flammability were disregarded. Fisher's "t" test and Snedecor's F test were used to test the significance of the regressions. Both tests indicated that a sample's index of flammability (comparison number) is probably influenced by elevation. Insufficient data and the results for larch and fir call for more measurements to detect significant differences.

Because site classes II or worse did not appear to belong to the same population as site class I in the statistical analysis, the author believes that site classes might be differentiated in a burning process by: 1) high self ignition temperatures and/or, 2) longer ignition delay periods found for the poorer site class samples.

Further research, if limited to one species, two site classes, and more samples over a large range in elevation would give more conclusive information.

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APPENDIX

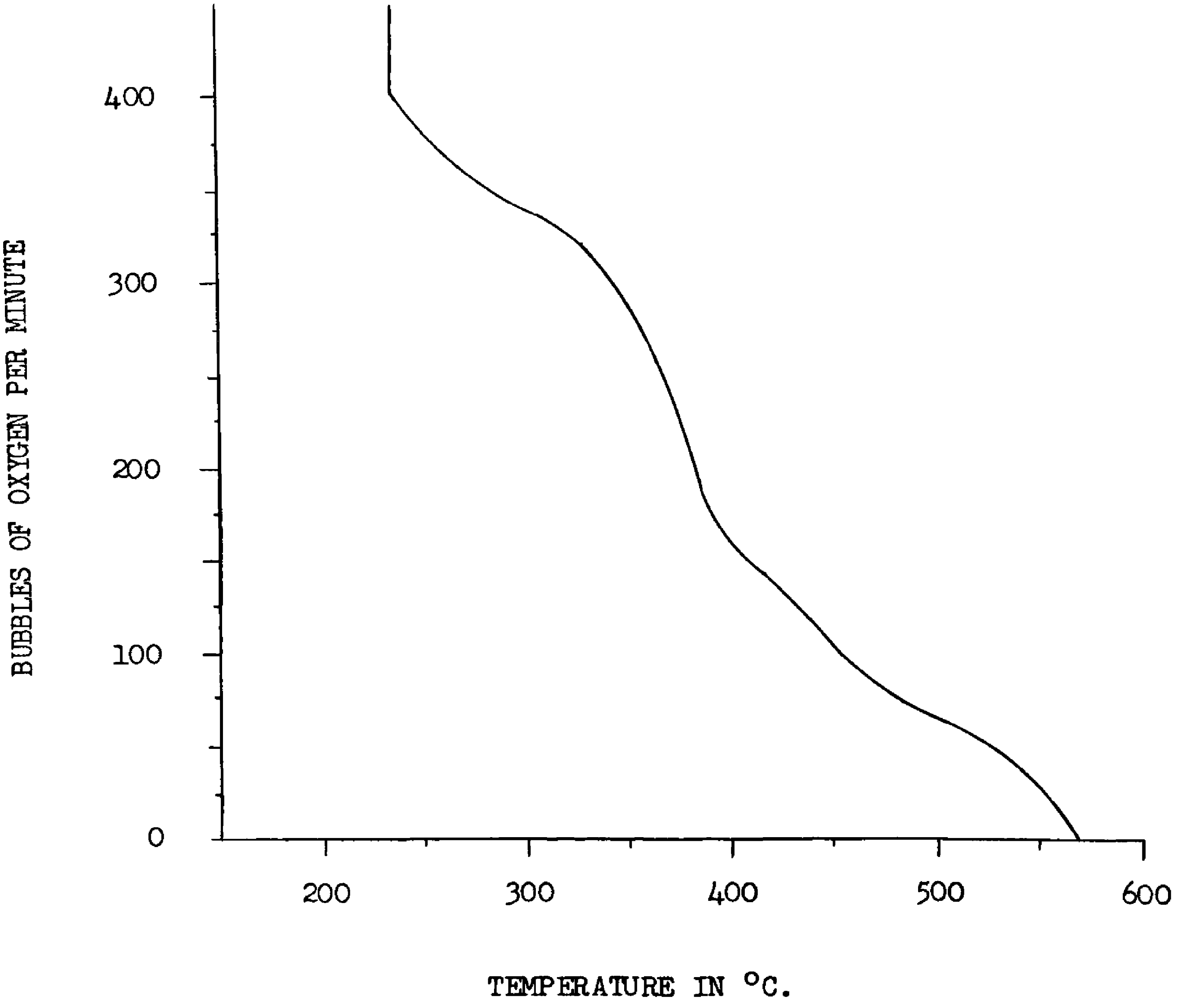

Figure 6. Autogeneous Ignition Curve for spruce sample 1.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 1 from Ratzeburg	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	236	5	26	30.35	69
Intermediate ignition points	375	254	4	26	30.35	69
	350	282	5	25	30.30	66
	325	326	3	25	30.30	66
	300	342	5	25	30.30	66
	275	356	4	25	30.30	67
	250	372	4	25	30.30	67
	225	378	3	28	30.15	68
	200	382	4	28	30.15	68
	175	390	7	28	30.20	66
	150	416	8	33	29.75	74
	125	440	4	33	29.75	74
	100	458	5	33	29.75	74
	75	480	6	33	29.80	78
	50	526	7	33	29.80	78
	25	554	5	33	29.80	78
Upper ignition value	0	568	13	33	29.80	78
Ignition delay (75 seconds)	400	320	5	30	30.05	72

Dates tested: Dec. 28, 29, & 30, 1959

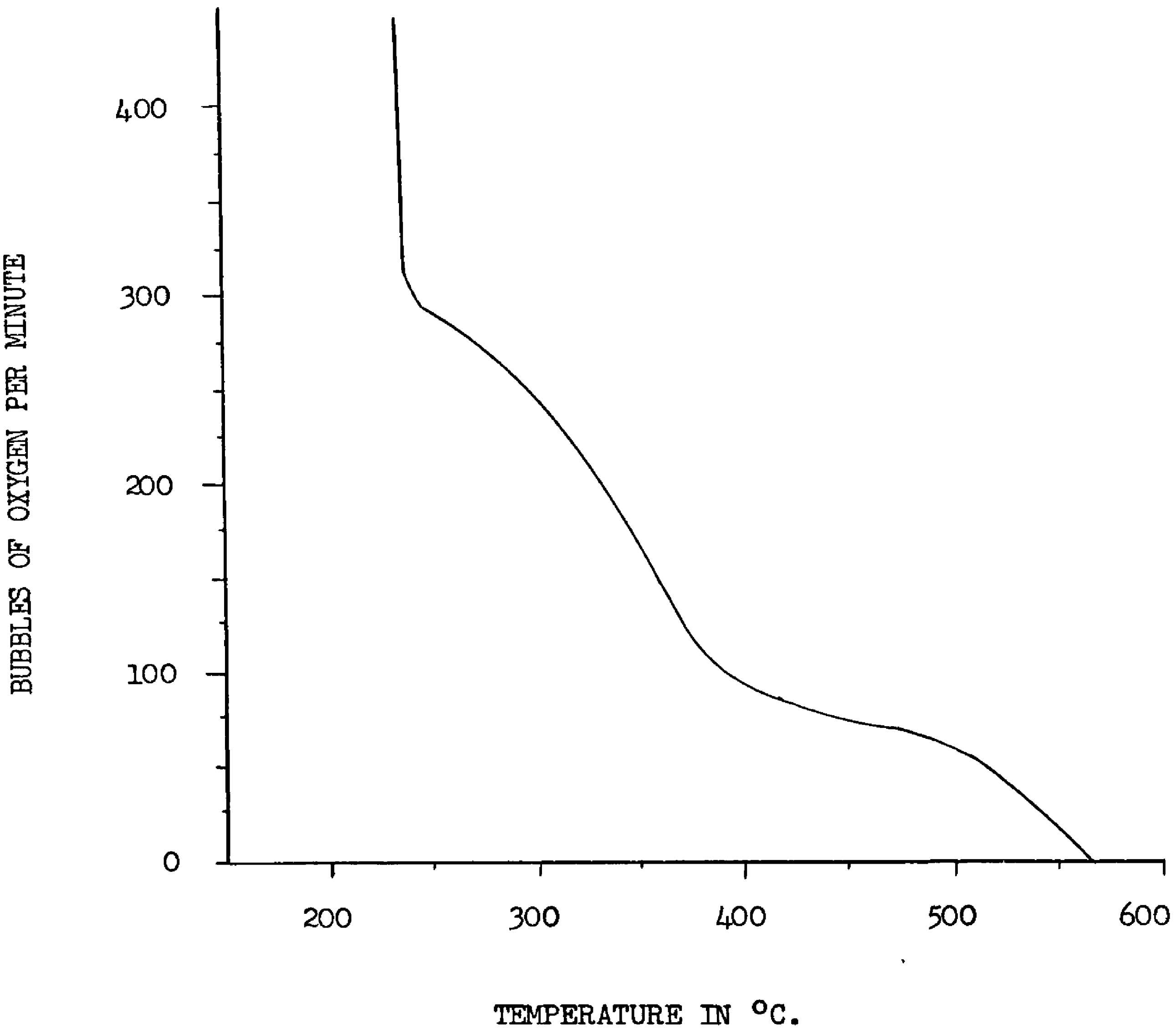

Figure 7. Autogeneous Ignition Curve for spruce sample 2.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 2 from Oberammergau	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	236	10	29	30.10	67
Intermediate ignition points	375	236	6	29	30.10	67
	350	236	6	29	30.10	67
	325	236	5	29	30.10	67
	300	242	4	29	30.10	67
	275	274	9	29	30.10	68
	250	282	4	29	30.10	68
	225	314	9	29	30.10	68
	200	336	5	29	30.10	68
	175	346	5	30	30.15	67
	150	358	6	30	30.15	67
	125	374	5	30	30.15	68
	100	384	4	30	30.15	68
	75	448	9	30	30.15	68
	50	514	6	29	30.15	67
	25	548	5	30	30.15	68
Upper ignition value	0	570	10	30	30.15	68
Ignition delay (54 seconds)	400	320	5	30	30.05	72

Dates tested: Jan. 2, 3, & 5, 1960

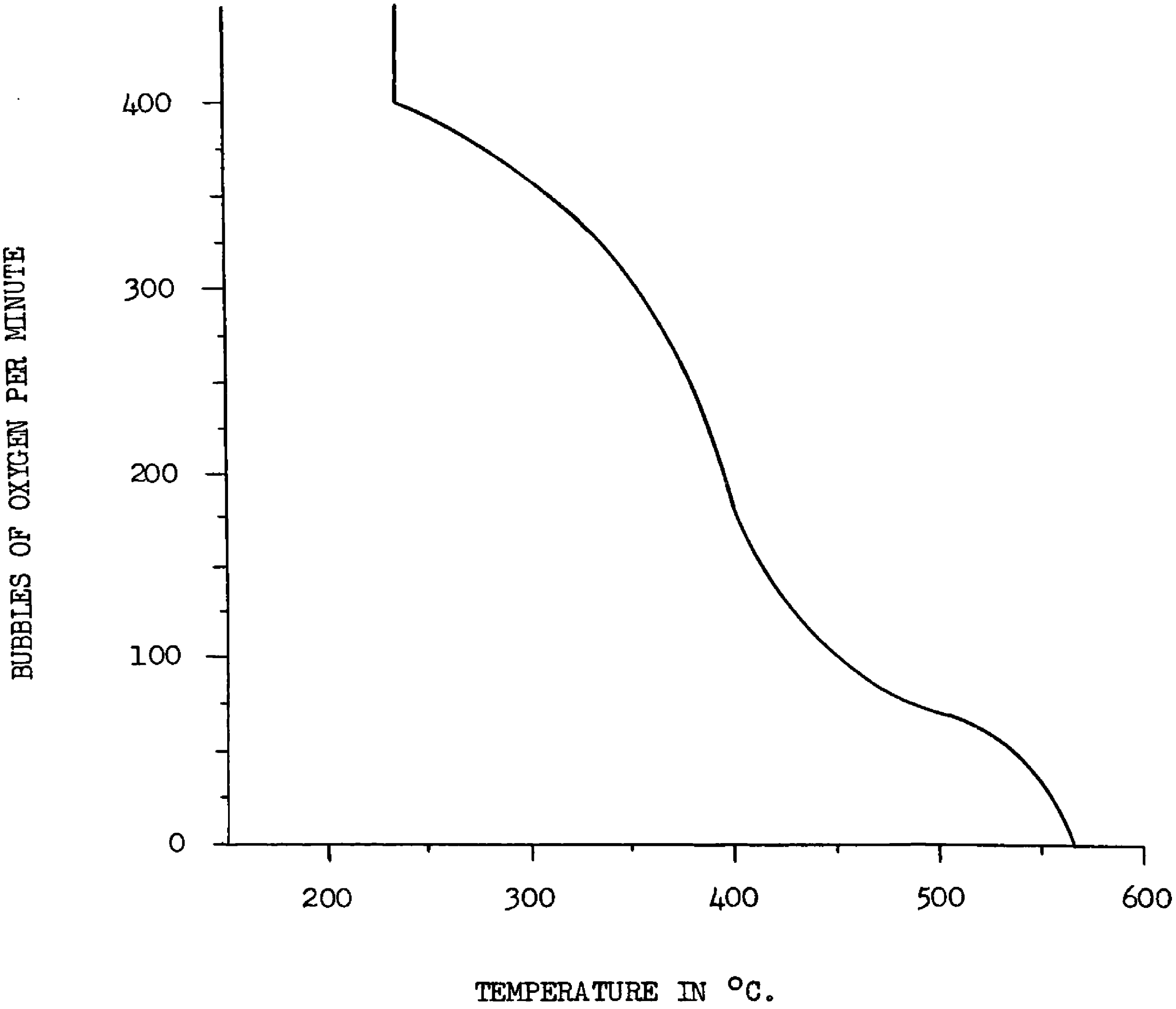

Figure 8. Autogeneous Ignition Curve for spruce sample 3.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 3 from Rödgen	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	236	14	28	30.00	77
Intermediate ignition points	375	276	9	28	30.25	69
	350	306	6	28	30.25	76
	325	338	9	30	30.00	66
	300	354	11	28	30.40	69
	275	358	5	31	30.05	68
	250	380	7	28	30.00	69
	225	388	5	30	30.00	66
	200	394	13	28	30.05	69
	175	398	3	31	30.30	67
	150	414	11	31	30.00	65
	125	438	5	31	30.00	67
	100	448	11	30	30.35	69
	75	484	12	29	30.10	66
	50	540	16	29	30.10	67
	25	556	5	28	30.10	67
Upper ignition value	0	564	25	28	30.10	67
Ignition delay (66 seconds)	400	320	5	30	30.05	72

Dates tested: Dec. 18 & 22, 1959

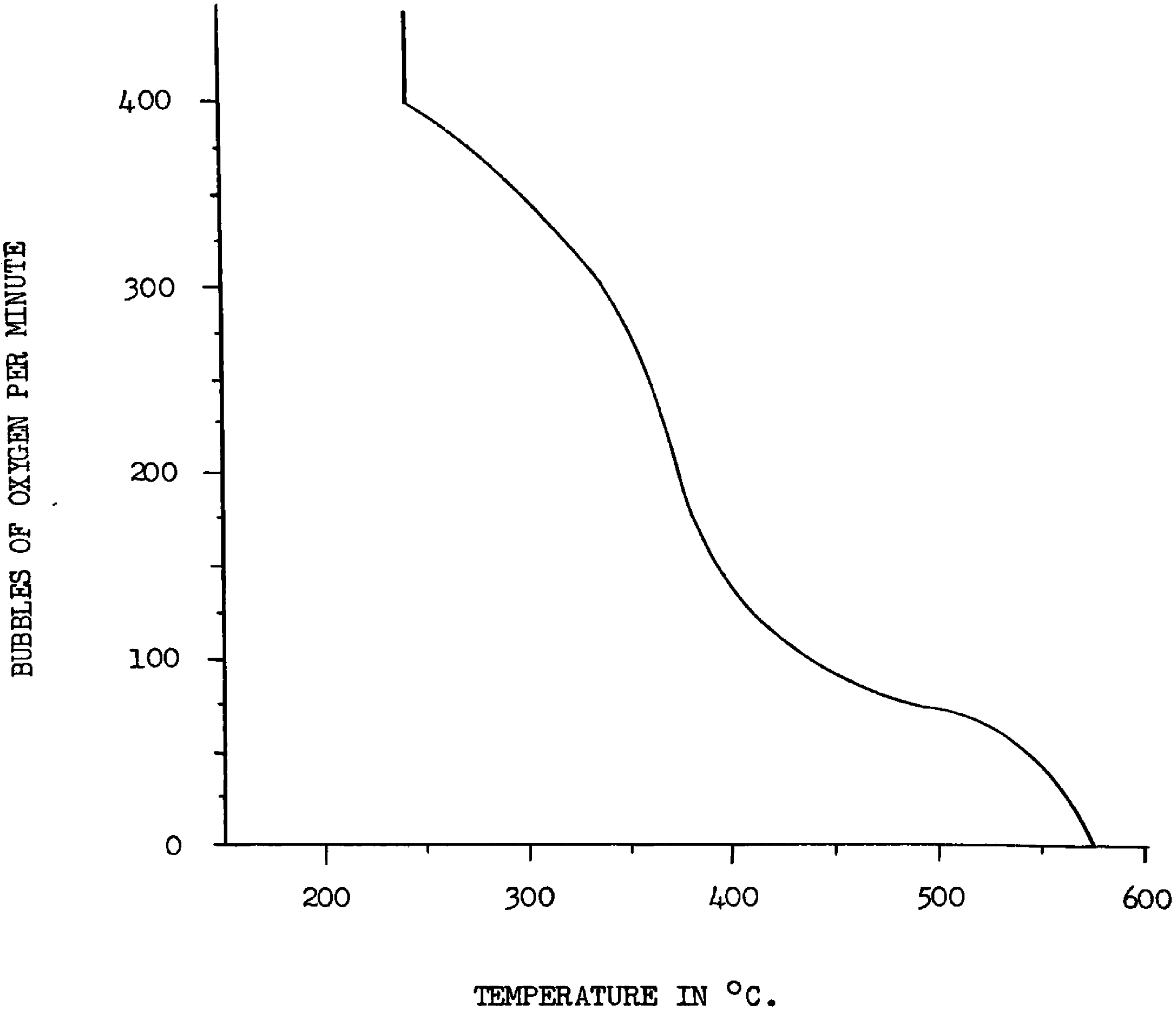

Figure 9. Autogeneous Ignition Curve for spruce sample 4.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 4 from Westerhof	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	242	7	28	30.00	69
Intermediate ignition points	375	274	5	31	29.95	70
	350	300	7	28	29.90	71
	325	322	7	28	29.90	71
	300	342	5	27	29.90	71
	275	352	6	27	29.90	71
	250	356	6	25	30.35	76
	225	366	5	25	30.00	72
	200	374	6	25	30.35	75
	175	380	6	25	30.35	74
	150	394	5	25	30.40	75
	125	410	4	25	30.40	74
	100	434	4	25	30.40	74
	75	488	11	25	30.40	74
	50	544	8	26	30.40	72
	25	564	4	26	30.40	68
Upper ignition value	0	574	8	26	30.40	68
Ignition delay (70 seconds)	400	320	5	30	30.05	72

Dates tested: Dec. 22, 26, & 28, 1959

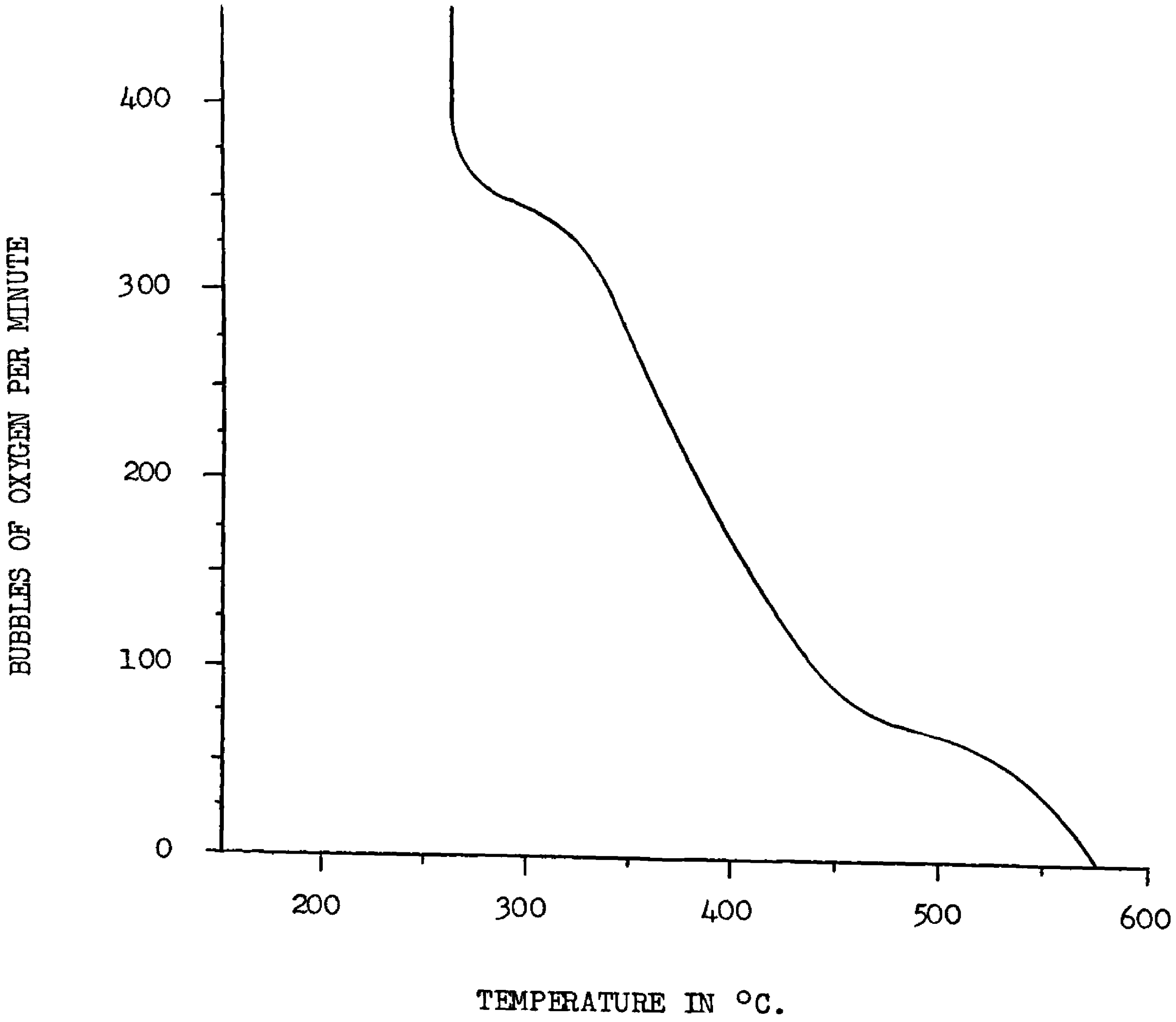

Figure 10. Autogeneous Ignition Curve for spruce sample 5.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 5 from Stryck	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	260	11	29	30.20	67
Intermediate ignition points	375	262	7	30	30.10	70
	350	282	9	28	30.30	72
	325	326	5	28	30.30	72
	300	340	6	30	30.10	70
	275	342	4	30	30.10	70
	250	346	4	28	30.30	71
	225	356	8	28	30.30	71
	200	388	11	30	30.25	66
	175	398	4	30	30.05	69
	150	408	5	30	30.05	69
	125	422	4	30	30.05	69
	100	438	5	30	30.05	69
	75	472	6	30	30.05	69
	50	524	5	29	30.05	71
	25	554	5	29	30.05	72
Upper ignition value	0	574	8	30	30.05	72
Ignition delay (65 seconds)	400	320	5	30	30.05	72

Dates tested: Jan. 13, 16, & 17, 1960

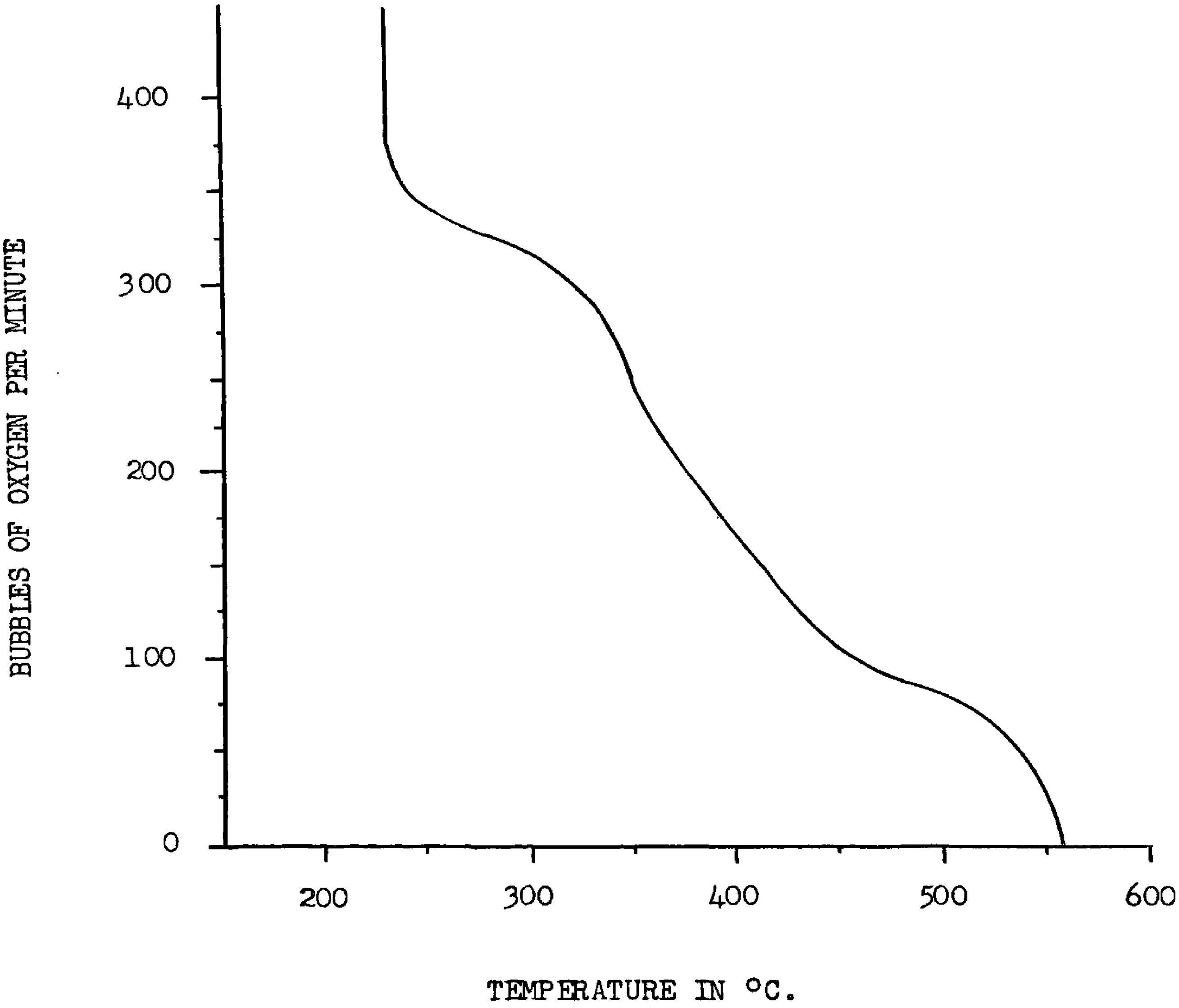

Figure 11. Autogeneous Ignition Curve for spruce sample 6.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 6 from Rothenkirchen	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	230	9	26	30.05	80
Intermediate ignition points	375	230	3	25	30.05	79
	350	242	4	26	30.05	79
	325	284	7	26	30.05	79
	300	330	17	27	30.00	76
	275	342	5	27	30.00	78
	250	348	5	27	29.95	79
	225	360	4	29	29.95	79
	200	378	5	29	29.95	79
	175	390	5	27	29.90	80
	150	408	5	27	29.90	80
	125	430	6	26	29.85	81
	100	452	6	26	29.85	81
	75	508	7	26	29.85	81
	50	536	4	26	29.85	81
	25	550	4	26	29.85	81
Upper ignition value	0	554	7	26	29.85	81
Ignition delay (70 seconds)	400	320	5	30	30.05	72

Dates tested: Mar. 23 & 24, 1960

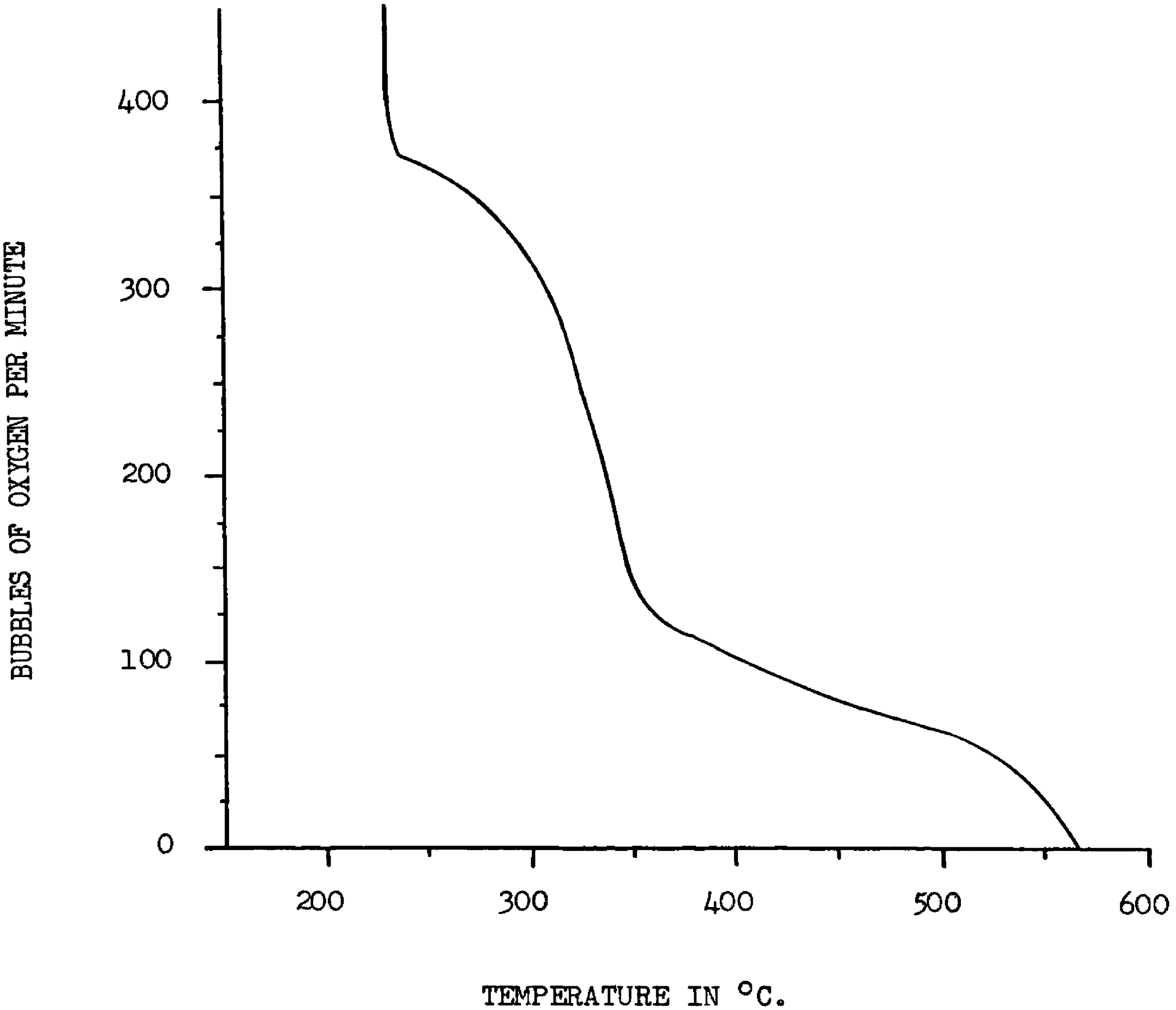

Figure 12. Autogeneous Ignition Curve for spruce sample 7.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 7 from Schluchsee	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	232	4	33	30.00	72
Intermediate ignition points	375	236	7	32	29.75	68
	350	274	5	32	29.75	69
	325	304	6	32	29.75	70
	300	310	4	32	29.75	70
	275	316	5	32	29.75	70
	250	324	3	32	29.75	71
	225	330	3	33	30.00	72
	200	338	10	33	30.00	72
	175	344	5	33	30.00	73
	150	348	4	33	30.00	73
	125	362	7	30	30.00	73
	100	408	5	30	30.00	73
	75	456	4	30	30.00	73
	50	522	6	30	30.00	73
	25	548	5	30	30.00	73
Upper ignition value	0	564	5	30	30.00	73
Ignition delay (63 seconds)	400	320	5	30	30.05	72

Dates tested: Jan. 6, 8, & 9, 1960

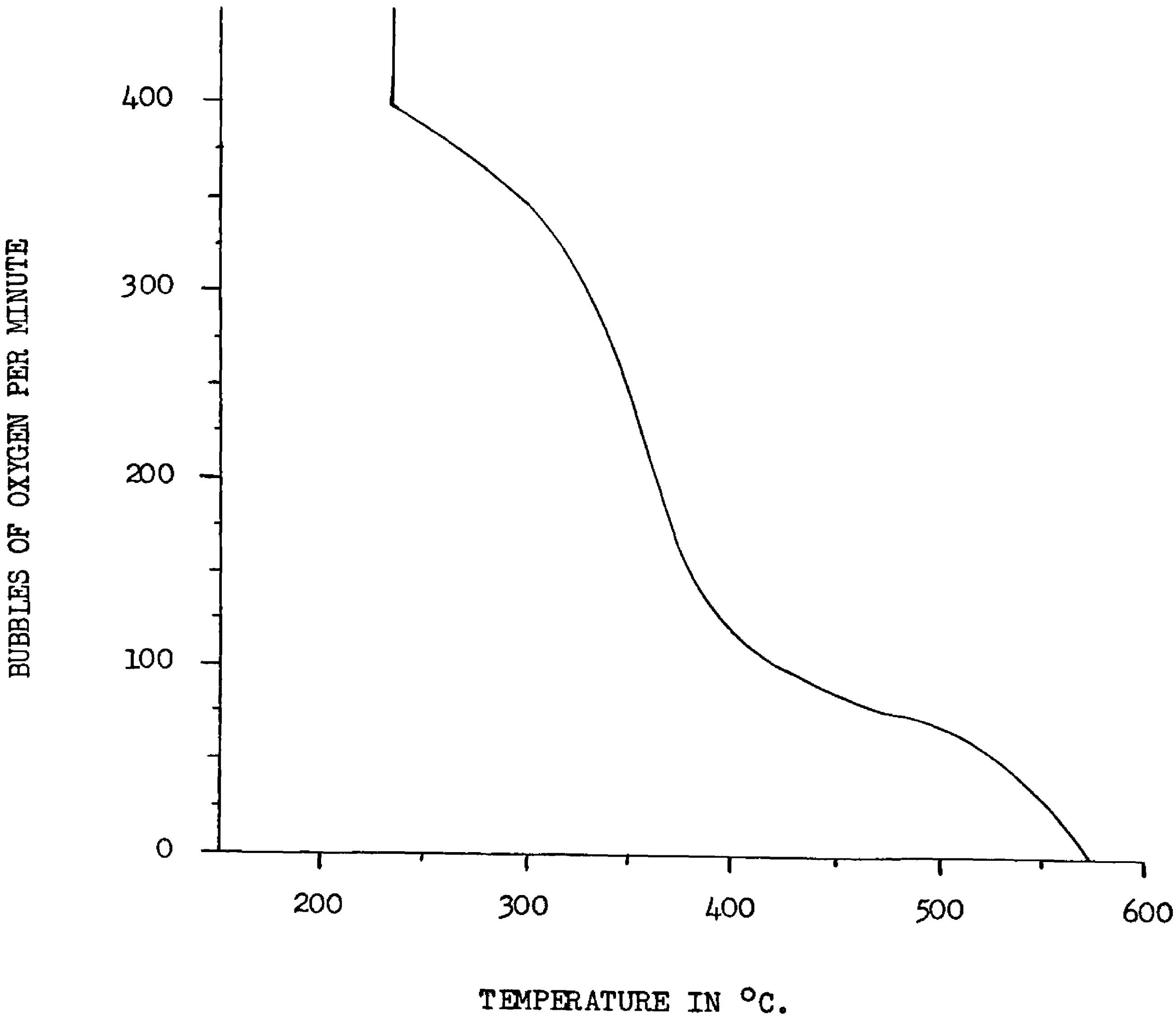

Figure 13. Autogeneous Ignition Curve for spruce sample 8.

INDIVIDUAL SPECIES DATA SHEET

Spruce No. 8 from Denklingen	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	234	7	29	30.30	67
Intermediate ignition points	375	262	3	30	30.10	68
	350	298	5	30	30.10	68
	325	318	5	30	30.10	68
	300	324	9	30	30.25	66
	275	338	6	30	30.10	70
	250	350	4	30	30.10	71
	225	356	3	30	30.10	72
	200	364	4	29	30.10	70
	175	372	3	29	30.10	71
	150	382	3	29	30.10	71
	125	396	4	29	30.20	72
	100	422	6	29	30.20	67
	75	478	6	29	30.20	67
	50	526	5	30	30.05	72
	25	554	5	30	30.05	72
Upper ignition value	0	568	8	30	30.05	72
Ignition delay (69 seconds)	400	320	5	30	30.05	72

Dates tested: Jan. 15 & 16, 1960

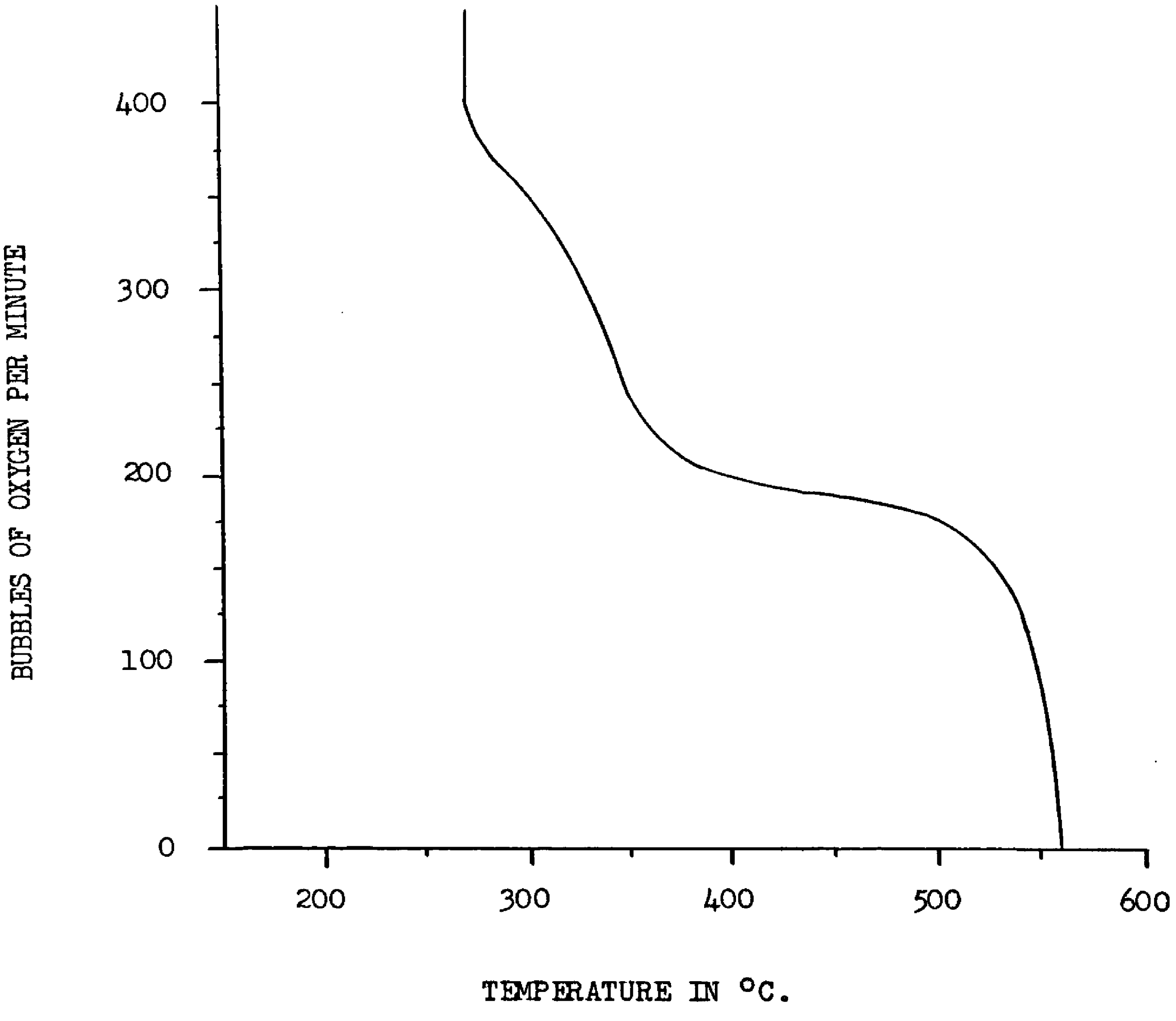

Figure 14. Autogeneous Ignition Curve for pine sample 1.

INDIVIDUAL SPECIES DATA SHEET

Pine No. 1 from Erdmannshausen	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	272	13	26	29.90	77
Intermediate ignition points	375	278	4	26	29.90	77
	350	300	8	26	29.90	78
	325	314	5	26	29.90	78
	300	330	7	27	30.00	76
	275	340	4	27	29.95	78
	250	346	4	27	29.95	78
	225	360	13	27	29.95	78
	200	392	7	27	29.95	78
	175	496	11	27	29.95	78
	150	534	5	26	29.95	79
	125	542	3	26	29.95	79
	100	546	5	26	29.95	79
	75	550	4	26	29.90	80
	50	554	5	26	29.90	80
	25	556	5	26	29.90	80
Upper ignition value	0	558	4	26	29.90	79
Ignition delay (101 seconds)	400	320	5	27	30.00	76

Dates tested: Mar. 24 & 25, 1960

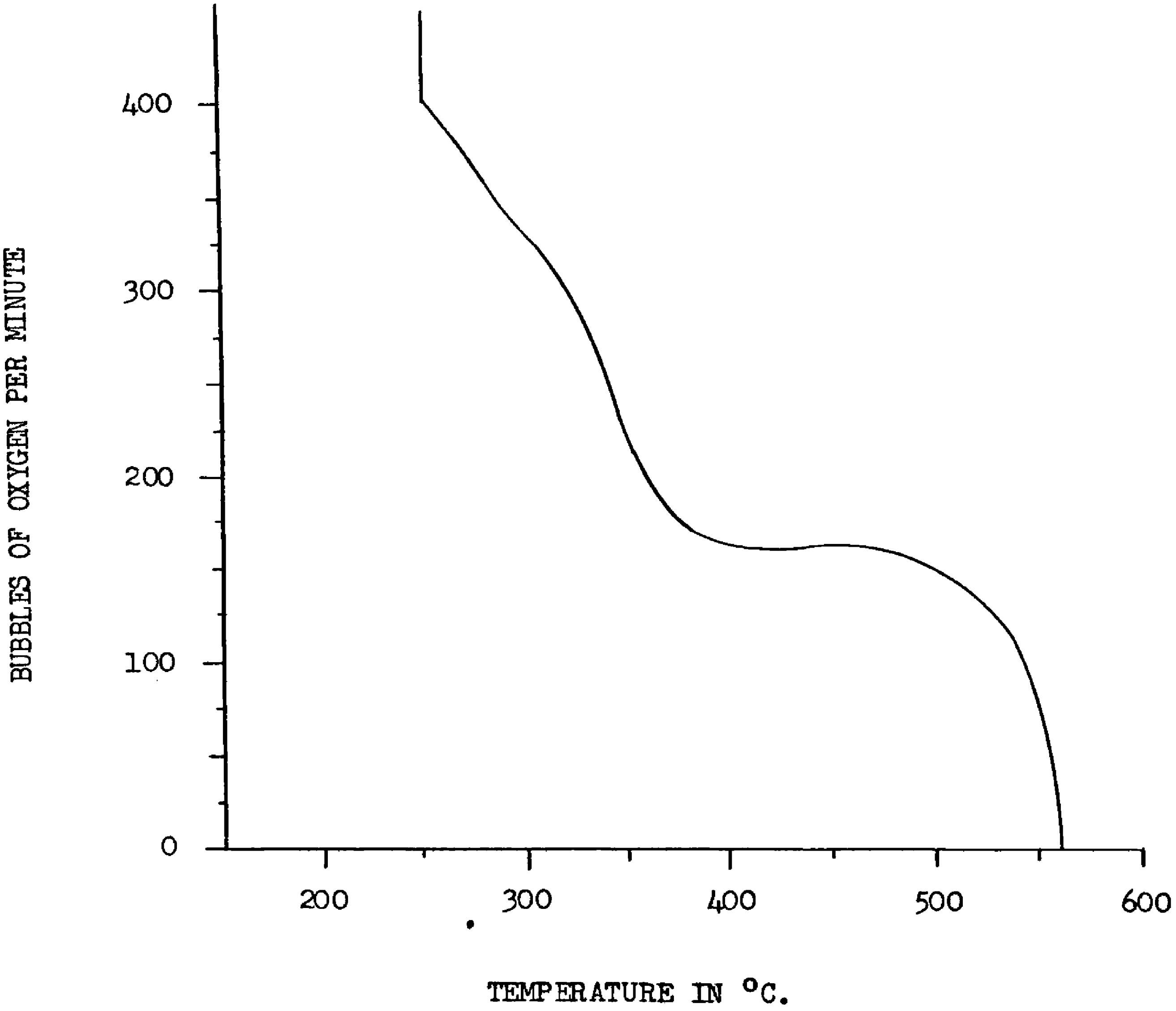

Figure 15. Autogeneous Ignition Curve for pine sample 2.

INDIVIDUAL SPECIES DATA SHEET

Pine No. 2 from Sigmaringen	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	252	8	28	29.75	73
Intermediate ignition points	375	268	4	28	29.75	73
	350	286	5	28	29.75	73
	325	304	4	30	29.80	74
	300	318	8	30	29.80	74
	275	334	4	30	29.80	74
	250	342	5	30	29.80	74
	225	348	3	30	29.80	74
	200	358	3	30	29.80	74
	175	374	4	30	29.80	73
	150	498	3	30	29.80	74
	125	526	11	30	29.80	74
	100	546	4	30	29.80	74
	75	550	3	30	29.80	74
	50	554	4	30	29.80	74
	25	558	6	30	29.80	74
Upper ignition value	0	560	3	30	29.80	74
Ignition delay (83 seconds)	400	320	5	27	30.00	76

Dates tested: Jan. 25, 26, & Mar. 24, 1960

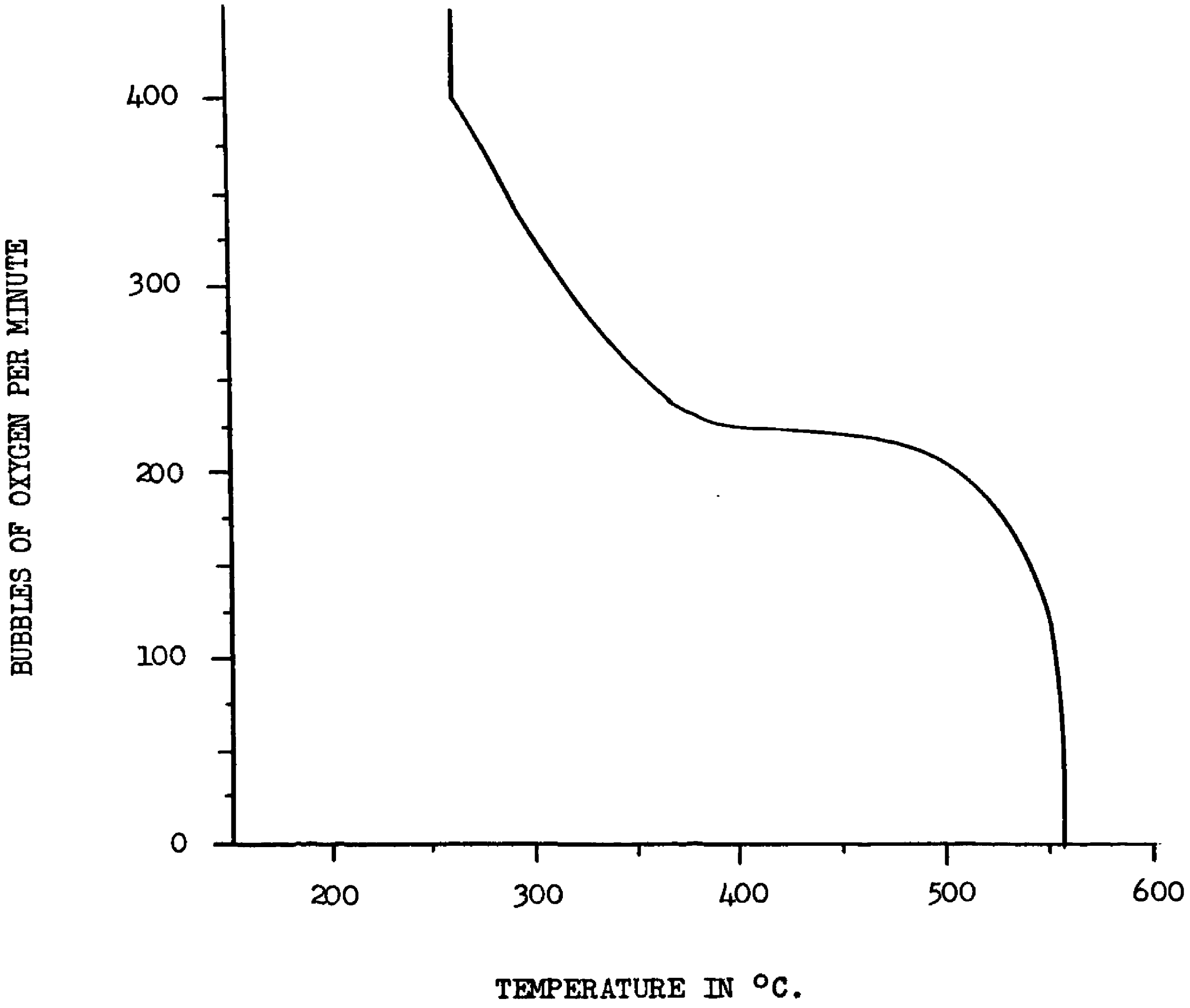

Figure 16. Autogeneous Ignition Curve for pine sample 3.

INDIVIDUAL SPECIES DATA SHEET

Pine No. 3 from Burgebrach	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	262	14	30	29.90	74
Intermediate ignition points	375	274	3	30	29.90	75
	350	290	3	30	29.90	75
	325	302	4	30	29.90	74
	300	316	3	29	29.90	75
	275	334	7	29	29.90	75
	250	352	5	29	29.90	75
	225	384	9	29	29.90	75
	200	502	7	28	29.90	76
	175	524	7	28	29.90	76
	150	540	5	28	29.90	76
	125	548	3	28	29.90	76
	100	548	6	28	29.90	76
	75	552	3	28	29.90	76
	50	554	3	28	29.90	76
	25	554	4	28	29.90	76
Upper ignition value	0	556	4	28	29.90	76
Ignition delay (98 seconds)	400	320	5	27	30.00	76

Dates tested: Jan. 27 & Mar. 24, 1960

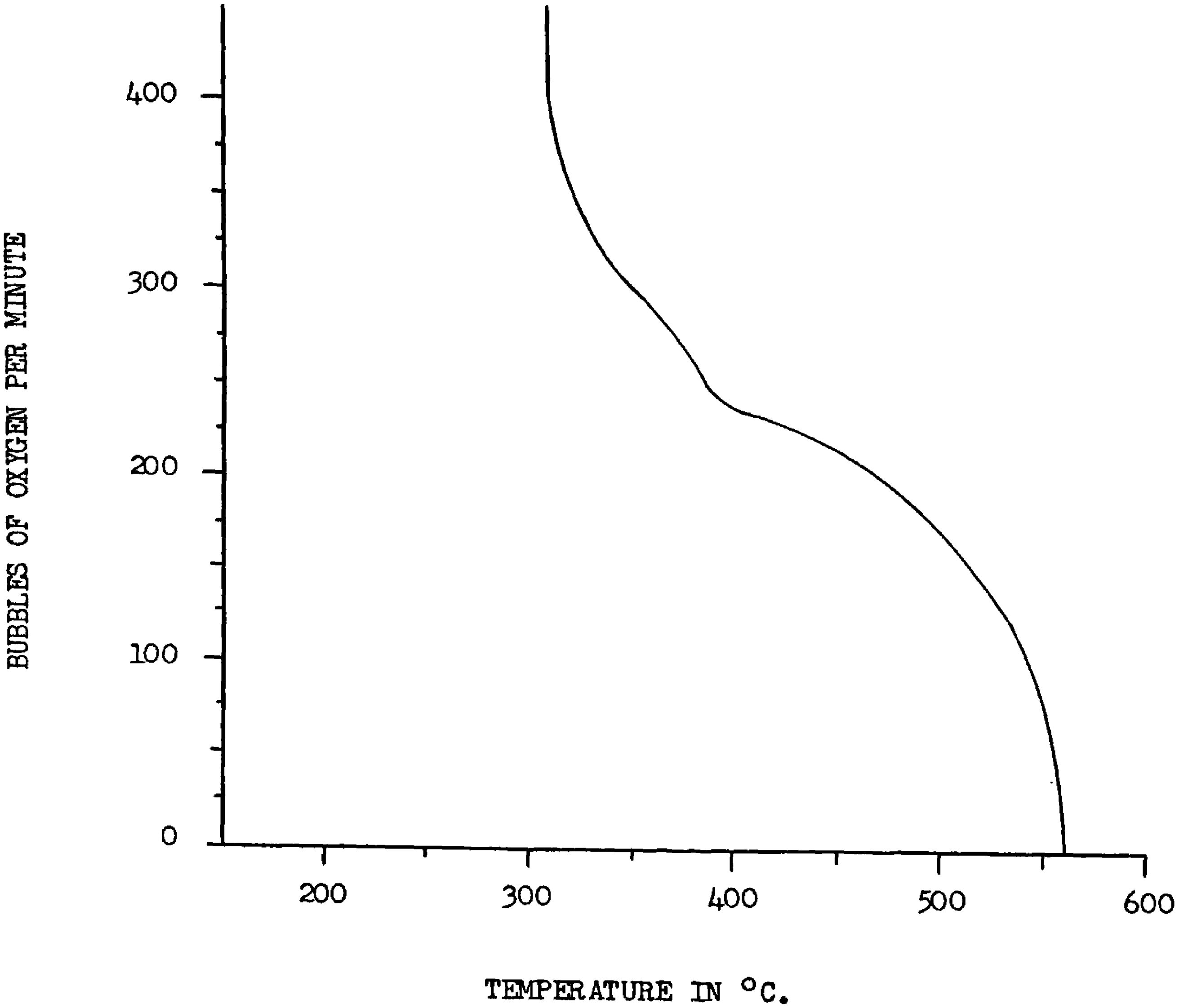

Figure 17. Autogeneous Ignition Curve for pine sample 4.

INDIVIDUAL SPECIES DATA SHEET

Pine No. 4 from Breitenbach	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	306	10	28	30.10	74
Intermediate ignition points	375	314	3	28	30.10	74
	350	320	5	28	30.10	75
	325	328	3	28	30.10	75
	300	352	6	28	30.10	75
	275	368	3	28	30.10	74
	250	382	4	28	30.10	74
	225	418	7	29	30.10	73
	200	466	17	27	29.75	71
	175	486	9	27	29.75	71
	150	512	3	27	29.75	71
	125	534	7	27	29.75	71
	100	552	8	27	29.75	71
	75	558	4	27	29.75	71
	50	558	3	27	29.75	71
	25	558	4	27	29.75	71
Upper ignition value	0	558	5	27	29.75	71
Ignition delay (135 seconds)	400	320	5	27	30.00	76

Dates tested: Jan. 30, Feb. 1, & Mar. 24, 1960

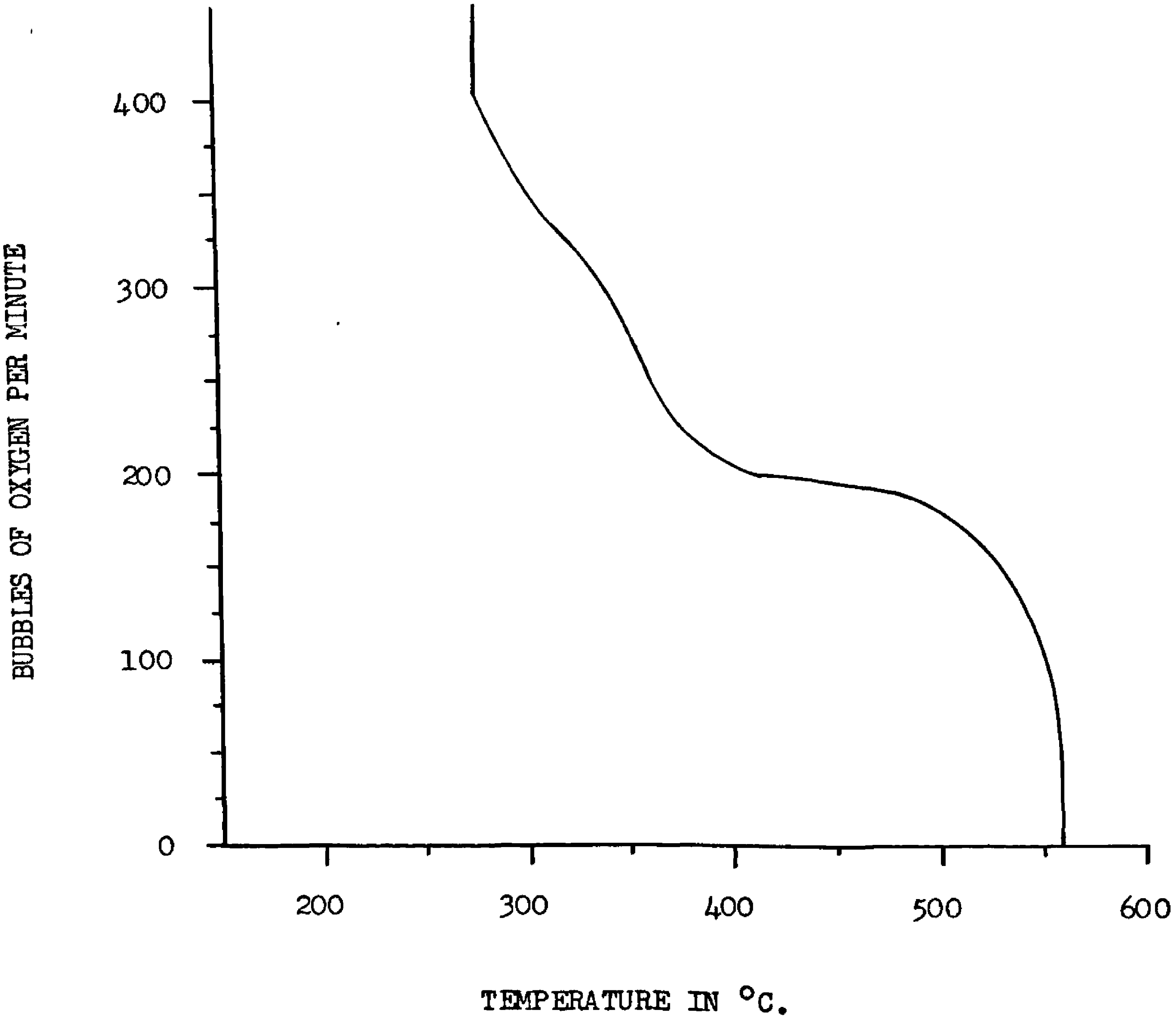

Figure 18. Autogeneous Ignition Curve for pine sample 5.

INDIVIDUAL SPECIES DATA SHEET

Pine No. 5 from Bitburg	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	278	10	29	29.95	76
Intermediate ignition points	375	290	4	29	29.95	76
	350	302	5	29	29.95	76
	325	320	4	30	29.95	75
	300	338	14	28	29.95	77
	275	352	5	27	29.85	78
	250	360	6	27	29.85	78
	225	374	5	28	29.85	77
	200	406	4	28	29.85	77
	175	508	7	28	29.85	77
	150	528	11	27	29.85	77
	125	546	5	28	29.90	77
	100	550	4	28	29.90	77
	75	558	3	28	29.90	77
	50	558	3	28	29.90	77
	25	558	3	28	29.90	77
Upper ignition value	0	558	5	28	29.90	77
Ignition delay (94 seconds)	400	320	5	27	30.00	76

Dates tested: Feb. 3 & Mar. 24, 1960

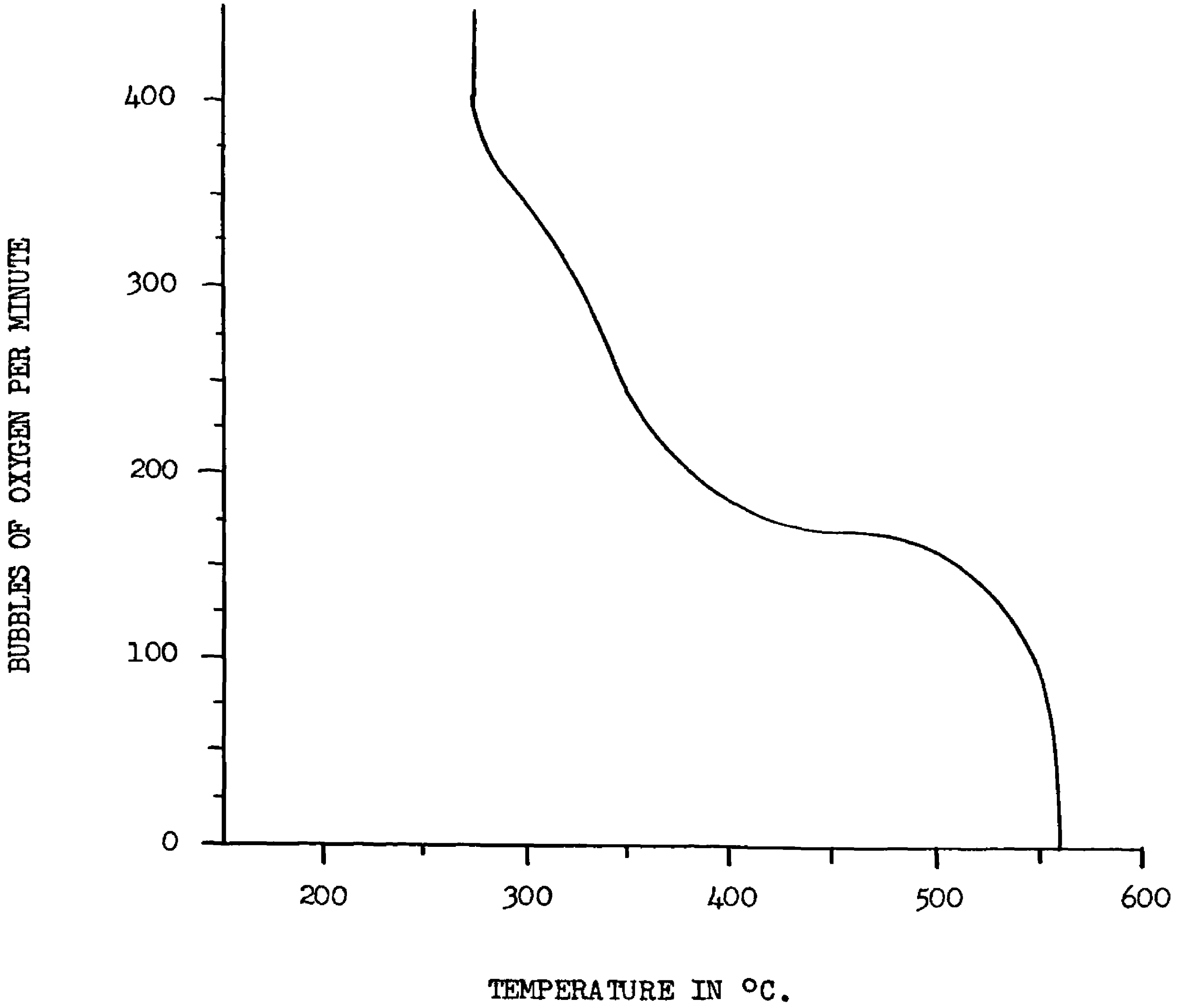

Figure 19. Autogeneous Ignition Curve for pine sample 6.

INDIVIDUAL SPECIES DATA SHEET

Pine No. 6 from Altengronau	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	274	9	27	30.15	75
Intermediate ignition points	375	282	4	27	30.15	75
	350	298	5	26	30.15	75
	325	310	3	26	30.15	75
	300	322	3	26	30.10	75
	275	336	5	26	30.10	75
	250	346	4	28	30.10	72
	225	358	4	28	30.10	72
	200	382	5	28	30.05	72
	175	436	11	27	30.25	76
	150	514	5	27	30.30	77
	125	532	5	27	30.30	77
	100	550	6	27	30.30	77
	75	554	4	27	30.30	77
	50	556	4	25	30.30	78
	25	556	5	25	30.30	78
Upper ignition value	0	558	11	27	30.30	77
Ignition delay (92 seconds)	400	320	5	27	30.30	76

Dates tested: Feb. 6, Mar. 18, & 24, 1960

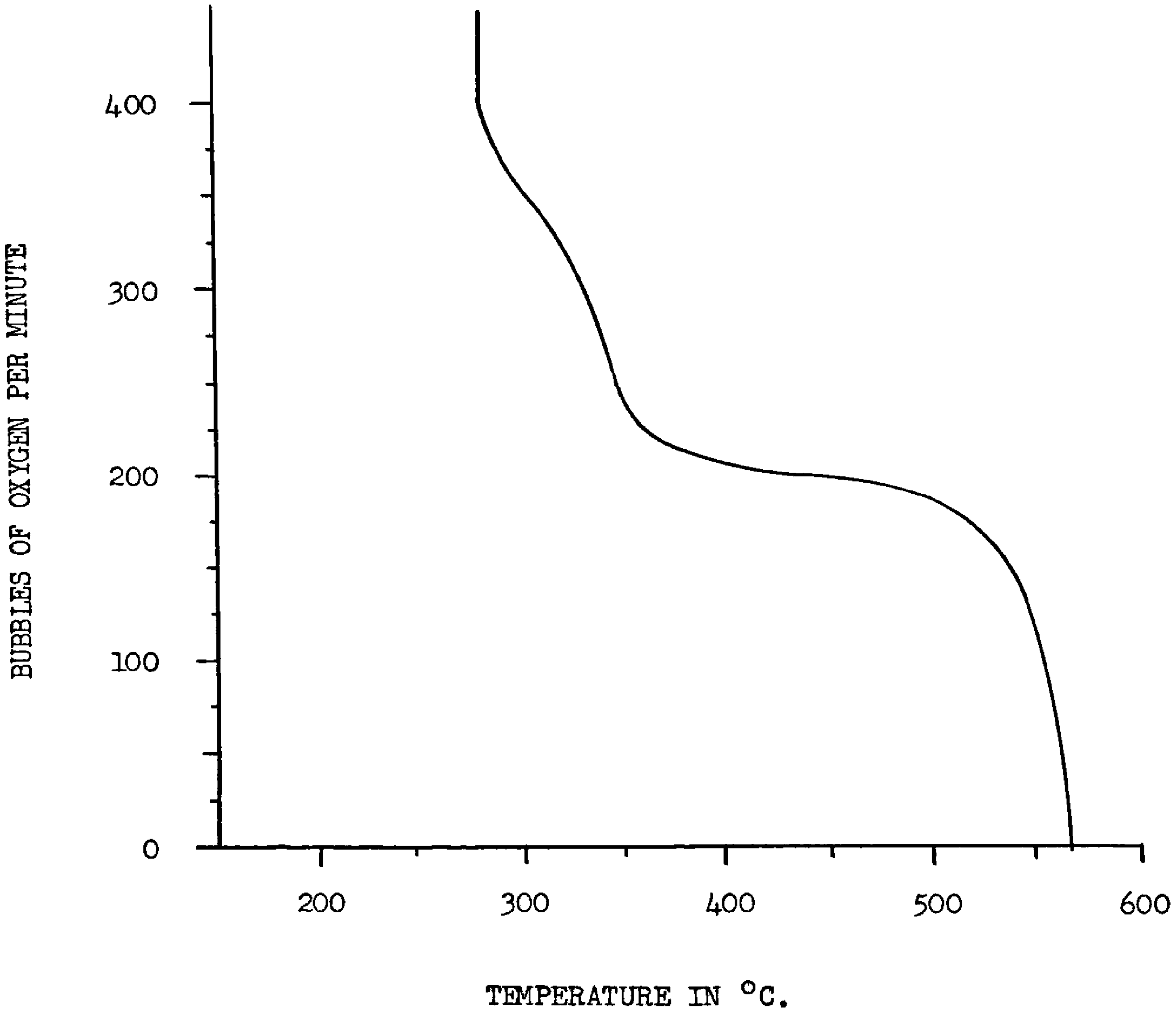

Figure 20. Autogeneous Ignition Curve for pine sample 7.

INDIVIDUAL SPECIES DATA SHEET

Pine No. 7 from Wolfgang	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	278	9	25	30.05	71
Intermediate ignition points	375	288	5	25	30.05	71
	350	300	4	25	30.05	71
	325	322	4	25	30.05	71
	300	328	6	25	30.05	71
	275	338	4	25	30.05	71
	250	344	3	25	30.05	71
	225	358	5	26	30.05	72
	200	428	10	25	30.25	76
	175	514	10	25	30.25	75
	150	538	6	25	30.25	76
	125	546	4	25	30.30	76
	100	554	4	25	30.30	77
	75	558	4	25	30.30	77
	50	560	5	27	30.30	75
	25	564	4	27	30.30	75
Upper ignition value	0	566	9	27	30.30	75
Ignition delay (102 seconds)	400	320	5	27	30.00	76

Dates tested: Feb. 13 & Mar. 24, 1960

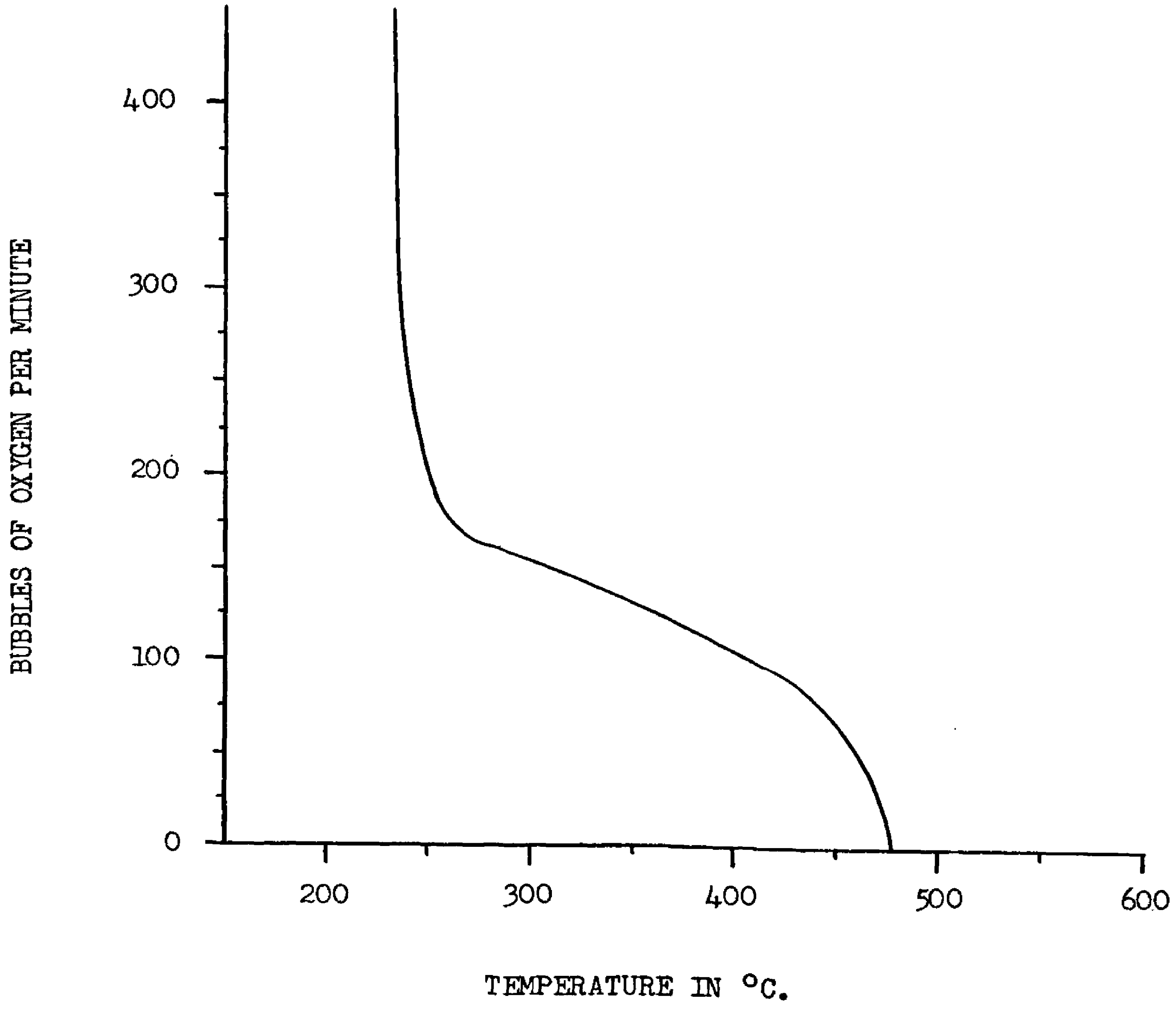

Figure 21. Autogeneous Ignition Curve for larch sample 1.

INDIVIDUAL SPECIES DATA SHEET

Larch No. 1 from Schlitz	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	234	5	28	30.05	72
Intermediate ignition points	375	234	4	28	30.05	72
	350	234	4	28	30.05	72
	325	236	3	28	30.05	72
	300	236	3	26	30.05	72
	275	238	4	26	30.05	72
	250	240	3	26	30.05	72
	225	244	3	26	30.05	72
	200	248	12	28	30.05	72
	175	260	3	26	30.05	72
	150	308	12	25	30.05	72
	125	362	7	25	30.05	73
	100	414	9	26	30.05	76
	75	446	4	26	30.10	77
	50	462	5	26	30.10	77
	25	468	3	26	30.10	75
Upper ignition value	0	470	6	26	30.10	75
Ignition delay (44 seconds)	400	320	5	26	30.10	75

Dates tested: Feb. 13 & 14, 1960

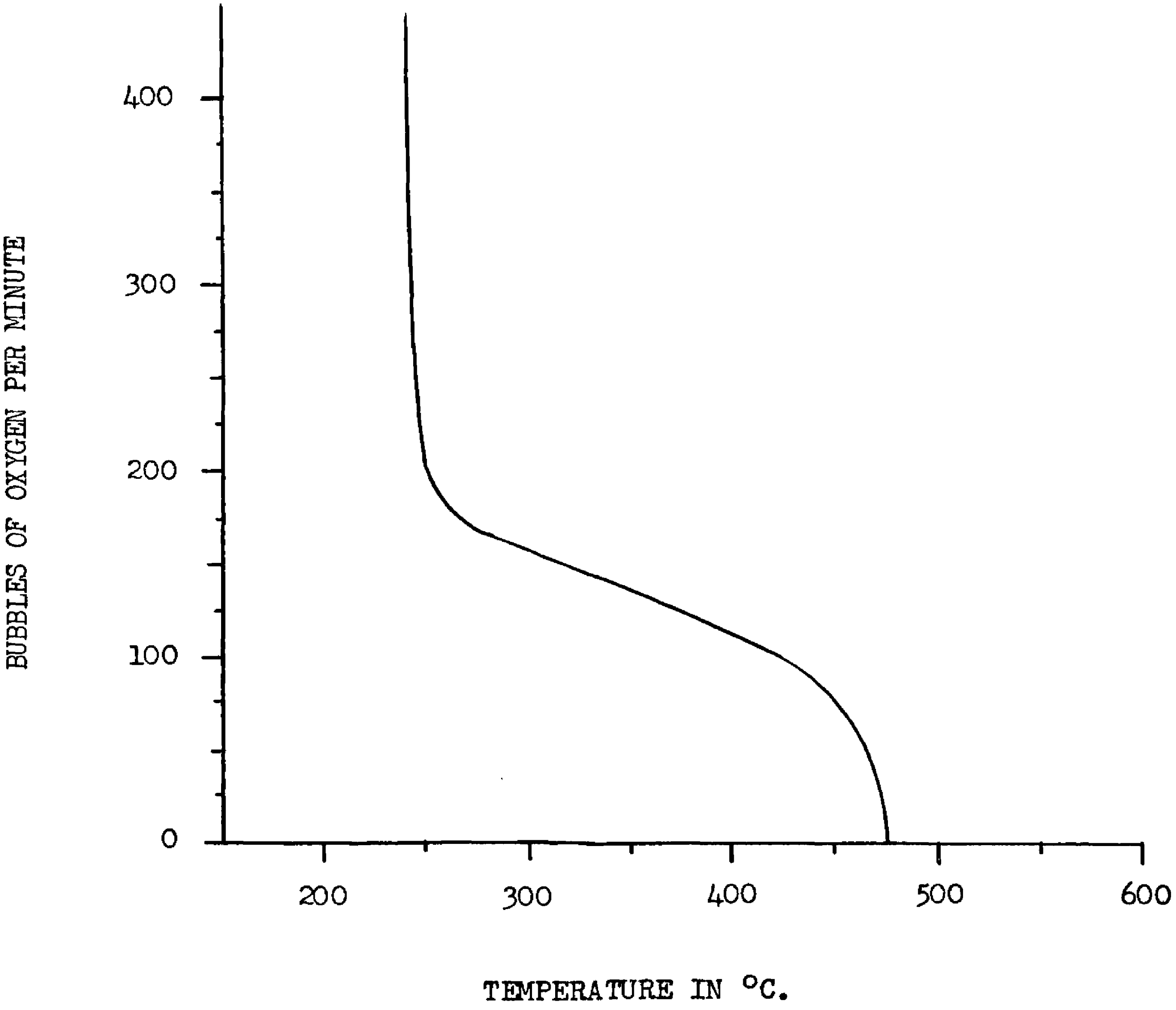

Figure 22. Autogeneous Ignition Curve for larch sample 2.

INDIVIDUAL SPECIES DATA SHEET

Larch No. 2 from Schweckhausen	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	238	6	26	30.40	74
Intermediate ignition points	375	238	3	26	30.40	74
	350	240	3	26	30.40	74
	325	242	3	26	30.40	74
	300	244	4	26	30.40	74
	275	244	4	26	30.40	74
	250	244	4	26	30.40	74
	225	246	3	26	30.40	74
	200	248	4	26	30.40	74
	175	268	8	27	30.40	75
	150	316	5	29	30.25	75
	125	368	6	29	30.25	75
	100	420	6	27	30.20	75
	75	446	4	27	30.20	75
	50	466	4	26	30.20	72
	25	470	5	26	30.20	72
Upper ignition value	0	472	4	26	30.20	72
Ignition delay (47 seconds)	400	320	5	26	30.10	75

Dates tested: Feb. 17, 1960

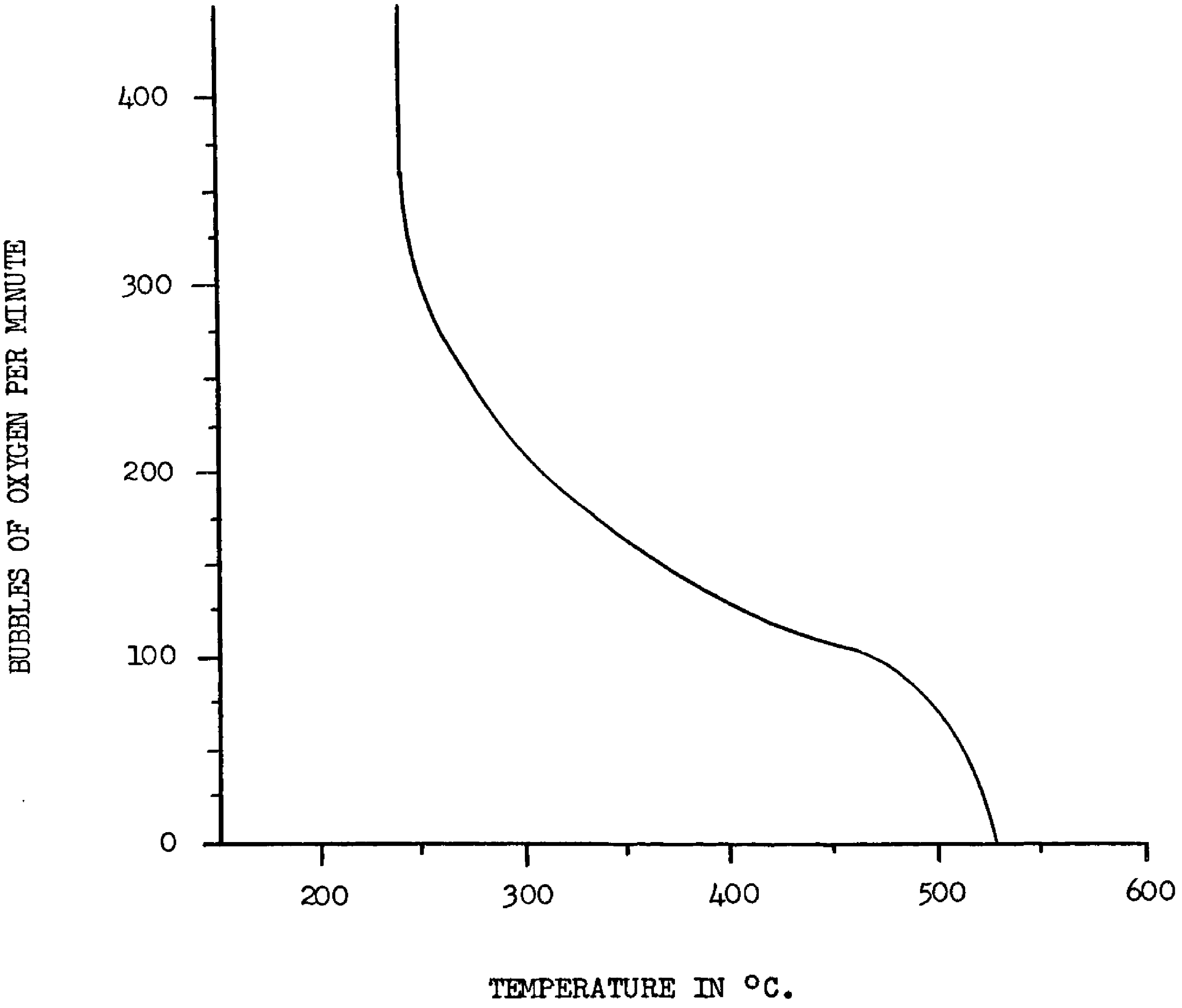

Figure 23. Autogeneous Ignition Curve for larch sample 3.

INDIVIDUAL SPECIES DATA SHEET

Larch No. 3 from Czechoslavakia	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	240	6	28	29.95	71
Intermediate ignition points	375	240	3	28	29.95	71
	350	242	3	26	29.95	72
	325	244	3	26	29.90	72
	300	248	3	26	29.90	72
	275	264	4	25	30.25	73
	250	276	7	25	30.25	73
	225	282	4	25	30.25	73
	200	306	9	25	30.25	71
	175	342	6	26	30.25	70
	150	368	5	26	30.25	70
	125	392	4	25	30.25	71
	100	474	17	27	29.85	75
	75	496	9	27	29.85	75
	50	514	14	27	29.85	75
	25	522	6	27	29.85	75
Upper ignition value	0	530	11	27	29.85	75
Ignition delay (49 seconds)	400	320	5	26	30.10	75

Dates tested: Feb. 18, 20, & Mar. 5, 1960

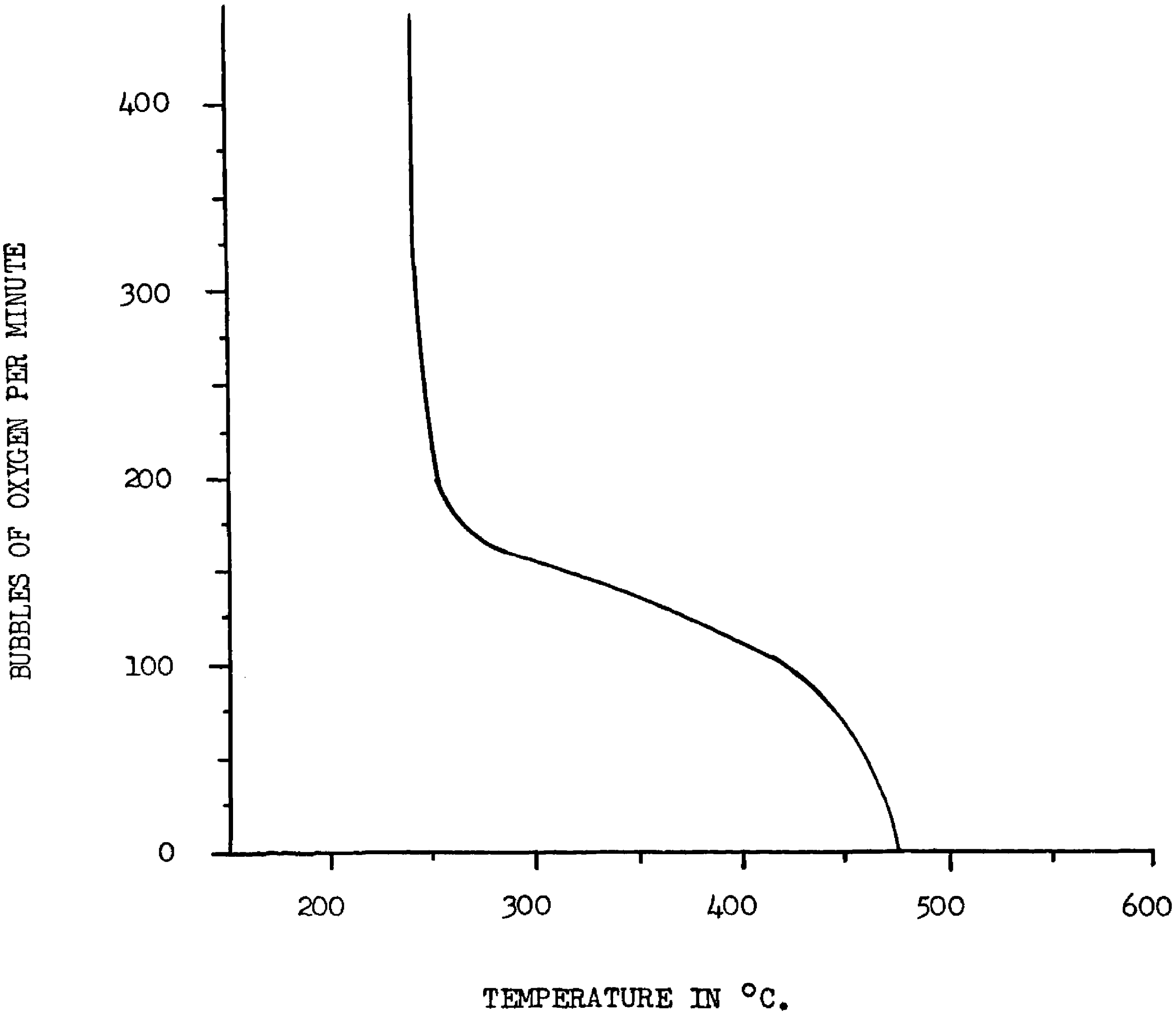

Figure 24. Autogeneous Ignition Curve for larch sample 4.

INDIVIDUAL SPECIES DATA SHEET

Larch No. 4 from Bad Homburg	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	240	5	25	30.25	71
Intermediate ignition points	375	240	3	25	30.25	71
	350	240	4	25	30.25	71
	325	240	3	25	30.25	71
	300	242	3	25	30.25	71
	275	244	3	25	30.25	71
	250	246	3	25	30.25	71
	225	248	4	25	30.25	71
	200	250	5	25	30.25	70
	175	256	4	25	30.20	71
	150	320	13	25	30.20	71
	125	374	9	26	30.05	68
	100	422	9	27	30.05	68
	75	446	6	27	30.05	68
	50	464	8	27	30.05	68
	25	470	5	27	30.20	65
Upper ignition value	0	474	6	27	30.20	65
Ignition delay (49 seconds)	400	320	5	26	30.10	75

Dates tested: Feb. 20 & Mar. 2, 1960

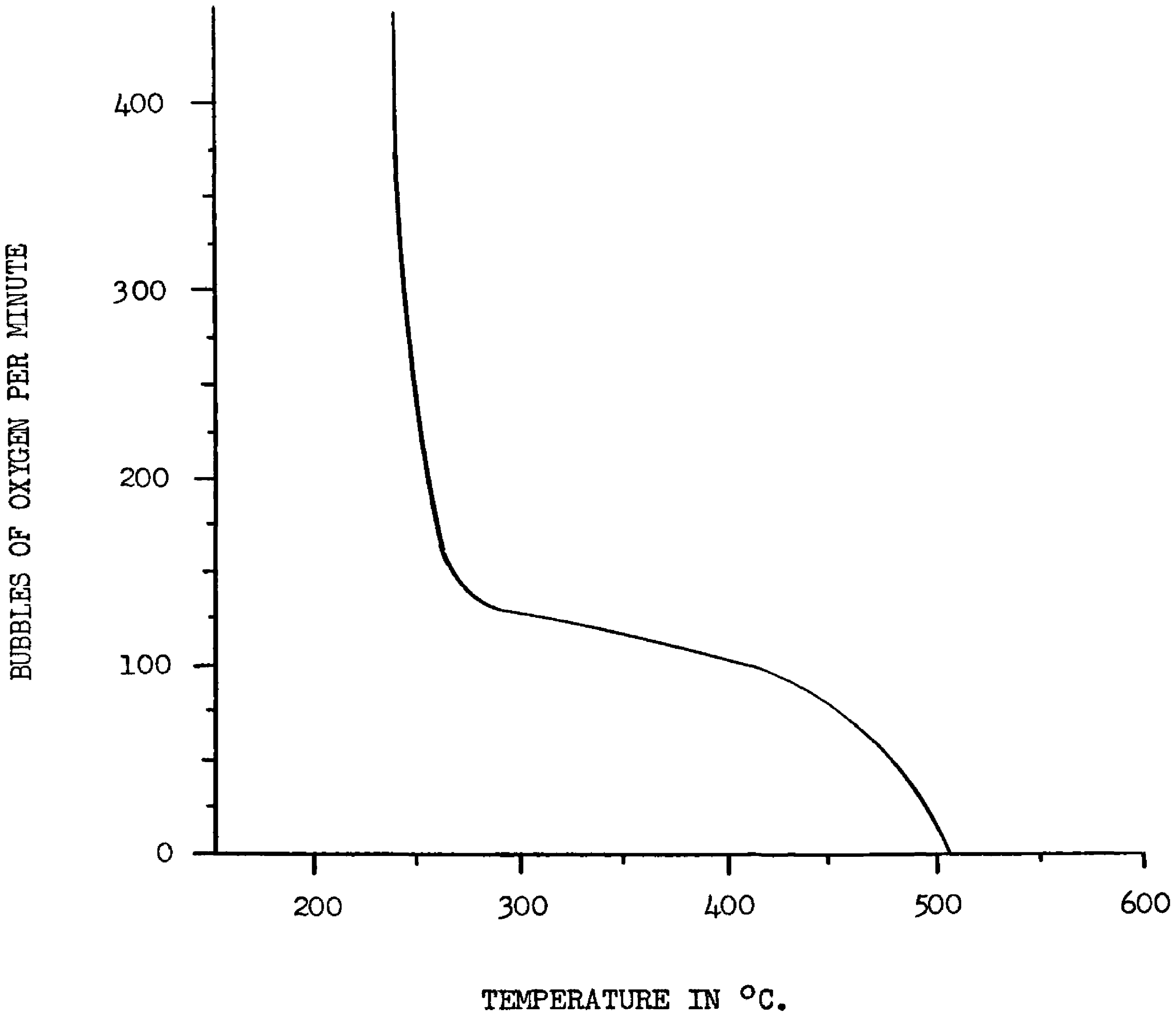

Figure 25. Autogeneous Ignition Curve for larch sample 5.

INDIVIDUAL SPECIES DATA SHEET

Larch No. 5 from Helmstedt	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	238	4	25	30.10	71
Intermediate ignition points	375	238	3	25	30.10	71
	350	240	3	25	30.10	71
	325	242	4	25	30.05	70
	300	244	4	25	30.05	70
	275	246	3	25	30.05	70
	250	248	4	25	30.05	70
	225	252	3	27	30.05	72
	200	254	4	27	30.05	72
	175	258	3	29	30.05	75
	150	264	4	29	30.05	75
	125	320	13	27	29.90	71
	100	412	6	27	29.85	74
	75	454	7	27	29.85	75
	50	482	8	27	29.85	75
	25	494	5	28	29.85	75
Upper ignition value	0	506	12	28	29.85	75
Ignition delay (48 seconds)	400	320	5	26	30.10	75

Dates tested: Feb. 21, Mar. 4, & 5, 1960

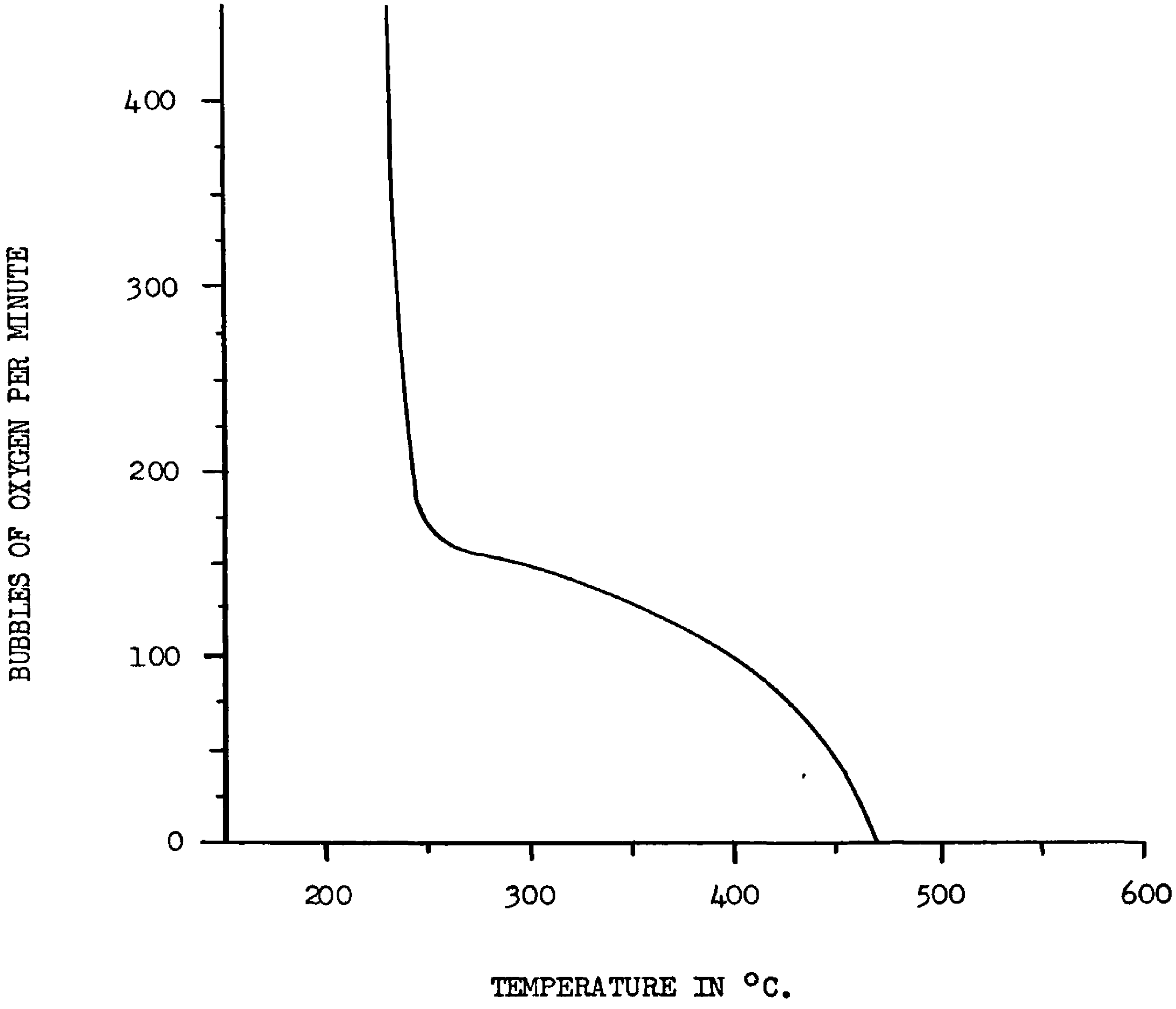

Figure 26. Autogeneous Ignition Curve for larch sample 6.

INDIVIDUAL SPECIES DATA SHEET

Larch No. 6 from Nastätten	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	232	7	26	29.75	72
Intermediate ignition points	375	232	3	27	29.75	72
	350	234	3	27	29.75	72
	325	236	3	27	29.75	72
	300	238	4	27	29.75	72
	275	240	3	26	30.10	70
	250	242	4	26	30.10	70
	225	242	3	26	30.10	70
	200	244	3	25	30.10	70
	175	246	4	25	30.10	70
	150	310	16	27	30.15	68
	125	362	7	27	30.15	67
	100	400	7	26	30.05	68
	75	430	7	26	30.05	68
	50	452	8	26	30.05	68
	25	462	6	27	30.20	65
Upper ignition value	0	470	8	27	30.20	65
Ignition delay (43 seconds)	400	320	5	26	30.10	75

Dates tested: Feb. 24 & Mar. 2, 1960

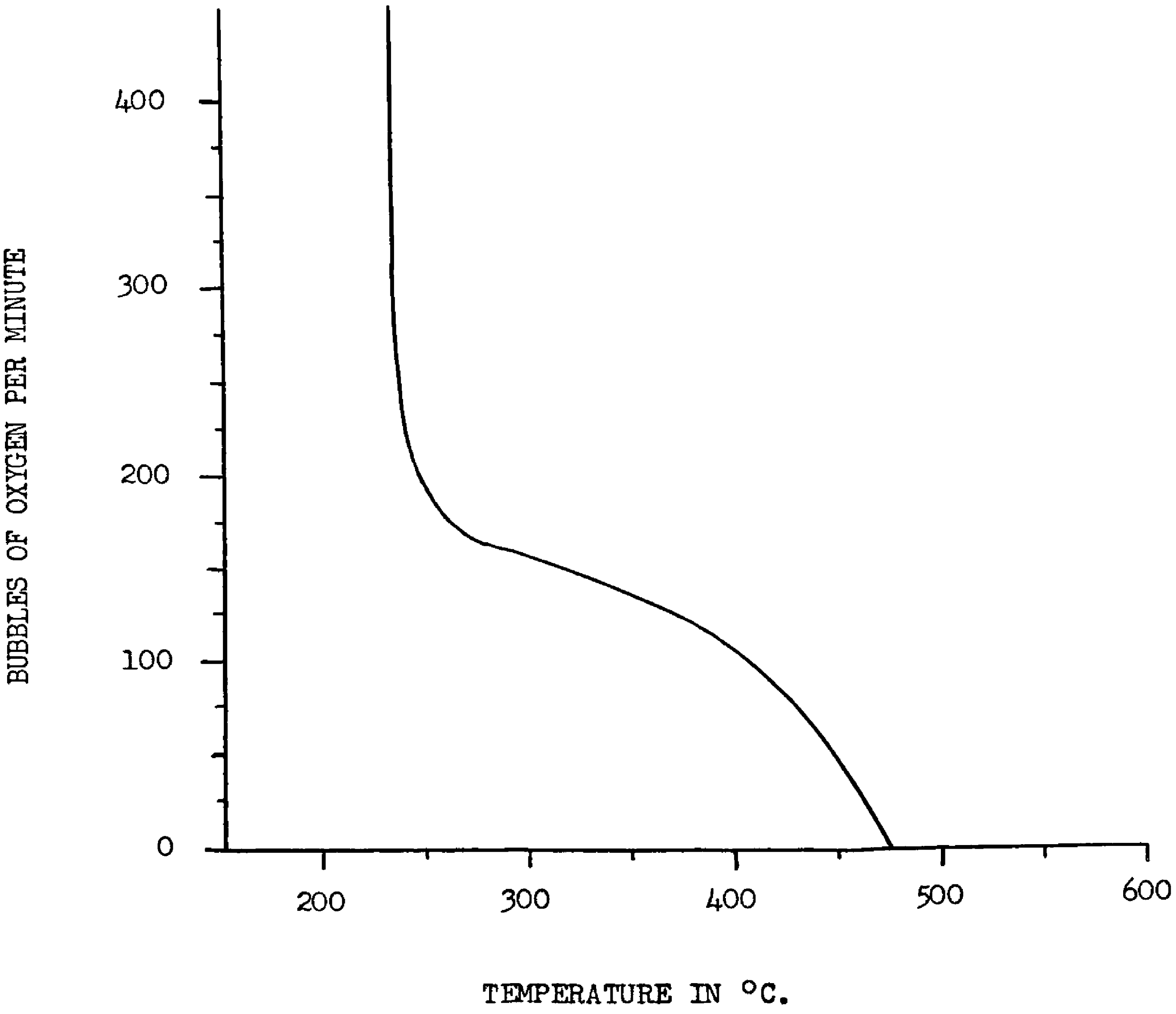

Figure 27. Autogeneous Ignition Curve for larch sample 7.

INDIVIDUAL SPECIES DATA SHEET

Larch No. 7 from Salem	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	234	5	25	30.05	73
Intermediate ignition points	375	234	3	25	30.05	73
	350	234	3	27	30.05	73
	325	234	3	27	30.05	73
	300	234	5	27	30.05	73
	275	236	3	29	30.05	73
	250	238	3	29	30.05	73
	225	238	3	29	30.05	73
	200	248	6	29	30.05	73
	175	262	8	27	30.15	68
	150	314	7	27	30.15	68
	125	372	8	26	30.05	68
	100	406	6	26	30.05	68
	75	432	7	27	30.05	68
	50	452	7	29	30.05	68
	25	464	6	27	30.20	65
Upper ignition value	0	474	6	27	30.20	65
Ignition delay (44 seconds)	400	320	5	26	30.10	75

Dates tested: Feb. 21 & Mar. 2, 1960

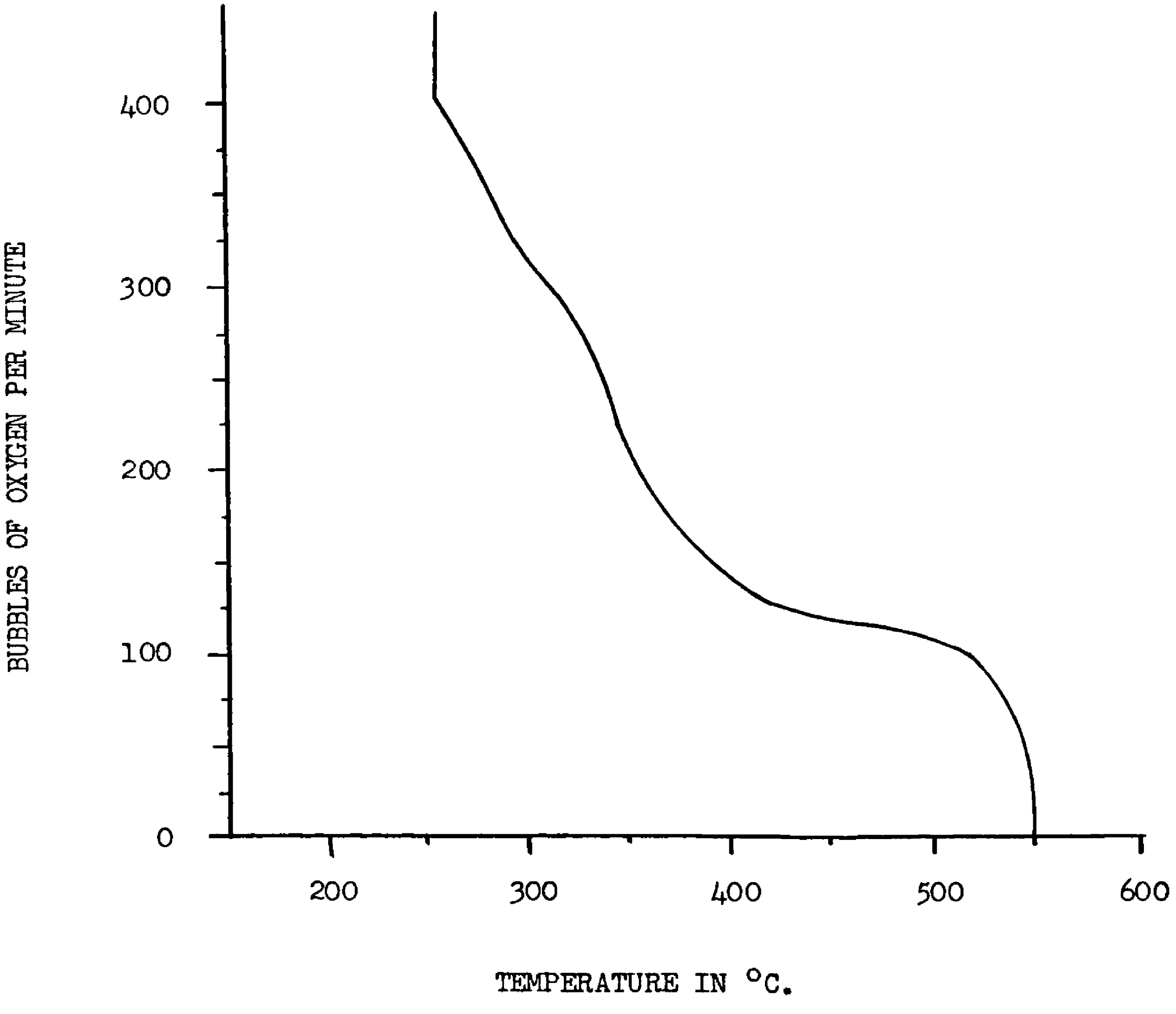

Figure 28. Autogeneous Ignition Curve for fir sample 1.

INDIVIDUAL SPECIES DATA SHEET

Fir No. 1 from Stockach	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	256	13	26	29.95	76
Intermediate ignition points	375	270	4	26	29.95	76
	350	282	6	26	29.95	76
	325	296	5	26	29.95	76
	300	310	5	27	30.15	75
	275	326	5	26	30.20	76
	250	338	5	26	30.20	76
	225	346	4	26	30.20	76
	200	354	5	27	30.20	75
	175	370	4	27	30.20	75
	150	388	4	27	30.20	75
	125	426	5	27	30.20	75
	100	514	6	26	29.95	75
	75	534	5	26	29.95	75
	50	550	4	26	29.95	75
	25	550	3	26	29.95	75
Upper ignition value	0	550	5	26	29.95	75
Ignition delay (117 seconds)	400	320	5	26	29.95	75

Dates tested: Mar. 29, 31, & Apr. 1, 1960

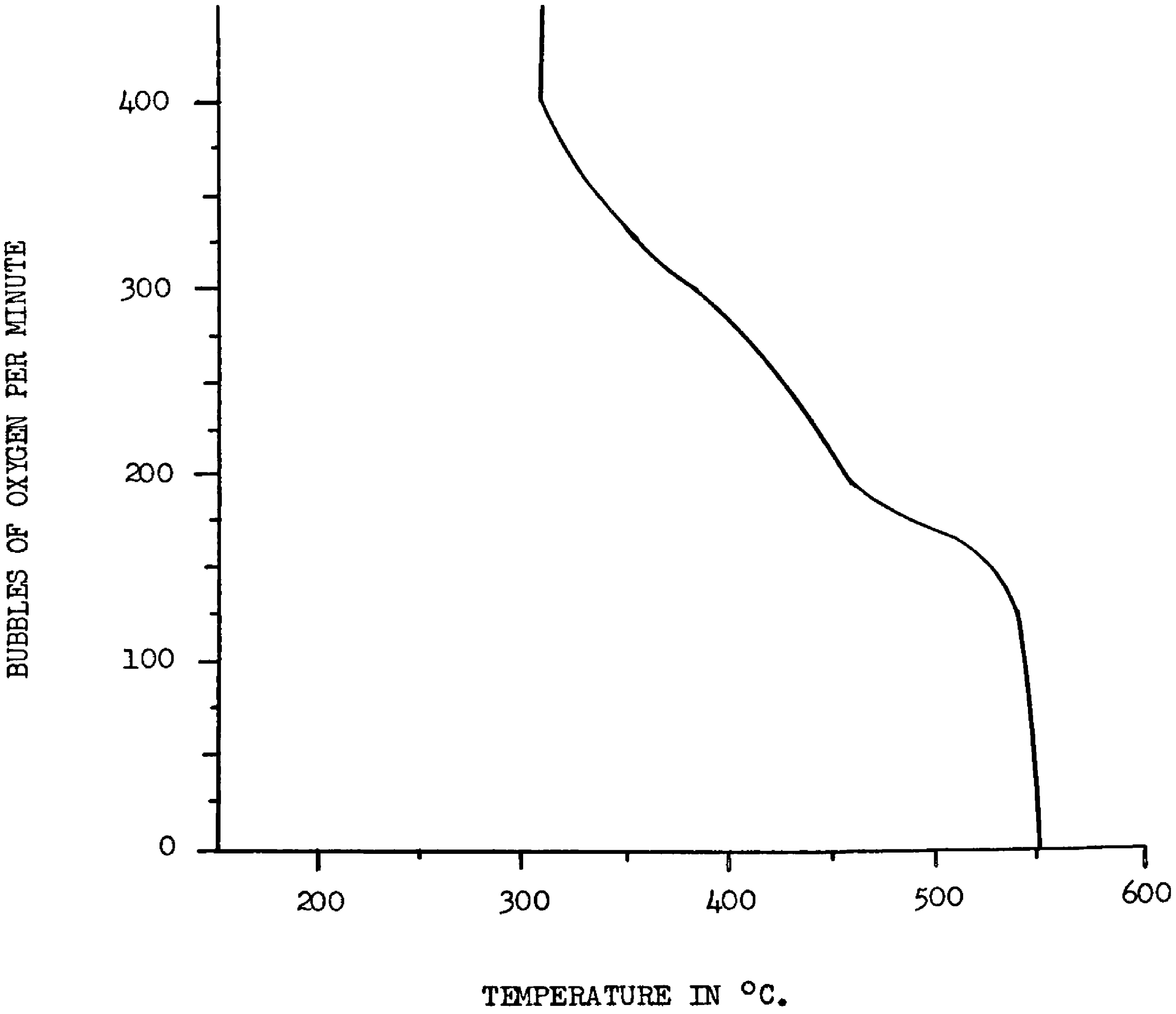

Figure 29. Autogeneous Ignition Curve for fir sample 2.

INDIVIDUAL SPECIES DATA SHEET

Fir No. 2 from Erdmannshausen	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	316	12	27	30.25	80
Intermediate ignition points	375	324	6	25	30.10	75
	350	338	5	25	30.10	75
	325	356	5	25	30.10	75
	300	384	9	25	30.10	74
	275	406	5	26	30.10	74
	250	426	10	25	30.05	79
	225	444	6	25	30.05	79
	200	458	10	25	30.05	79
	175	486	7	25	30.05	79
	150	524	10	25	30.05	80
	125	542	5	27	30.10	79
	100	544	5	27	30.10	79
	75	544	4	27	30.10	79
	50	546	3	27	30.10	80
	25	548	4	27	30.10	80
Upper ignition value	0	550	13	27	30.10	80
Ignition delay (132 seconds)	400	320	5	26	29.95	75

Dates tested: Mar. 21 & 22, 1960

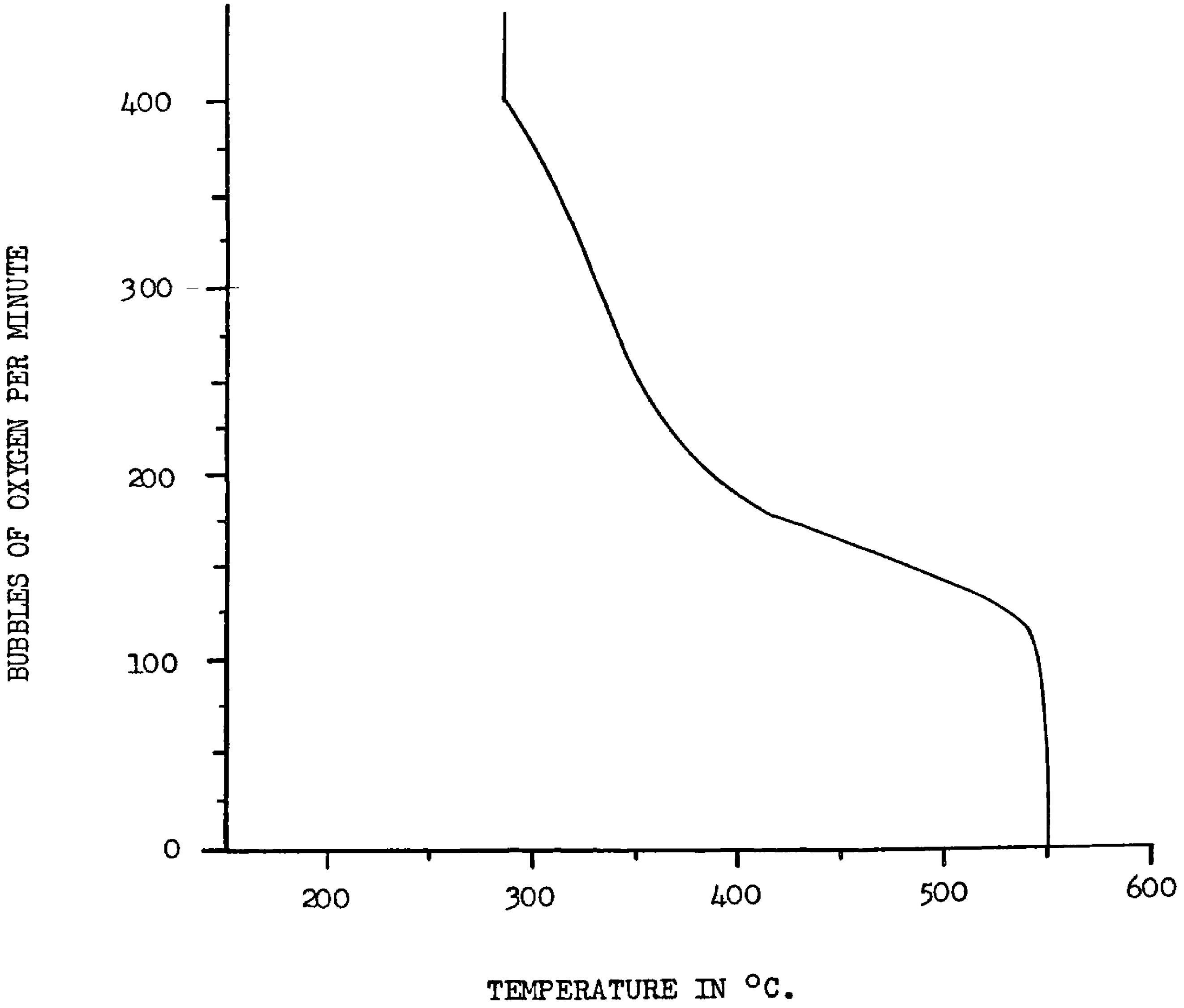

Figure 30. Autogeneous Ignition Curve for fir sample 3.

INDIVIDUAL SPECIES DATA SHEET

Fir No. 3 from Daun	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	286	5	29	29.90	73
Intermediate ignition points	375	300	5	25	29.95	73
	350	312	4	25	29.95	73
	325	322	5	27	30.15	75
	300	330	8	27	30.15	75
	275	342	4	27	30.15	75
	250	352	7	27	30.15	75
	225	364	4	27	30.20	75
	200	386	4	27	30.20	75
	175	430	6	26	30.20	76
	150	478	11	26	30.20	76
	125	544	6	26	30.20	76
	100	548	4	26	29.95	75
	75	548	3	25	29.95	76
	50	550	3	25	29.95	76
	25	550	3	26	29.95	75
Upper ignition value	0	550	5	26	29.95	75
Ignition delay (119 seconds)	400	320	5	26	29.95	75

Dates tested: Mar. 29, 31, & Apr. 1, 1960

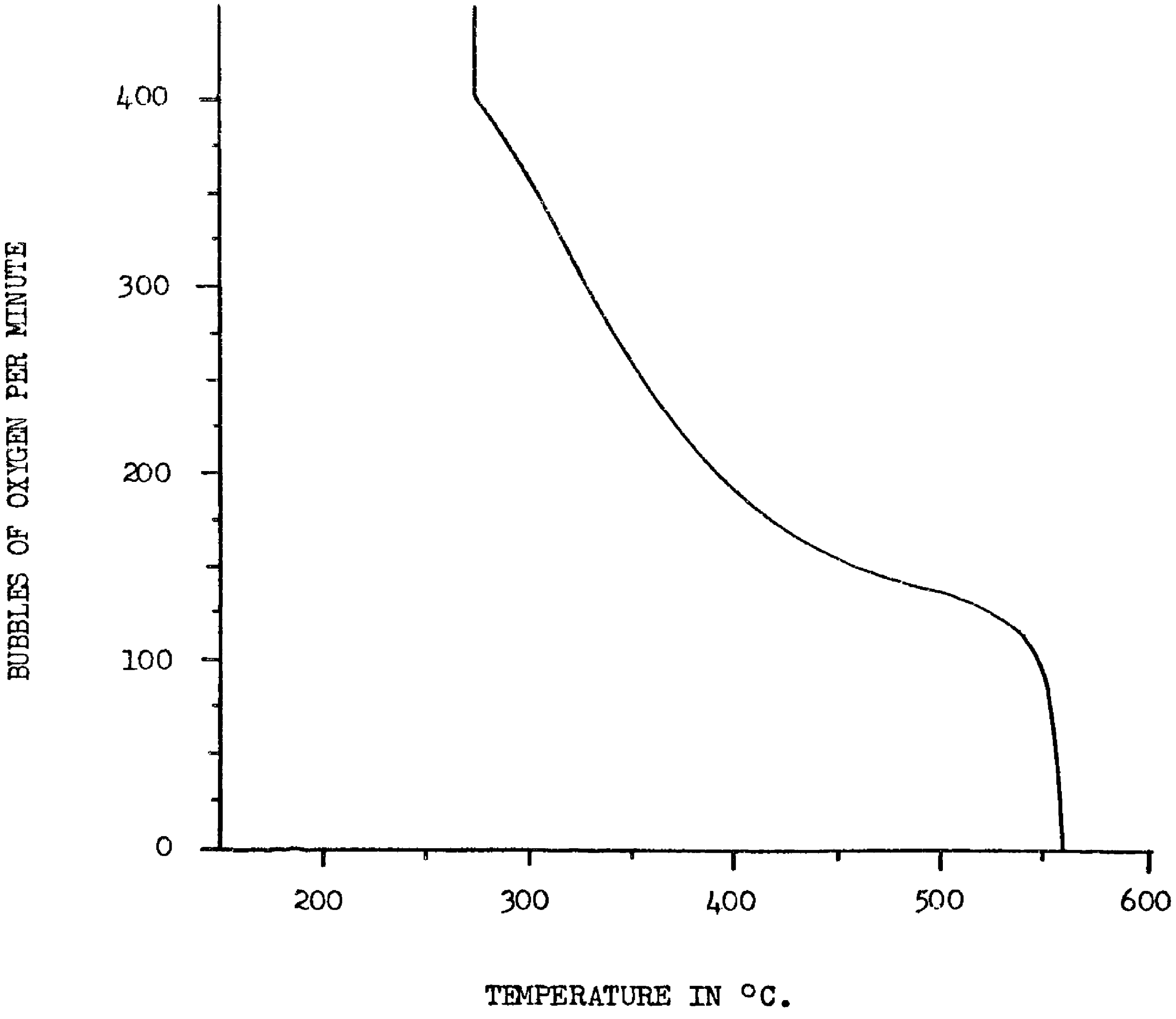

Figure 31. Autogeneous Ignition Curve for fir sample 4.

INDIVIDUAL SPECIES DATA SHEET

Fir No. 4 from Kirchberg	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	274	11	26	29.95	75
Intermediate ignition points	375	288	6	26	29.95	75
	350	304	6	26	29.95	75
	325	316	5	26	29.95	75
	300	328	6	27	30.15	75
	275	344	4	27	30.15	75
	250	350	5	27	30.15	75
	225	374	4	27	30.20	75
	200	390	5	27	30.20	75
	175	422	6	26	30.20	76
	150	458	6	26	30.20	76
	125	532	6	26	30.20	76
	100	552	5	25	29.95	76
	75	554	3	25	29.95	76
	50	556	3	26	29.95	75
	25	558	4	26	29.95	75
Upper ignition value	0	560	5	26	29.95	75
Ignition delay (106 seconds)	400	320	5	26	29.95	75

Dates tested: Mar. 29, 31, & Apr 1, 1960

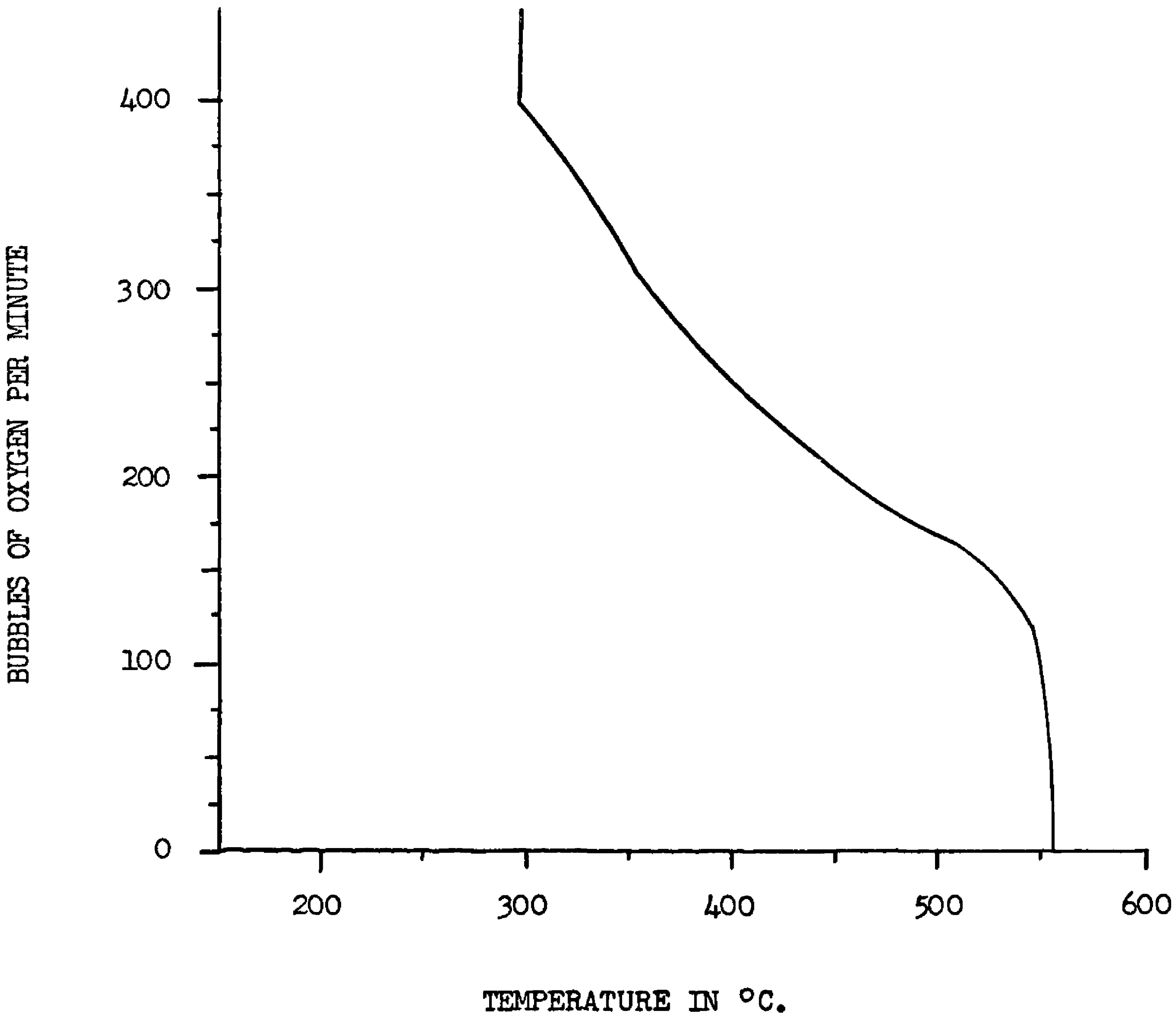

Figure 32. Autogeneous Ignition Curve for fir sample 5.

INDIVIDUAL SPECIES DATA SHEET

Fir No. 5 from Obereimer	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	296	12	27	30.35	75
Intermediate ignition points	375	314	5	27	30.35	75
	350	328	5	27	30.35	75
	325	344	5	27	30.35	75
	300	360	6	26	29.95	76
	275	378	5	26	29.95	76
	250	404	6	26	29.95	76
	225	428	5	27	30.35	75
	200	454	5	26	30.35	76
	175	484	6	26	30.35	76
	150	524	7	26	30.35	76
	125	542	5	27	30.35	75
	100	550	3	26	29.95	75
	75	552	4	26	29.95	75
	50	552	3	26	29.95	75
	25	554	3	26	29.95	75
Upper ignition value	0	554	5	26	29.95	75
Ignition delay (120 seconds)	400	320	5	26	29.95	75

Dates tested: Mar. 29, 31, & Apr. 1, 1960

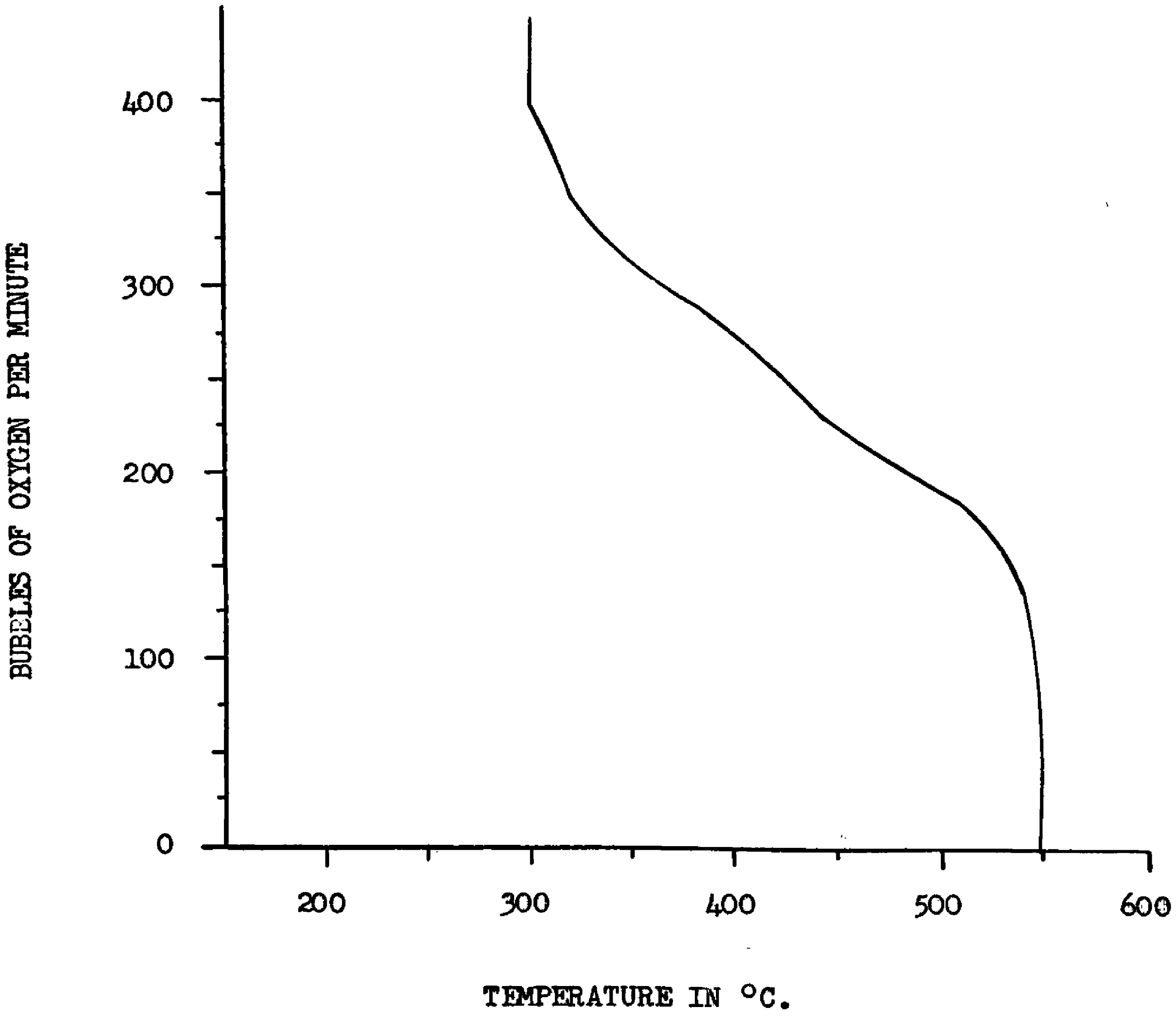

Figure 33. Autogeneous Ignition Curve for fir sample 6.

INDIVIDUAL SPECIES DATA SHEET

Fir No. 6 from Bad Homburg	Bubbles of O_2/min.	Temp. (°C.)	Number of tests	Relative humidity	Barometer reading (in. of Hg)	Room temp. (°F.)
Self ignition point	400	298	5	26	29.90	73
	375	310	4	25	29.95	73
	350	320	5	25	29.95	73
	325	338	6	26	29.95	74
	300	368	5	26	29.95	75
	275	398	6	26	29.95	75
	250	424	6	27	30.35	75
	225	454	5	27	30.35	75
	200	488	7	26	30.35	76
	175	516	5	26	30.35	76
	150	532	6	26	30.35	76
	125	540	5	26	30.35	76
	100	544	5	26	29.95	75
	75	546	3	26	29.95	75
	50	546	3	25	29.95	76
	25	546	3	26	29.95	75
Upper ignition value	0	546	7	26	29.95	75
Ignition delay (125 seconds)	400	320	5	26	29.95	75

Dates tested: Mar. 29, 31, & Apr. 1, 1960

TABLE XI

STATISTICAL FORMULAS USED

Coefficient of regression (b)

$$b = \frac{\Sigma XY - \frac{\Sigma X \Sigma Y}{n}}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}$$

Where:

Σ = Summation
X = Variate elevation
Y = Variate comparison number
n = Total number of items

Correlation coefficient (r)

$$r = \frac{\frac{\Sigma XY - \frac{\Sigma X \Sigma Y}{n}}{n}}{\sqrt{\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}{n}} \times \sqrt{\frac{\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}}{n}}}$$

Standard error of the estimate (SE_e)

$$SE_e = \sqrt{\frac{\Sigma(Y^2) - \frac{(\Sigma Y)^2}{n} - \frac{\left[\Sigma XY - \frac{(\Sigma X \Sigma Y)}{n}\right]^2}{\Sigma(X^2) - \frac{(\Sigma X)^2}{n}}}{n - 2}}$$

Standard error of the regression coefficient (SE_b)

$$SE_b = \frac{SE_e}{\sqrt{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}}$$

TABLE XI (Continued)

Tests of significance

$$\text{Sample } t = \frac{b}{SEb}$$

Comparing sample t with $t_{.05}$ and $t_{.01}$ from Student's "t" table for (n - 2) degrees of freedom.

Snedecor's F test

$$F = \frac{\text{Greater Variance Estimate}}{\text{Lesser Variance Estimate}}$$

Where:
The Greater Variance Estimate = the regression variance and the Lesser Variance Estimate = SE_e variance.

Total sum of squares (Tot. Σ of Sq.)

$$\text{Tot. } \Sigma \text{ of Sq.} = \Sigma Y^2 - \frac{(\Sigma Y)^2}{n}$$

Regression sum of squares (Reg. Σ of Sq.)

$$\text{Reg. } \Sigma \text{ of Sq.} = \frac{\left[\Sigma XY - \frac{\Sigma X \Sigma Y}{n}\right]^2}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}$$

Standard error of the estimate sum of squares (SE_e Σ of Sq.)

$$SE_e \ \Sigma \text{ of Sq.} = \left[\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}\right] - \frac{\left[\Sigma XY - \frac{\Sigma X \Sigma Y}{n}\right]^2}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}$$

Variance

$$\text{Variance} = \frac{\text{Sum of squares}}{\text{Degrees of freedom}}$$