THE DETERMINATION OF IGNITION TEMPERATURES OF ORGANIC MATERIALS

by

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TABLE OF CONTENTS

		Page
I.	INTRODUCTION.	1
II.	STATEMENT OF PROBLEM.	5
III.	EQUIPMENT	6
IV.	OPERATION OF EQUIPMENT.	18
V.	PRELIMINARY TESTS	21
VI.	TESTS OF PAPER.	26
VII.	TESTS OF WOOD	57
VIII.	TESTS OF FABRICS.	72
IX.	CONCLUSIONS	88
X.	BIBLIOGRAPHY.	94
XI.	APPENDIX I - OVEN CURVES.	95
XII.	APPENDIX II - PAPER SAMPLES	111

LIST OF TABLES

Table		Page
1.	Yellow Copy Paper and Newspaper Data. . . .	36
2.	Paper Data.	43
3.	Ponderosa Pine Data..	62
4.	Wood Data..	64
5.	Effect of Relative Humidity of the Air on Ignition Temperature.	67
6.	Fabric Data..	77

ILLUSTRATIONS

Figure		Page
1.	Oven Assembly.	7
2.	A. C. Wiring Diagram..	8
3.	Arrangement of Sample and Thermocouples. . .	11
4.	Interior of Oven..	12
5.	Cams for Constant Rates of Temperature Rise.	13
6.	Apparatus Used in Determinations..	14
7.	Typical Ignition Curves - Bluewhite Newsprint.	15
8.	Typical Ignition Curves - Toilet Tissue and Oiled Canary Citrus.	16
9.	Typical Ignition Curves - White Cotton Flannel and Oregon Big Leaf Maple.	17
10.	Prepared Samples in Wire Racks..	22
11.	Data Sheet..	25
12.	Curves Obtained from Tests of Yellow Copy Paper, Variation of Air Flow and Rate of Temperature Rise.	28
13.	Curves Obtained from Tests of Yellow Copy Paper, Variation of Sample Weight.	29
14.	Curves Obtained from Tests of Newspaper, Variation of Air Flow and Sample Weight.. . . .	33
15.	Curve Obtained from Tests of Newspaper, Variation of Rate of Temperature Rise..	34
16.	Copy of Data Sheet sent to Sample Donors.. .	41
17.	Distribution of Ignition Temperatures. . . .	53
18.	Curves Obtained from Tests of Ponderosa Pine.	58
19.	Curves Obtained from Tests of Ponderosa Pine and Oregon Oak..	59

ILLUSTRATIONS (Continued)

Figure		Page
20.	Curves Obtained from Tests of White Cotton Flannel.	73
21.	Curves Obtained from Tests of Wool Fabric. .	74
22.	Curves Obtained from Tests of Linen Fabric..	75
23.	Curves Obtained from Tests of Acetate Rayon.	76

I.
INTRODUCTION

THE DETERMINATION OF IGNITION TEMPERATURES OF ORGANIC MATERIALS

INTRODUCTION

The ignition phenomenon has been the object of research, study, and experimentation for over a century. Investigators as early as 1813 (3) reported experiments with the ignition of phosphorus, sulphur, and gunpowder, while more recent work has been done on the ignition of gases and of fuels such as coal and oil. As the danger from dust explosions became apparent, the conditions necessary for the explosion of an air and dust mixture were investigated, and with the increasing importance of plastics, tests are being made on the various types to determine their ignition temperatures. Some tests have been made on solid organic materials like paper, fabrics, and wood, but there is much room for additional experimentation.

Although an extensive body of data has been accumulated, many of the results are inconclusive. First, there is a wide divergence in the definitions of ignition as a phenomenon and of the critical temperature associated with it, that is, the ignition temperature. Second, the methods and apparatus used to determine the ignition temperature have differed widely and have given widely diversified results. Third, there are always differences in the materials themselves, even in those of the same general class.

A few of the various definitions of ignition temperature, quoted by some authors, are as follows: Beyersdorfer (2, p. 2568) states that it is an occurrence which produces visible combustion. Nernst (9, p. 773) says it is that temperature to which a part of the system must be heated to cause combustion. Plenz (10, p. 478) defined it as the temperature at which fuel in contact with air at the same temperature undergoes oxidation at such a rate that marked temperature rise and production of combustion result. Davis and Reynolds (4) stated the definition simply as the temperature at which the rate of generation of heat becomes greater than its rate of dissipation under certain fixed conditions. This agrees fairly closely with the definition given by Brown (3). The ignition temperature is the temperature in the combustible at which the rate of heat developed by the reactions inducing ignition just exceeds the rate at which heat is dissipated by all causes, under the given conditions. Deming (5, p. 24) defined the "kindling temperature" as the temperature at which oxidation becomes self-supporting, and heat is given off fast enough to offset the losses.

The definition to be used in this paper agrees fairly well with the last three mentioned. It can be briefly stated thus: The ignition temperature is the temperature at which the rate of heating in the substance being tested exceeds the rate of heating induced by the external source of heat applied, with combustion accompanied by glow or flame as the ultimate result (the test being run under certain fixed conditions). This implies that there is a distinct difference between ignition and inflammability. In fact, the factors which affect the inflammability or ability of a substance to burn when once ignited may affect the ignition temperature altogether differently (12, p. 671).

All of the above definitions assume that the requirements for ignition have been met. Brown (3) lists the requirements for ignition, obtained from several references (1, p. 15; 7, p. 18; 8, p. 630; 11, p. 136).

1) A combustible must be present.

2) A source of oxygen, such as air, must be available within certain concentrations relative to the combustible.

3) Heat must be evolved as the net result of the reaction, or reactions, producing active combustion.

4) The reactions must proceed more or less rapidly over a certain temperature range.

5) The reaction must be accelerated by a rise in temperature.

6) A supply of energy, sufficient to raise the temperature of the reacting substances to the point where the reaction becomes autogenous, is necessary.

Surveying these conditions, some of the pertinent variables become immediately evident. A few of these are: (1) Type of combustible and preparation and size of sample; (2) Condition of atmosphere and amount of air (if used) flowing; (3) Heat radiation; (4) Place where temperature is measured; (5) Method of designating ignition temperature; (6) Heating rate imposed on sample and time of exposure.

For solid substances like paper, wood, and fabrics, there is available relatively little reliable data on ignition temperatures. A few tests have been made, but they do not begin to cover the wide field. In the interest of fire prevention as affecting public safety it is desirable that more such reliable data be accumulated. It was with this thought in mind that Charles W. Harrison (6) designed and built the apparatus which was used in the determinations of ignition temperatures. The apparatus was designed to give a wide variety of conditions which could be controlled easily and effectively to duplicate natural conditions in order to determine minimum possible ignition temperatures.

II.
STATEMENT OF PROBLEM

STATEMENT OF THE PROBLEM

Briefly stated, the problem was to obtain the ignition temperatures of the classes of organic materials for which there was little data. For immediate tests, three classes of materials were suggested: paper, wood, and fabrics, all three being common combustible materials. Emphasis was placed on an approach to values of minimum possible ignition temperatures rather than on the ignition phenomenon itself, actual values being of more immediate practical use. It was decided to vary the air flow rate, sample weight, rate of temperature rise*, and the composition of samples for the first group of tests as the apparatus was already set up for the control of these variables, and it was determined from the available literature that these factors probably affect the ignition temperature the most. Air of normal room temperature and humidity, and air dried samples were used throughout the tests.

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* The terms, heating rate and rate of temperature rise, will be used interchangeably in this discussion.

III.
EQUIPMENT

EQUIPMENT

The apparatus used consisted of four primary elements: (1) The oven; (2) The temperature control; (3) The air supply; (4) The pyrometer recorder.

The oven was made up of a double walled metal box with insulation and electric strip heaters placed between the walls (Figure 1). Extending horizontally through this box was a pyrex glass tube. Air was introduced into the left end of the tube (Figure 1), and the specimen was placed in the right end, just inside the oven. As the air traveled almost the length of the box before reaching the specimen, it was preheated to approximately oven temperature, the exact temperature attained depending on the amount of air flowing.

The temperature control consisted of two separate circuits (Figure 2) with separate sets of heaters. The fixed circuit heaters (No. 2) were controlled solely by the variac or auto-transformer (No. 2). The current flowing in this circuit was constant as long as the variac setting remained the same and the main switch was closed. An auxiliary switch was provided through mercoid relay No. 2.

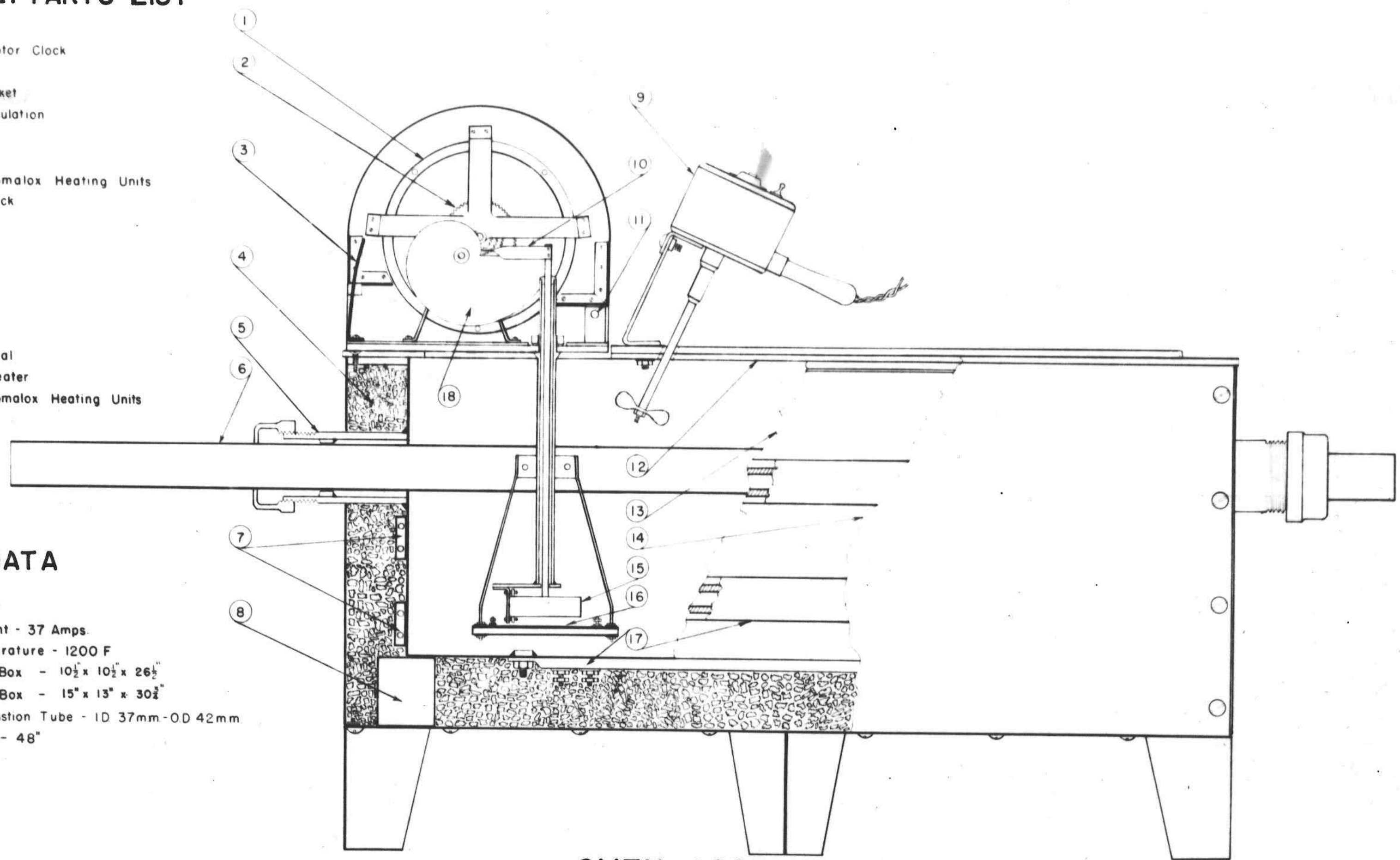
The control circuit heaters (No. 1) were controlled by the variac (No. 1) and also by the mercoid relay (No.

ASSEMBLY PARTS LIST

1 Synchronous Motor Clock
2 Change Gears
3 Gear Shift Bracket
4 Vermiculite Insulation
5 Packing Gland
6 Pyrex Tube
7 350 Watt Chromalox Heating Units
8 Sil - O - Cel Brick
9 Circulation Fan
10 Contact Arm
11 Clock Hinge
12 Transite Cover
13 Inner Box
14 Outer Box
15 Bimetallic Spiral
16 Anticipatory Heater
17 500 Watt Chromalox Heating Units
18 Cam

OVEN DATA

Voltage - 120
Maximum Current - 37 Amps.
Maximum Temperature - 1200 F
Size of Inner Box - $10\frac{1}{2}" \times 10\frac{1}{2}" \times 26\frac{1}{2}"$
Size of Outer Box - $15" \times 13" \times 30\frac{3}{4}"$
Size of Combustion Tube - ID 37mm - OD 42mm
Length of Tube - 48"



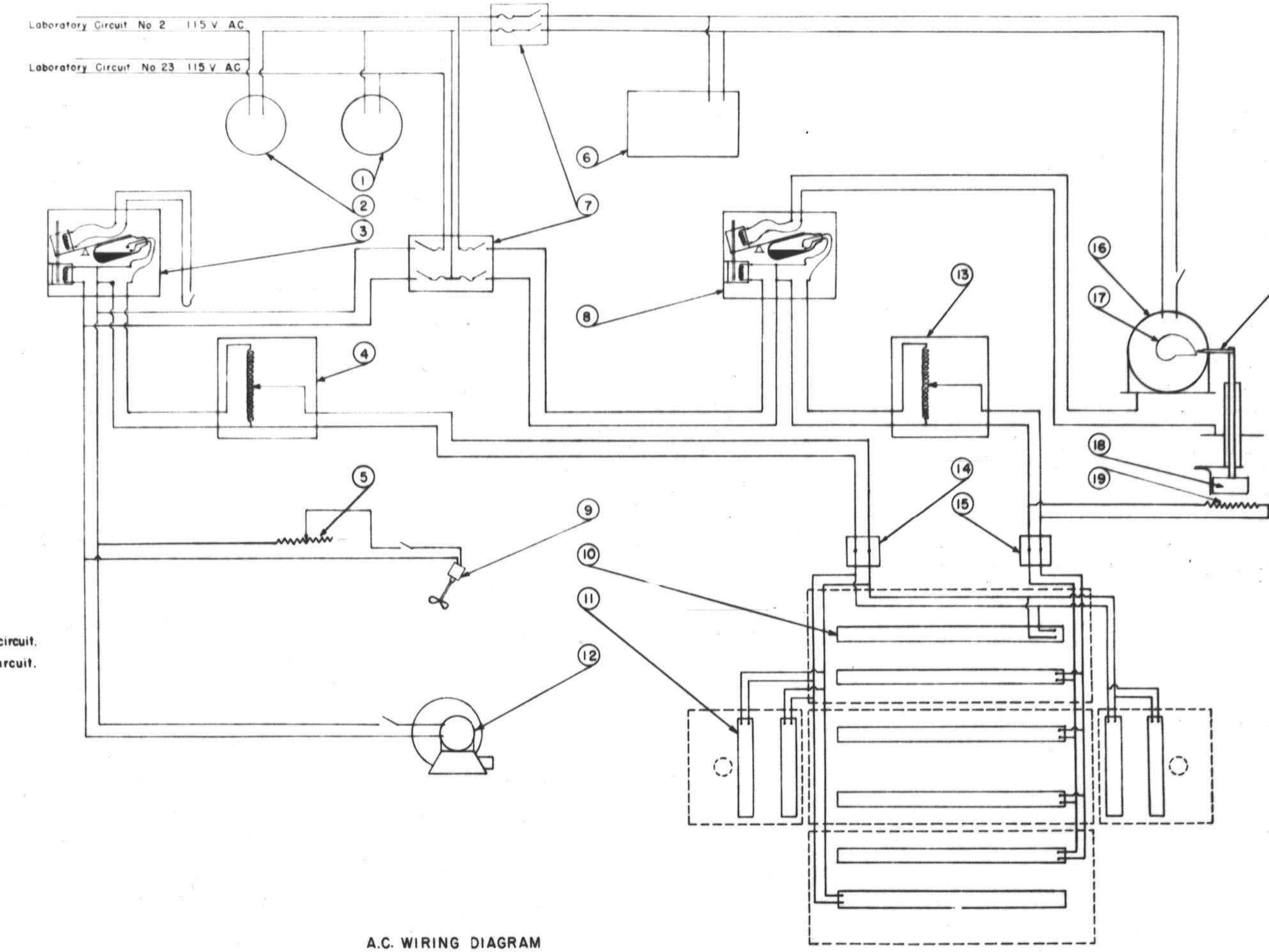
OVEN ASSEMBLY
Figure 1.

LIST OF APPARATUS SHOWN ON DIAGRAM

1	Voltmeter
2	Ammeter
3	Mercoid Relay (Circuit No 2)
4	Variac (Circuit No 2)
5	Variable Resistance
6	Brown Recording Pyrometer
7	Switch and Fuse Board
8	Mercoid Relay (Circuit No. 1)
9	Circulating Fan Motor
10	500 Watt Chromalox Heating Unit
11	350 Watt Chromalox Heating Unit
12	Blower Motor
13	Variac (Circuit No. 1)
14	Terminal Board (Circuit No. 1)
15	Terminal Board (Circuit No. 2)
16	Synchronous Motor Clock
17	Cam
18	Bimetallic Spiral
19	Anticipatory Heater
20	Contact Arm

NOTE:

Circuit No. 1 used with reference to control circuit.
Circuit No. 2 used with reference to fixed circuit.



A.C. WIRING DIAGRAM

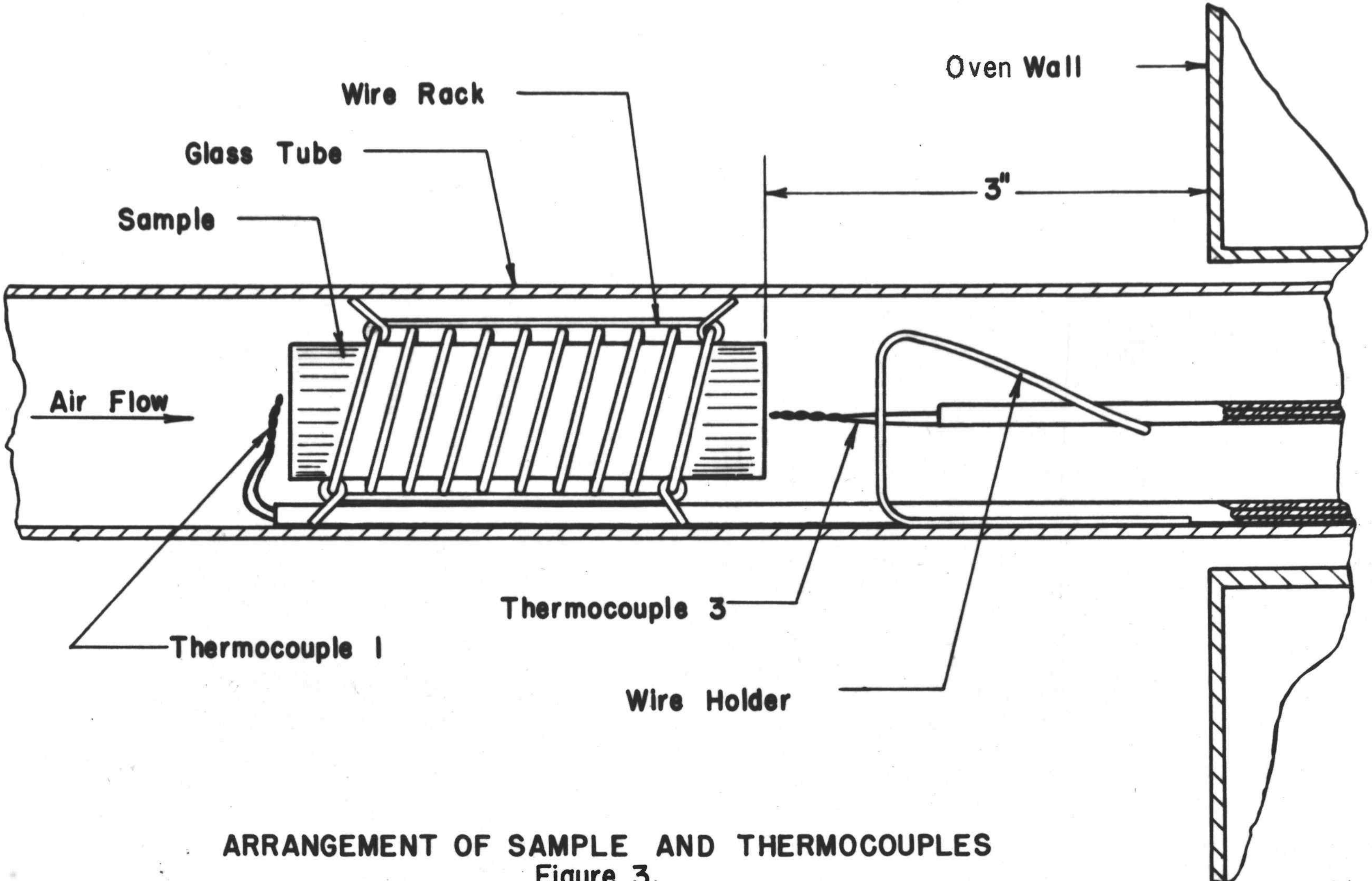
Figure 2.

1) which was actuated by a pilot circuit. The pilot circuit consisted of a cam and arm contact and the secondary coil in the mercoid relay. When contact was made, the relay was excited and the No. 2 heater circuit was closed. The arm was attached to a bimetallic strip thermostat which provided for a gradual temperature rise in the oven when the cam was turned by clockwork. An anticipatory heater was installed just below the bimetallic spiral to act as a damper on fluctuations of temperature in the oven. By the use of different clock gear ratios and different cam shapes, the rate of temperature rise was controlled over a wide range. (See Figures 1, 2, 4, 5, and 6).

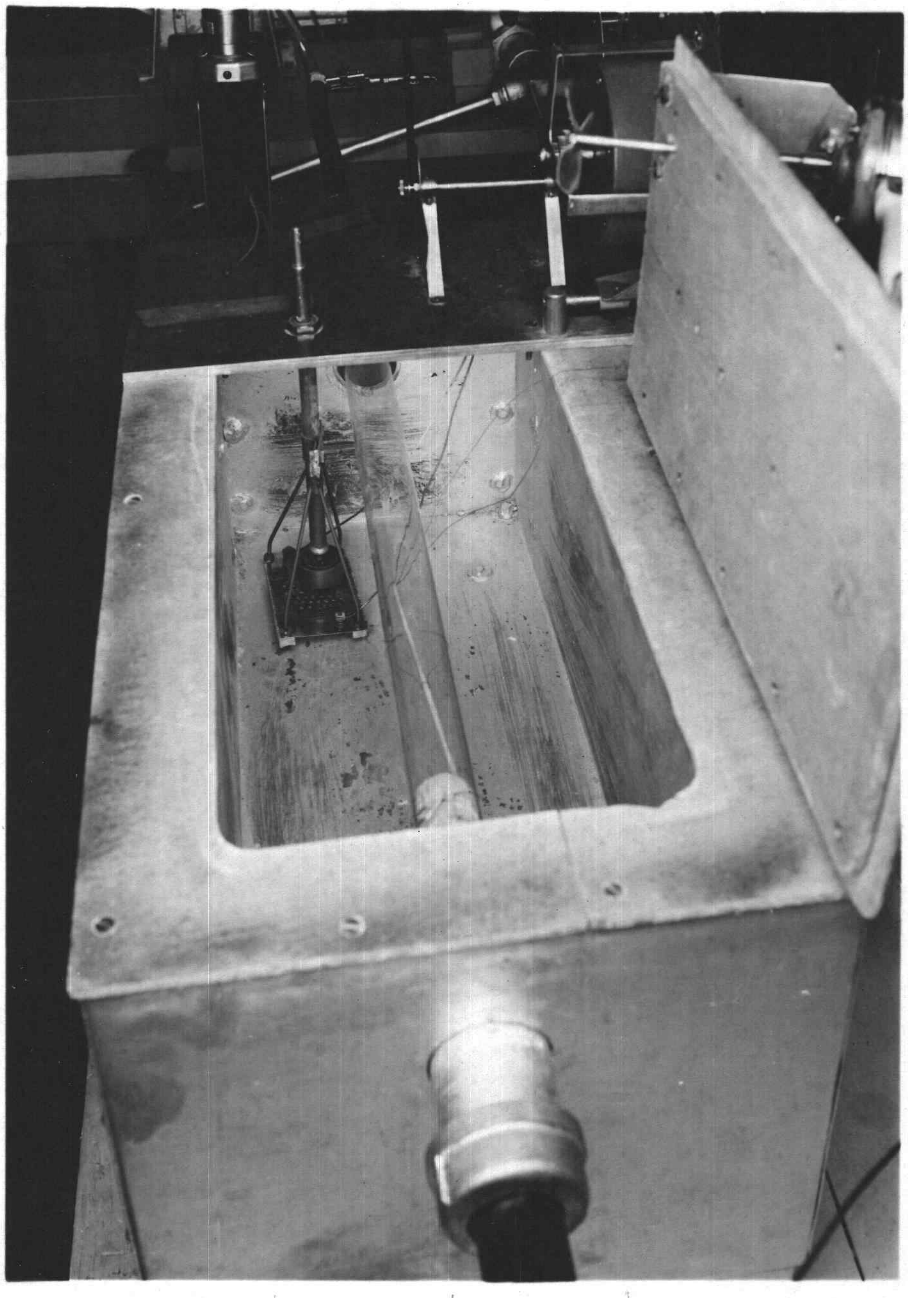
The air flow was controlled by two hand valves and a rotameter or flowmeter situated between the fan and the oven (Figure 6). Rates of air flow varying from zero to one cubic foot per minute were used in the tests.

The pyrometer was a Brown recording type with four thermocouple attachments. The instrument recorded electronically and automatically the oven temperature, temperature behind the specimen, temperature in front of the specimen, and the difference between the two specimen temperatures (see Figures 7, 8, and 9). With this arrangement, the equipment could be run automatically for almost any length of time with a continual visual record of temperatures available. It was necessary to stop the recorder only to change paper rolls.

For further details on the equipment, the thesis, "An Apparatus for Determining the Ignition Temperatures of Organic Substances," by Charles W. Harrison (6) may be consulted.



ARRANGEMENT OF SAMPLE AND THERMOCOUPLES
Figure 3.



INTERIOR OF OVEN
Figure 4.

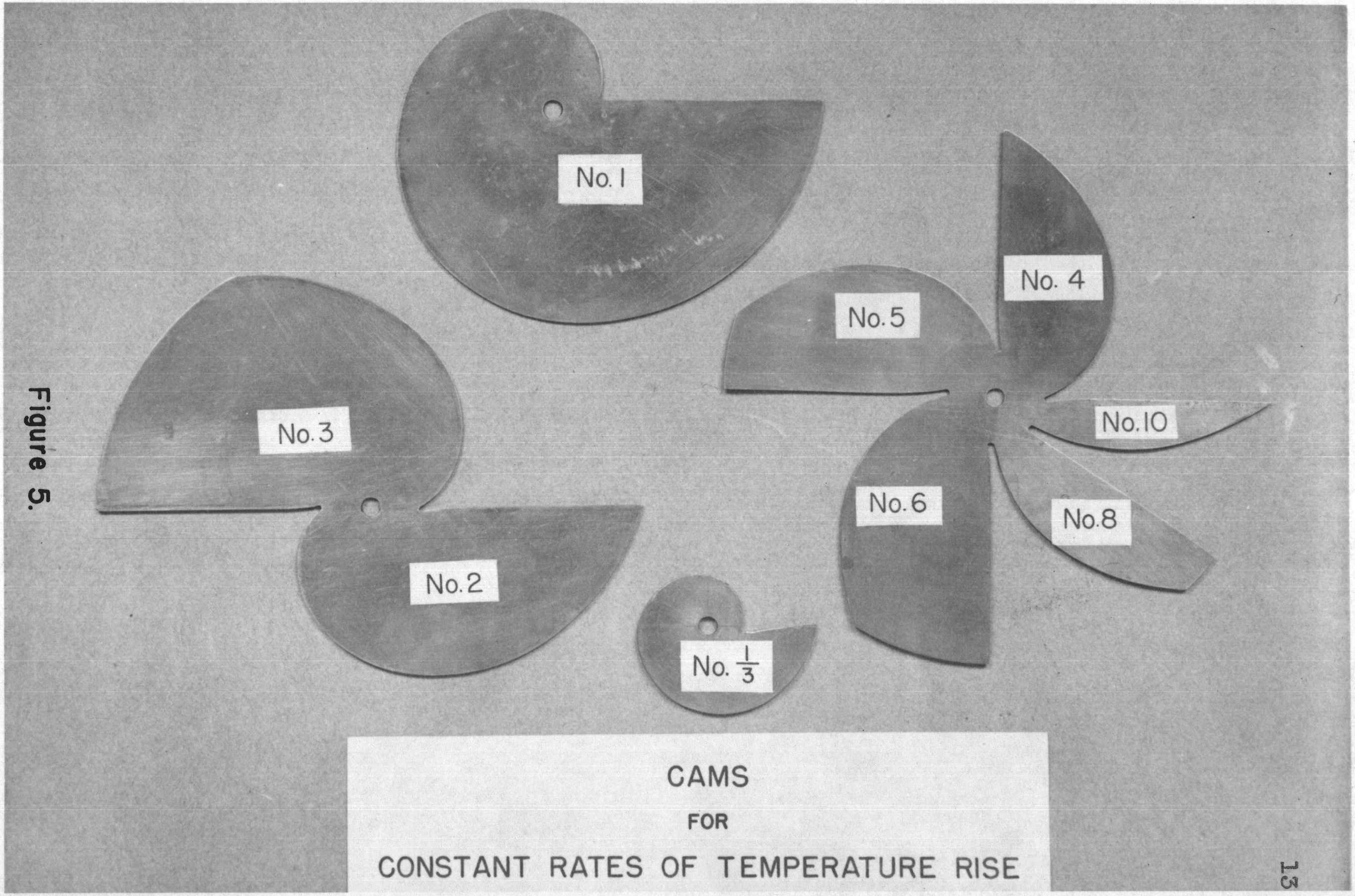
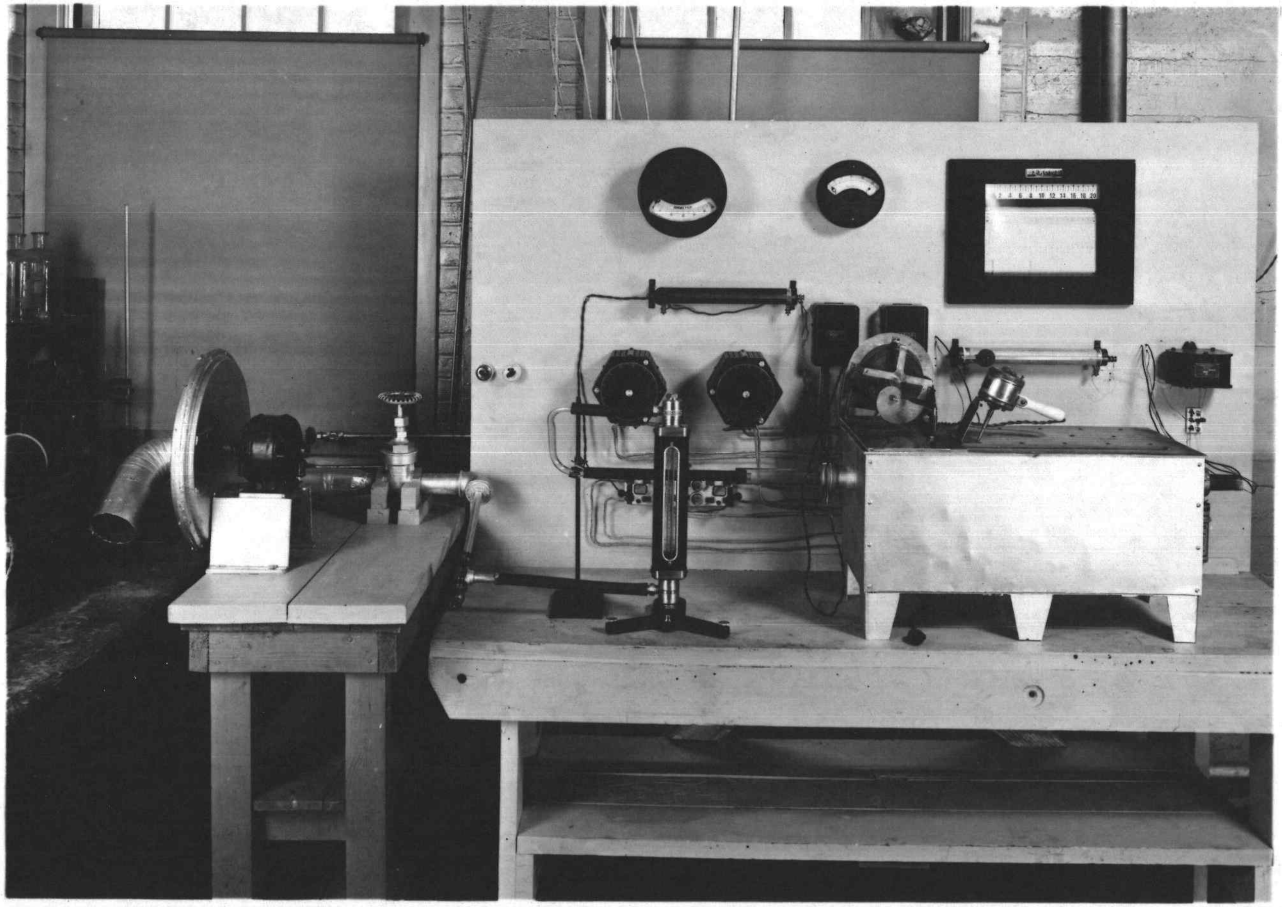


Figure 5.

CAMS
FOR
CONSTANT RATES OF TEMPERATURE RISE



APPARATUS USED IN DETERMINATIONS

Figure 6.

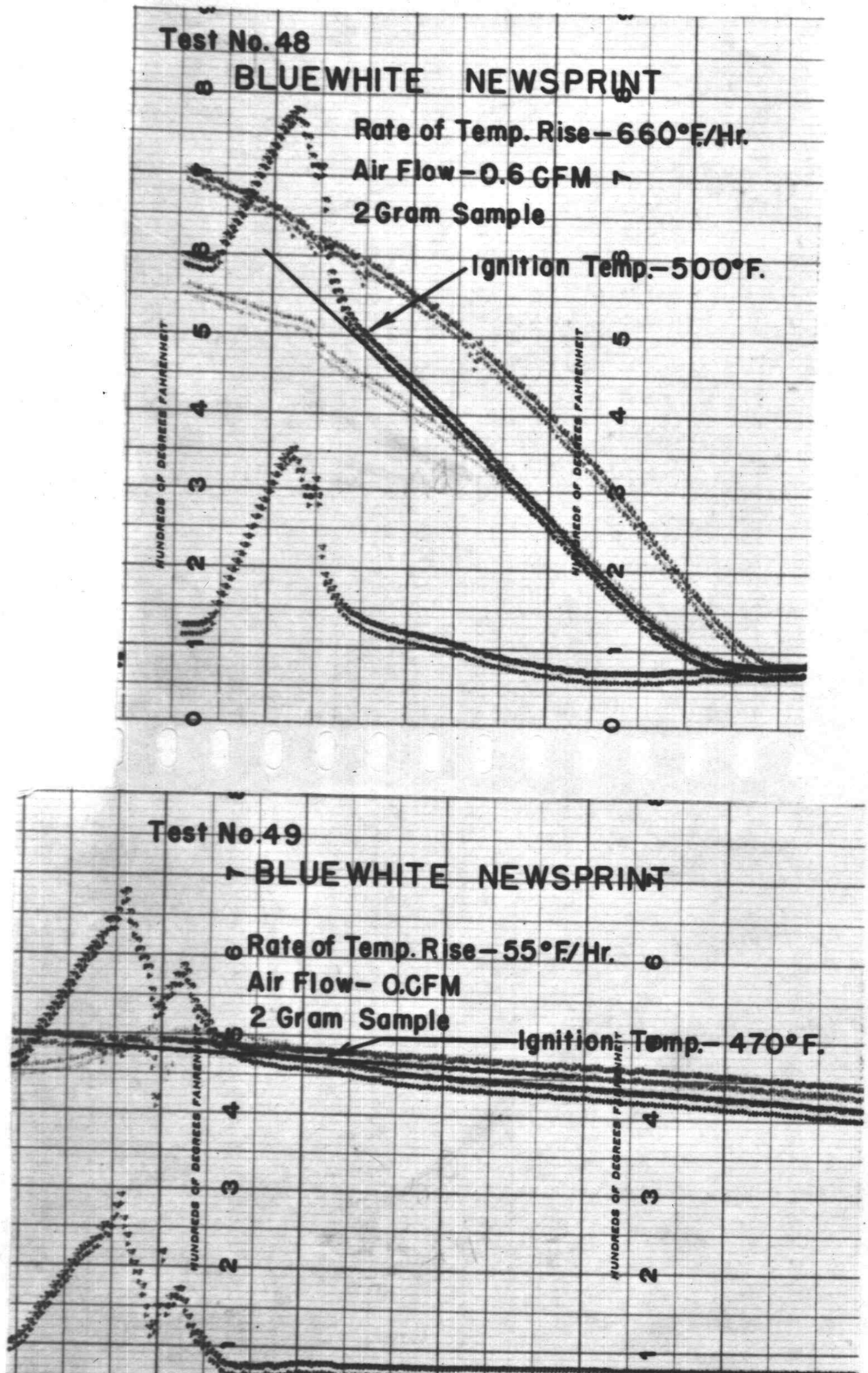
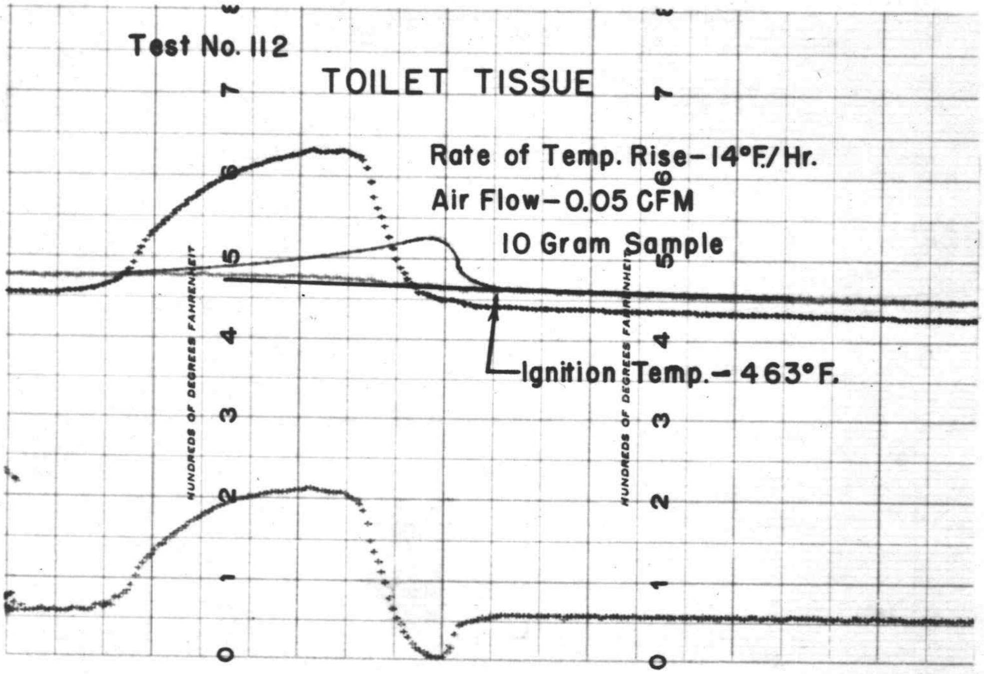

Test No. 48
BLUEWHITE NEWSPRINT
Rate of Temp. Rise-660°F/Hr.
Air Flow-0.6 CFM
2 Gram Sample
Ignition Temp.-500°F.
HUNDREDS OF DEGREES FAHRENHEIT
Test No.49
BLUEWHITE NEWSPRINT
Rate of Temp. Rise-55°F/Hr.
Air Flow- O.CFM
2 Gram Sample
Ignition Temp.- 470°F.

Figure 7.


Test No. 112
TOILET TISSUE
Rate of Temp. Rise-14°F./Hr.
Air Flow-0.05 CFM
10 Gram Sample
Ignition Temp.-463°F.
HUNDREDS OF DEGREES FAHRENHEIT

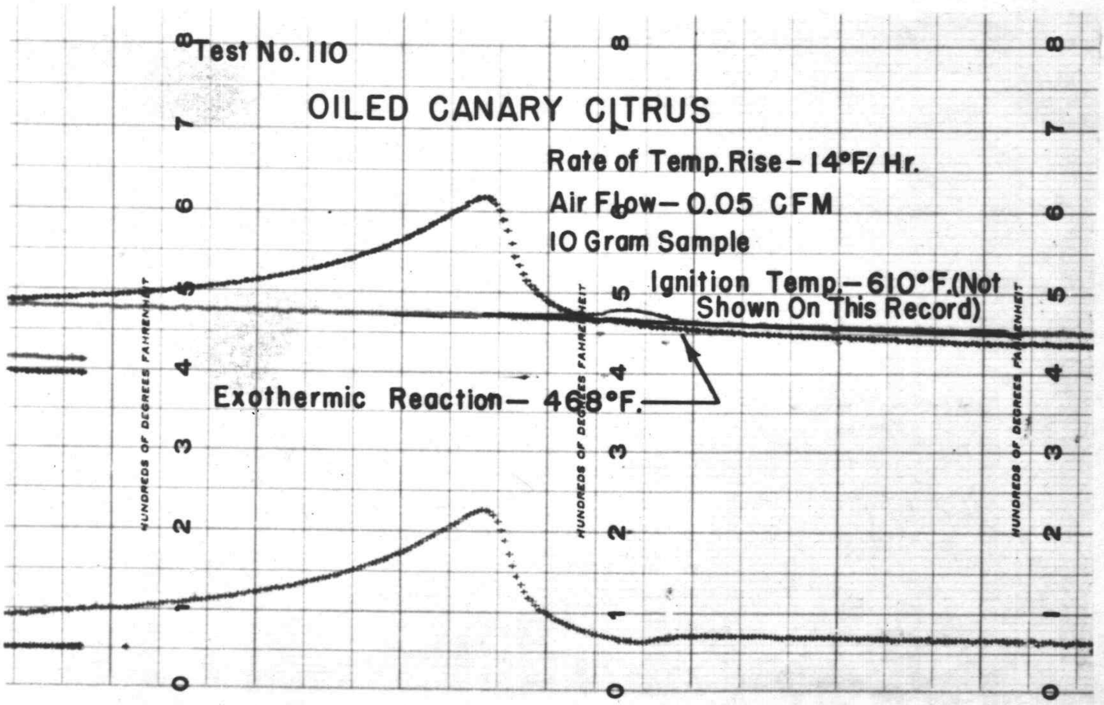
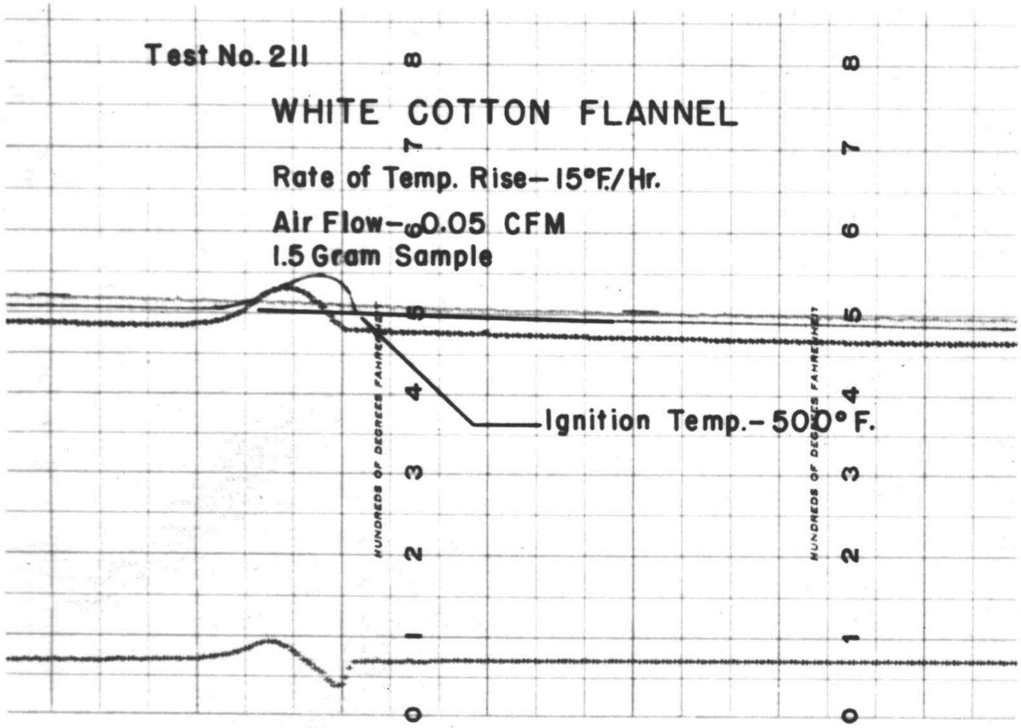

Test No. 110
OILED CANARY CITRUS
Rate of Temp. Rise-14°F./ Hr.
Air Flow-0.05 CFM
10 Gram Sample
Ignition Temp.-610°F.(Not Shown On This Record)
Exothermic Reaction-468°F.
HUNDREDS OF DEGREES FAHRENHEIT

Figure 8.


Test No. 211
WHITE COTTON FLANNEL
Rate of Temp. Rise—15°F./Hr.
Air Flow—0.05 CFM
1.5 Gram Sample
Ignition Temp.—500°F.
HUNDREDS OF DEGREES FAHRENHEIT

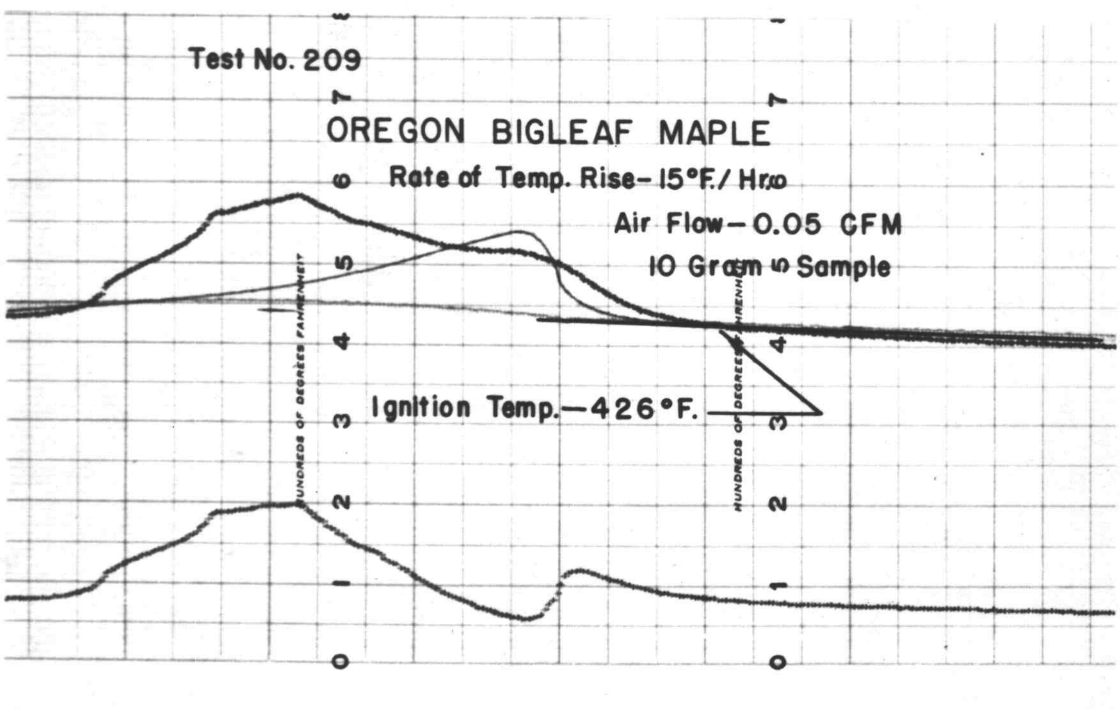

Test No. 209
OREGON BIGLEAF MAPLE
Rate of Temp. Rise—15°F./Hr.
Air Flow—0.05 CFM
10 Gram Sample
Ignition Temp.—426°F.
HUNDREDS OF DEGREES FAHRENHEIT

Figure 9.

IV.
OPERATION OF EQUIPMENT

OPERATION OF EQUIPMENT

The main points considered in operation of the equipment were a few standard procedures and precautions observed because of the nature of the equipment and a few precautions learned from actual operation.

Before operating the equipment on a set of tests, a complete set of heating curves was recorded for various settings of the two variacs. These curves were taken directly from the recording roll of the potentiometer and are a plot of temperature against time. The curves, shown in Appendix I, pages 95 to 102, were recorded for variac settings of 20 to 100 using increments of 20. The possible maximum setting on each variac was 115 which means there was some reserve for high temperatures and heating rates. It was found that for any given combination of constant variac settings the oven would approach its maximum temperature in approximately four hours.

From the time-temperature curves, the heating rates or rates of temperature rise were taken by measuring the slope at various points along the curves. These heating rates were plotted against temperature, the complete set of curves being shown in Appendix I, pages 103 to 110. The heating rate-temperature curves were useful in determining the approximate settings and progressive changes of settings of the variacs for given temperatures and heating rates. After some experimentation, it was discovered that a rather high setting of the control circuit variac (No. 1) with a setting of the constant circuit variac (No. 2) slightly below the value given on the curve gave the best results. Large upward changes of variac settings produced higher heating rates for a short period of time after which the heating rate settled back to that given by the particular cam and clock gear ratio in use. Small increases of variac setting (2 or 3 points for lower heating rates) gave the smooth, straight line heating curve which was desired.

There were no special precautions taken with the contact arm-cam assembly other than to keep the contacts clean and to watch the wires to the anticipatory heater for short circuits and burned connections. The power connections to this heater were renewed periodically as they burned out.

The air flow was regulated by two valves, one large gate valve at the fan discharge and a small "bleed off" valve for fine adjustments. Care was taken to see that the fan discharge valve was closed when the air supply was first turned on to avoid injury to the float in the rotameter from forced contact with the upper stop. It was found necessary to regulate the air flow periodically as it tended to decrease when the system heated up.

After the first few tests, the pyrometer recorder was operated only when checking and at temperatures near the ignition temperature, but it was necessary to make sure that a sufficient length of curve was recorded to enable the heating rate to be determined. The shifting circuit was used primarily to keep the printing mechanism from striking the lower stop when only one thermocouple was in the glass tube, the tendency being to set up a negative differential temperature which caused the recorder to attempt to print below zero. The thermocouples and the potentiometer were checked simultaneously twice, once before and once after all the tests were run, with good results both times.

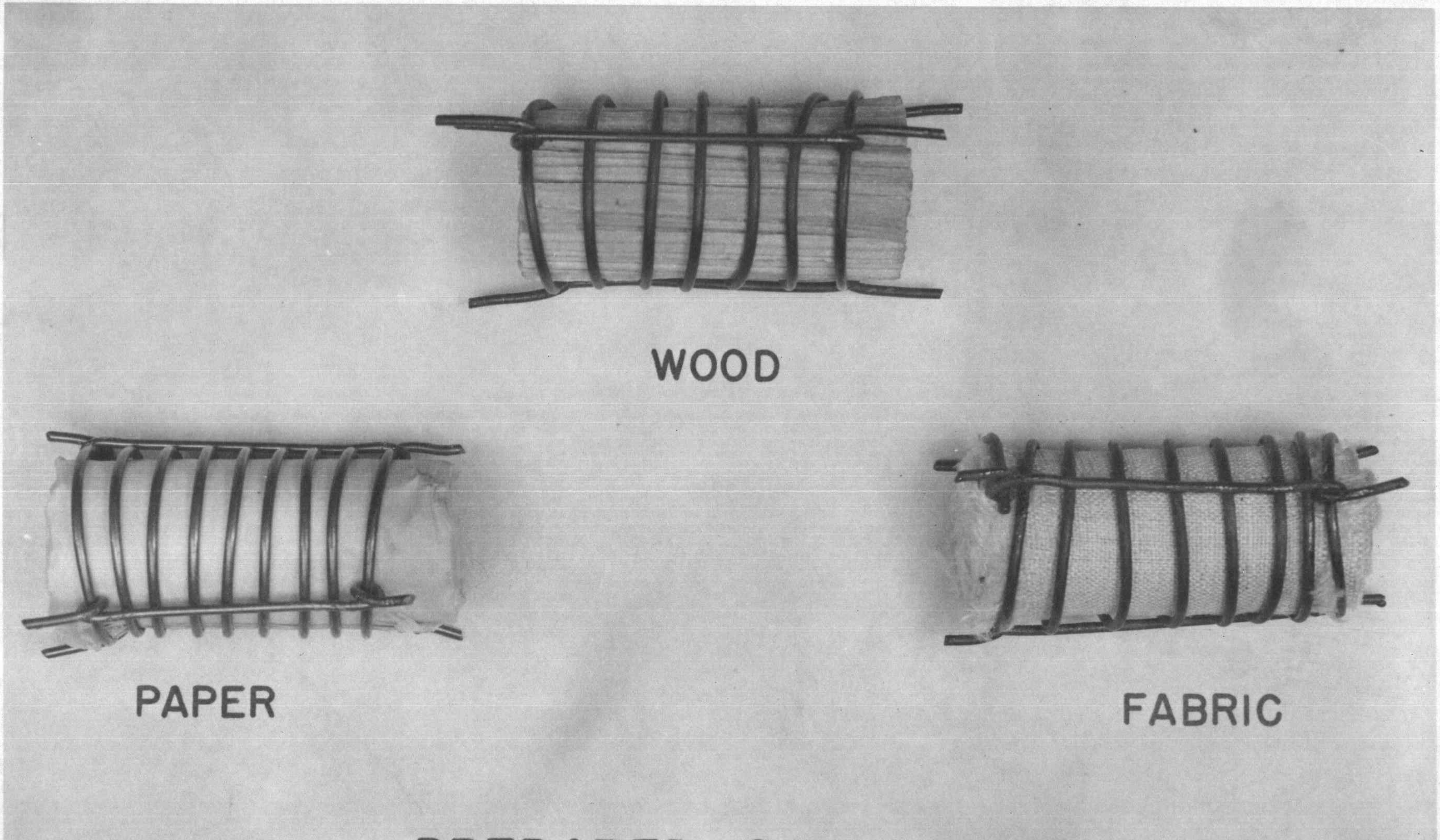
Several minor changes were made in the equipment during its operation. The small fan on top of the oven was eliminated because it was not needed, and a handle was substituted. A variable resistance was put in parallel with the cam and contact arm in the control pilot circuit to help eliminate sparking at the contacts. The fan and air piping were lowered and made more compact to save room, and the voltmeter and ammeter connections were changed so they read control circuit amperes and volts only.

V.
PRELIMINARY TESTS

PRELIMINARY TESTS

For a sample material during the preliminary tests, ordinary yellow copy paper was used (see Appendix II). This common paper was chosen because it was plentiful, cheap, and readily available. To hold the samples in the center of the glass tube and allow free circulation of air around them, two sizes of wire racks were constructed. These wire racks had inside diameters of approximately 1 inch and 5/8 inch and a length of approximately 2 inches (see Figures 3 and 10). Being constructed of loosely coiled wire, they served as a sort of grate in which the sample burned, allowed free circulation of air, and acted as a check on sample size. Satisfactory ignition was obtained using the racks in preliminary tests.

The exact thermocouple placement was also fixed during the first tests. As there was a slight temperature gradient from one end of a sample to the other, depending on how much air was flowing, and one end or the other therefore tended to be the hottest point of the sample, it seemed advisable to have a thermocouple placed at each end. Runs were made, however, with one thermocouple imbedded in the sample as was done by Brown (3) in his tests, but with this arrangement, curves were recorded which gave such a gradual change of the temperatures that it was almost



PREPARED SAMPLES
Figure 10.

impossible to judge the ignition temperature accurately when lower heating rates were used. With thermocouples located just outside the sample, a more abrupt temperature rise was noted at ignition which made it easier to judge the ignition temperature. Also, from a fire prevention standpoint, the external temperature which could cause ignition would be of the most practical use. The samples were therefore all placed three inches from the oven wall as shown in Figure 3 with thermocouples approximately 1/8 inch from each end.

The form of paper sample to use was next determined. Wads, loose rolls, and strips of paper permitted varying amounts of air to flow in and around the sample with standardization of size and shape of the sample also made difficult. Tight rolls of the paper allowed very little air to flow through the sample and made for standard sizes of samples of the same density; therefore, tight rolls inserted into the wire racks were used as standard for both paper and fabric samples (see Figure 10).

The weight of samples used was determined by trial cutting, weighing, and rolling of the paper. Samples weighing 10 grams or less were easily prepared and were of a size which eliminated extremely long samples with accompanying high temperature difference between ends. Weights from $\frac{1}{2}$ gram to 10 grams were used in the subsequent tests.

For record of the tests, a data sheet was drawn up as shown in Figure 11. The items indicated were not all entered for every test, some being included only for the investigator's own information and others for extreme conditions noted while tests were in progress. Notes were taken of conditions not provided for, which included peculiar reactions, abnormal or erratic heating rates, and apparatus failures.

ENGINEERING EXPERIMENT STATION

Oregon State College

Project No. 64

Date__________________________

Run No._________________________

Specimen: Name or No.______________________Wt._________

% Moisture_______________________Size________

How Prepared__________________________________

Appearance during test________________________

DB______WB_______RH%_______DB_______WB________RH%________

Clock gear ratio____Rate of temp. rise____°/Hr.____°/Min.

Time	Air Temp. At Inlet	Barometer	Temperatures 1	2	3	Transformer Settings H	C

Air Flow______K______Air flow, corrected______cu.ft./min.

Est. Vel. past specimen (Beginning)________(End)_________

Ignition point____________° F.

Point of deviation from straight line________________° F.

Miscellaneous notes:

Figure 11

VI.
TESTS OF PAPER

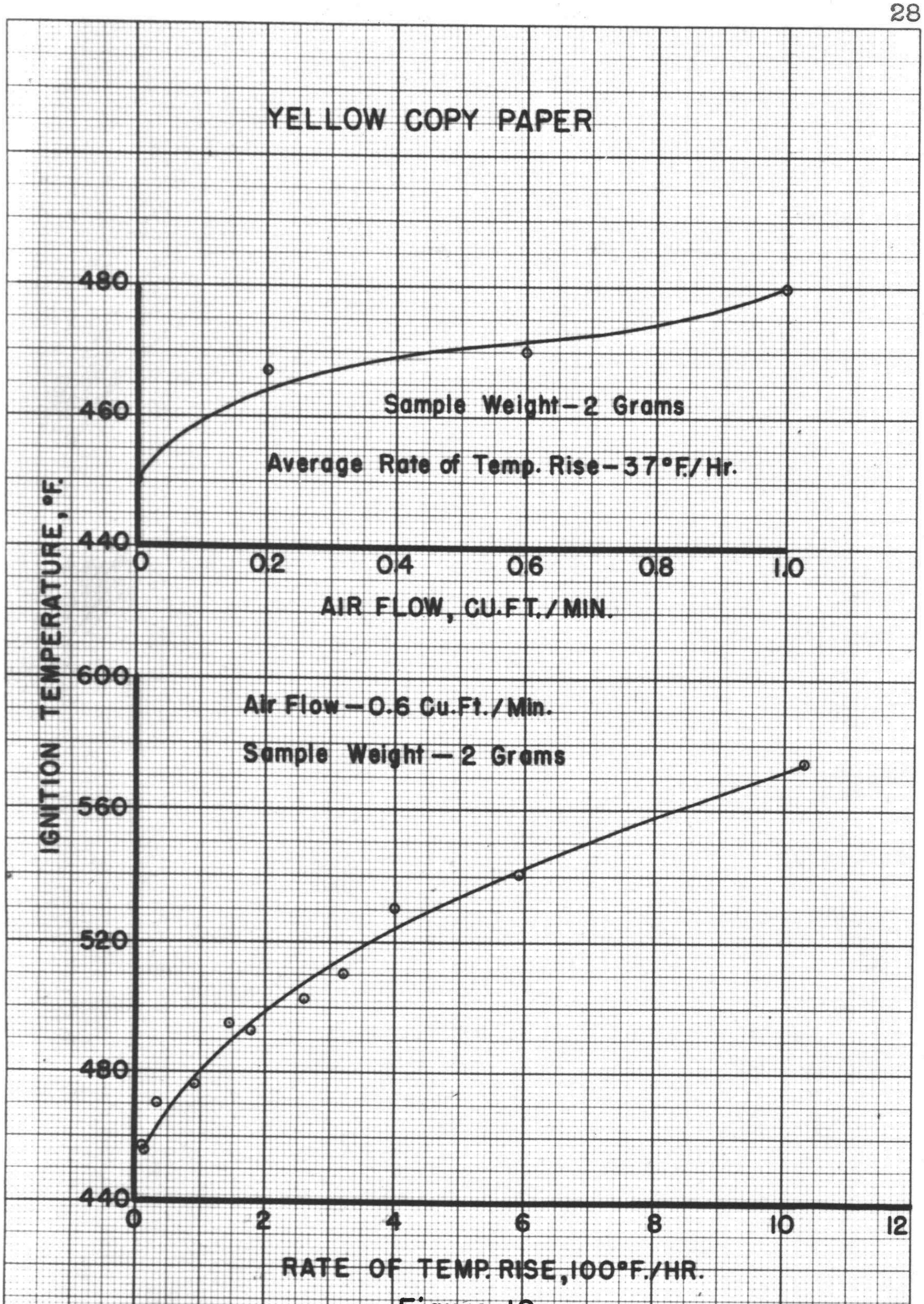
TESTS OF PAPER

To secure initial data, a series of tests was made on the yellow copy paper. This accomplished two purposes; it provided a series of ignition curves from which the basis for designating the ignition temperature was obtained, and it indicated the air flow, heating rate, and sample size required to give approximate minimum ignition temperatures for the other paper samples to be tested. Constant (straight line) heating rates were used throughout.

Figures 7, 8, and 9 show typical ignition curves taken from the recorder paper roll with the ignition temperatures indicated thereon. Attempts were made to take the ignition temperature from the curve at a point of definite upward break, but uniform results were obtained only by use of the point of deviation from the straight line temperature curve. Where the temperature curve from the hotter end of the sample deviated from the straight line, the value of the temperature was noted and designated as the ignition temperature. This was in agreement with the definition of ignition temperature given earlier. The heating rate or rate of temperature rise was determined by measuring the slope of the time-temperature curve taken from the recorder.

The curves shown in Figures 12 and 13 give the major resultant trends noted in the tests of yellow copy paper. The air flow-temperature curve shows a definite trend toward lower ignition temperatures at lower air flow rates. The point of zero air flow actually was not representative as a small quantity of air was introduced just before ignition started. Tests of 10 gram samples (not shown on curves) at zero air flow indicated that ignition would start but would not go to completion because of lack of oxygen. Therefore, a rate of air flow which would give just enough oxygen to permit ignition seemed to be the optimum for a minimum ignition point. This rate was found to be approximately 0.05 cubic feet of air per minute and was used in the subsequent paper tests.

There are several possible reasons for the upward trend of the ignition temperature with increased air flow as shown in Figure 12. As the sample was heated, it gave off gases and vapors which were more or less combustible. When the air was blown across the sample, it naturally took some of these gases with it, more of the gases being taken away at the higher air flow rates. It is conceivable that with a smaller amount of material present including gases and vapors, the ignition reaction would be slower starting. In addition, the more rapid air flow



YELLOW COPY PAPER
Sample Weight—2 Grams
Average Rate of Temp. Rise—37°F./Hr.
480
460
440
0
0.2
0.4
0.6
0.8
1.0
AIR FLOW, CU.FT./MIN.
IGNITION TEMPERATURE, °F.
Air Flow—0.6 Cu.Ft./Min.
Sample Weight—2 Grams
600
560
520
480
440
0
2
4
6
8
10
12
RATE OF TEMP. RISE, 100°F./HR.

Figure 12.

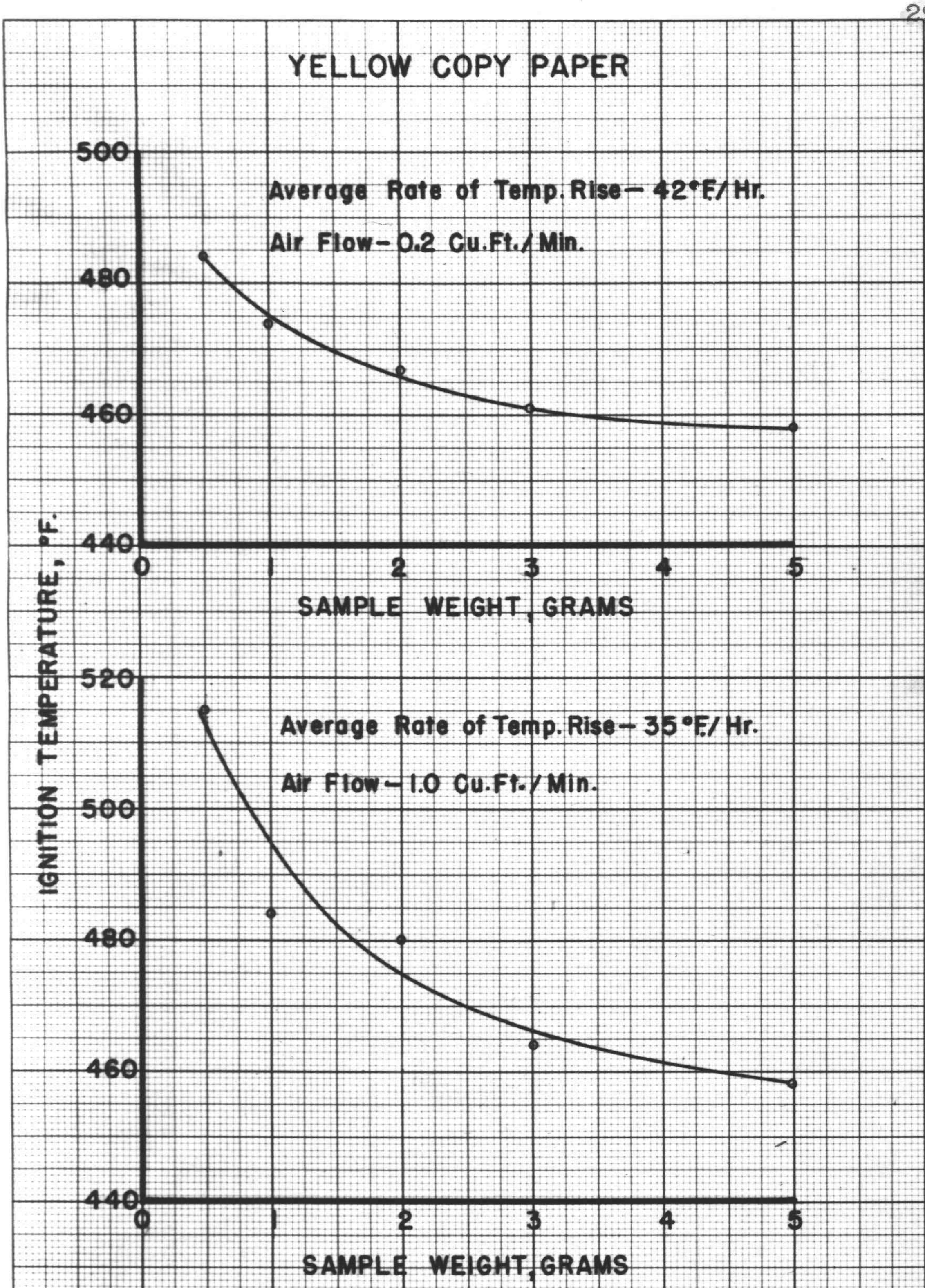

YELLOW COPY PAPER
Average Rate of Temp. Rise— 42°F./Hr.
Air Flow— 0.2 Cu.Ft./Min.
500
480
460
440
0
1
2
3
4
5
SAMPLE WEIGHT, GRAMS
IGNITION TEMPERATURE, °F.
Average Rate of Temp. Rise— 35°F./Hr.
Air Flow— 1.0 Cu.Ft./Min.
520
500
480
460
440
0
1
2
3
4
5
SAMPLE WEIGHT, GRAMS

Figure 13.

would conduct heat away from the sample more rapidly, again delaying the ignition reaction.

The sample size-temperature curves (Figure 13) show trends toward lower ignition temperatures for heavier samples. This may be due to the trapping of more of the combustible gases and vapors by larger samples and to the slower heat loss from the interior of larger samples, both of which could cause lower ignition temperatures. This reasoning is supported by the fact that the effect of sample weight was much more noticeable at the higher air flow rate of 1 cubic foot of air per minute as compared to that of 0.2 cubic feet of air per minute, the more rapid air flow conducting more heat and combustible vapors away as outlined in the preceding paragraph. With the apparatus used, it was impossible to reach the absolute minimum ignition temperature (if one exists) which would result from much larger samples, as samples over 10 grams were impracticable.

The heating rate or rate of temperature rise had the most pronounced effect on the ignition temperature of the yellow copy paper as shown in Figure 12. The results indicate that the ignition reaction is dependent largely on time in addition to temperature. A certain reaction range was noticed in which the ignition reaction started and finished. If the sample is subjected to temperatures in this range for a sufficient time, ignition will result, with slower heating rates giving lower ignition temperatures. Time in the range of temperatures below the reaction range has no affect on the ignition temperature. This was illustrated by later tests in which the sample temperature was raised quickly to 300° F. before the slower heating rate was established. The lack of time in the 70° F. to 300° F. range had no apparent affect on the ignition temperature at the slowest heating rate available, 13° F. to 17° F. per hour. The ignition reaction started at a temperature above 300° F. as evidenced by discoloration of the sample and the smell of fumes at the exhaust end of the glass tube. The slower heating rates allowed more time for the ignition reaction to be completed at a lower temperature. When the faster heating rates were used, the time necessary for the reaction to take place caused the ignition to be delayed until higher temperatures were reached.

It is possible that a minimum in the heating rate-temperature curve could be reached, as the slow heating rates might allow too much combustible material to escape as gases or vapors and thus raise the ignition temperature. Such minimums were recorded by Brown (3) at a rate of temperature rise of 67° F. to 200° F. per hour. No such minimum values, however, were noticed in the tests of the yellow copy paper. Brown's apparatus was somewhat different but operated on approximately the same principles as the apparatus used in the tests of the yellow copy paper. The difference in results was probably accounted for by differences in the paper tested, the apparatus, and its arrangement. Harrison (6, p. 29), in his preliminary tests with the equipment, also noted such a minimum at a heating rate of 60° F. to 180° F. per hour. He too was testing a different type of paper with a different arrangement of the specimen and thermocouples.

It was decided to use 10 gram samples, an air flow rate of 0.05 cubic feet per minute, and the lowest heating rate available (13° F. to 17° F. rise per hour or No. 1 cam and 24-hour gear ratio) for the tests of the other varieties of paper. A set of tests was made on newspaper*, however, to check the yellow copy paper results. The resultant curves are shown in Figures 14 and 15 with the same trends noted as in the previous tests. Later, while wood specimens were being tested, a cam with 1/3 the travel of No. 1 was constructed (see Figure 5) and newspaper was tested at a 6° F. per hour heating rate. No appreciable difference in the ignition temperature was

* Newsprint paper with printing on it.

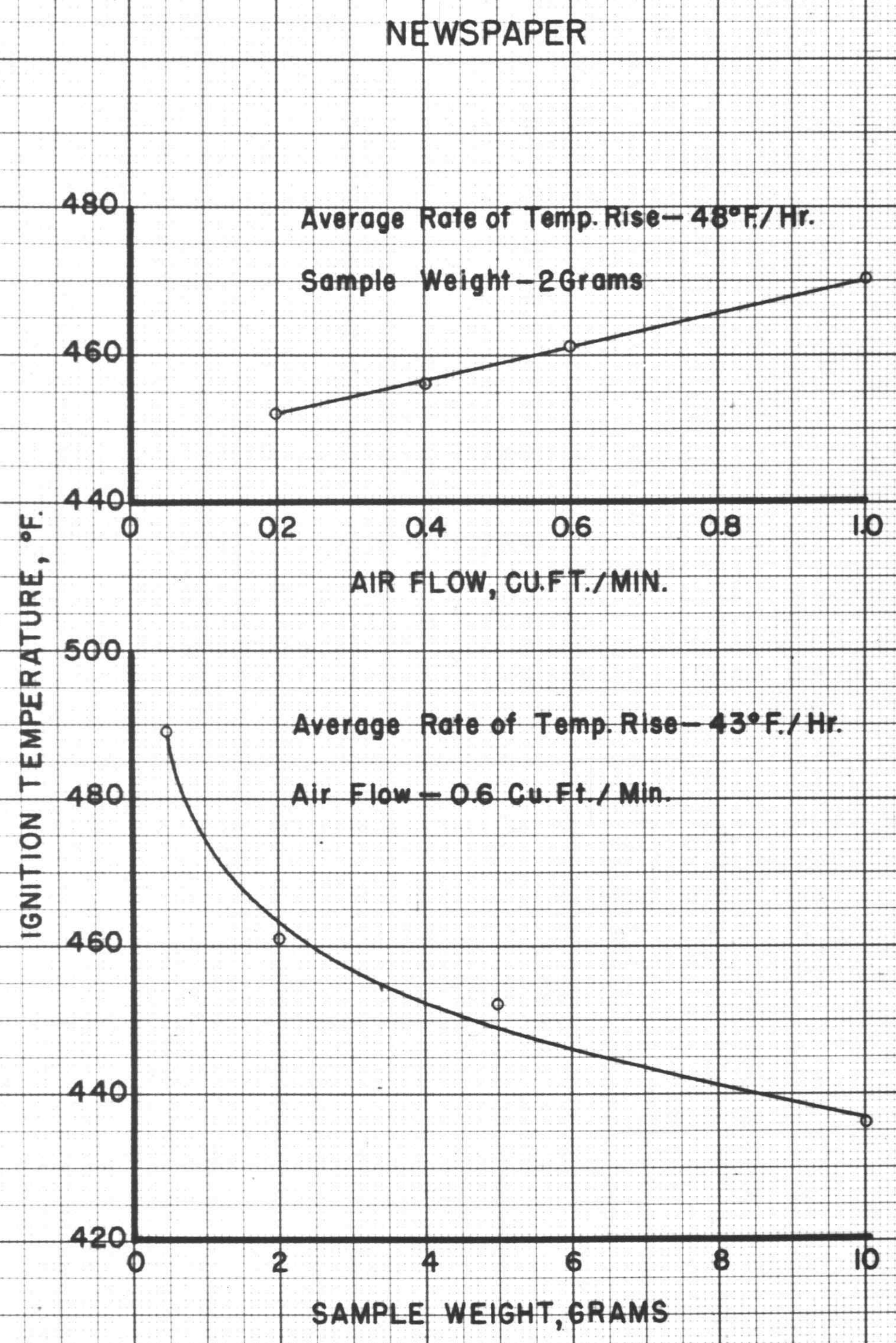

NEWSPAPER
Average Rate of Temp. Rise—48°F./Hr.
Sample Weight—2 Grams
480
460
440
0
0.2
0.4
0.6
0.8
1.0
AIR FLOW, CU.FT./MIN.
IGNITION TEMPERATURE, °F.
500
Average Rate of Temp. Rise—43°F./Hr.
Air Flow—0.6 Cu.Ft./Min.
480
460
440
420
0
2
4
6
8
10
SAMPLE WEIGHT, GRAMS

Figure 14.

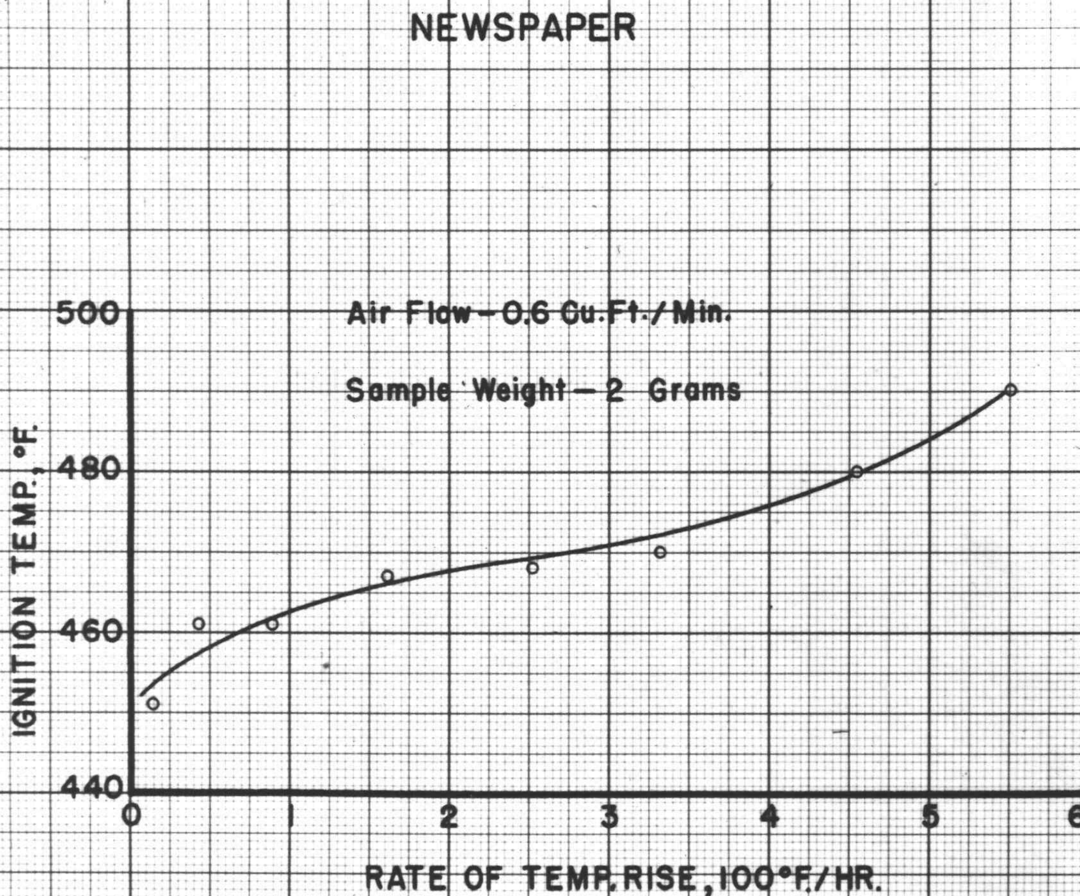

NEWSPAPER
Air Flow — 0.6 Cu. Ft./Min.
Sample Weight — 2 Grams
IGNITION TEMP., °F.
500
480
460
440
0
1
2
3
4
5
6
RATE OF TEMP. RISE, 100°F./HR.

Figure 15.

observed, indicating that the 13° F. to 17° F. per hour heating rate was at the approximate minimum point.

Table 1 gives the complete results of tests on yellow copy paper and newspaper.

Samples of the other varieties of paper tested were obtained from the manufacturers with accompanying data as shown on the data sheet, Figure 16. Samples of these papers are contained in the Appendix II with data on each given on the page preceding.

The object of the group of tests on paper samples was to determine the ignition temperatures and to correlate these temperatures with the composition and manufacturing history of each sample. Two runs were made on each sample at the previously determined conditions for minimum ignition temperature, and the temperatures were averaged. The temperatures were read to 2° F. and estimated to 1° F. The largest difference in temperatures recorded between the two runs on one variety of paper was 5° F. while the usual value was between 0° F. and 3° F. Thirty-five different samples were tested, each test taking between 12 and 18 hours, approximately.

The results of the tests on paper samples are shown in Table 2 along with the data on each sample. The samples are arranged in order of ascending ignition temperatures. Contrary to what might be surmised, it was found

TABLE 1.

Yellow Copy Paper

Run No.	Wt. of Sample, Grams	Air Flow Rate, Cu.Ft./Min.	Rate of Temp.Rise, °F./Hr.	Ignition Temp., °F.
1	2	0.2	47	485
2	1	0.2	37	464
3	½	0.2	41	484
4	1	0.2	43	474
5	2	0.2	37	467
6	5	0.2	45	458
7	3	0.2	45	461
8	2	0.6	36	470
9	2	1.0	36	480
10	½	1.0	35	515
11	5	1.0	35	482
14	3	1.0	35	464
15	1	1.0	36	484
17	5	1.0	33	458
18	2	0 until near ignition	39	450
19	10	0.2	42	448
20	2	0.6	13.6	457
21	2	0.6	18	455
22	2	0.6	1030	575
23	2	0.6	90	476

Yellow Copy Paper (Continued)

Run No.	Wt. of Sample, Grams	Air Flow Rate, Cu.Ft./Min.	Rate of Temp.Rise, ° F./Hr.	Ignition Temp., ° F.
24	2	0.6	145	495
25	2	0.6	182	492
26	2	0.6	260	505
27	2	0.6	320	510
28	2	0.6	400	530
29	2	0.6	590	540
33	2	0.6	45 approx.	*
34	2	0.0	45 approx.	*
35	2	0.6	35	454**
51	10	0.0	27	474
52	10	0.05	25	440
53	10	0.05	20	442

* Soaked with lubricating oil--no ignition.

** Typewritten on one side.

Yellow Copy Paper (Continued)

Sheets of paper were folded and rolled tightly, lengthwise.

Size of Samples

Weight, Grams	Diameter, Inches	Length, Inches
1/2	5/8	3/8
1	5/8	5/8
2	5/8	1 1/8
3	1	1
5	5/8	3
10	1	2 1/4

Newspaper

Run No.	Wt. of Sample, Grams	Air Flow Rate, Cu.Ft./Min.	Rate of Temp.Rise, ° F./Hr.	Ignition Temp., ° F.
30	2	0.6	455	480
31	2	0.6	550	490
32	2	0.6	334	470
36	2	0.6	44	461
37	2	0.2	46	452
38	2	0.4	42	456
39	2	1.0	60	470
41	10	0.6	50	436
42	5	0.6	40	452
43	½	0.6	38	489
44	2	0.6	21	451
45	2	0.6	90	461
46	2	0.6	161	467
47	2	0.6	253	468
54	10	0.05	20	428
55	10	0.05	17	428
55 (C)	10	0.05	6	427

Newspaper (Continued)

Sheets of paper were folded and rolled tightly, lengthwise.

Size of Samples

Weight, Grams	Diameter, Inches	Length, Inches
1/2	5/8	1/4
2	5/8	1 1/8
5	5/8	3
10	1	2 1/4

Engineering Experiment Station

Oregon State College

INVESTIGATION ON IGNITION TEMPERATURES OF ORGANIC MATERIALS

(Project No. 64)

Data on Sample

Common name of sample____________________________________

Supplied by____

Address____

Date_________________________Sample No. (Leave Blank)______

Raw material____

Pulp process____

Sizing____

Filler____

Bleaching process____

Surface or finish____

Coloring____

Special treatments, or remarks___________________________

____

____

____

____

____

Figure 16

impossible to draw any general conclusions by comparing ignition temperatures with the composition and manufacturing history of each sample. The different processes and additives used are shown to be well scattered throughout the entire temperature range indicated. From the data thus far obtained, it appears that the specific characteristics of each individual paper determined the ignition temperature while general trends because of similarities of composition were not consistent.

There are, however, some general and specific results which should be discussed further. All of the ignition temperatures of paper, with a few exceptions, fell within the range 425° F. to 475° F. which indicates that most wood pulp papers, regardless of composition and manufacturing history, will ignite within a 50° F. temperature range (see Figure 17). The ignition and color reactions of the papers were also similar. The samples appeared normal at 300° F., normal to tan at 350° F., tan to brown at 400° F., brown to black at 450° F. (if not ignited), and black at 500° F. (if not yet ignited). The samples consistently ignited at the hotter end first and burned with a bright red glow. Small flames were noted at higher air flow rates. The residue or ash varied some but tended to be whiter the more complete the ultimate combustion obtained. One exception, mimeograph paper (Sample No. 14),

TABLE 2.

Data on Papers Tested

No.	Name	Ignition Temp., ° F.	Extra Exothermic Reaction, ° F.	Size, Dia. & Length, Inches	Rate of Temp. Rise, ° F./Hr.	Thickness, Inches	Moisture by Wt., %	Wt., Grams	Pulp Process
12	Laminator Dust	405	None	1 X 2	14	----	---	8.7	Kraft
	Newspaper	428	None	1 X 2¼	18	0.0037	7.8	10	---
13	Bluewhite Newsprint	432	None	1 X 2¼	17	0.0033	5.9	10	Sulphite & Groundwood
21	Pulp Dust	434	None	1 X 2	16	----	---	7.4	Sulphate
30	Newsprint	435	None	1 X 2¼	15	0.0035	---	10	Sulphite 18% & Groundwood 82%
2	Oiled Fruit Wrap	434	None	1 X 2¼	16	0.0016	---	10	Sulphite
32	Corrugating Box Board	440	None	1 X 2¼	15	0.010	7.3	10	Sulphite & Groundwood
--	Yellow Copy	441	None	1 X 2¼	22	0.0028	5.0	10	---
24	Waxed Paper	450	None	7/8 X 2½	15	0.0024	4.9	10	Sulphate

TABLE 2. (Continued)

No.	Name	Ignition Temp., °F.	Extra Exothermic Reaction, °F.	Size, Dia. & Length, Inches	Rate of Temp. Rise, °F./Hr.	Thickness, Inches	Moisture by Wt., %	Wt., Grams	Pulp Process
27	Meat Wrap	452	None	1 X 2$\frac{1}{4}$	15	0.0037	5.6	10	Sulphite 90% & Groundwood 10%
26	Toilet Tissue	452	None	1 X 3$\frac{1}{4}$	20	0.0024	4.8	10	Sulphite 75% & Groundwood 25%
1	Paper Dust	452	None	1 X 2	14	----	---	5.2	Sulphite & Groundwood
28	Toweling	454	None	1 X 3	15	0.0070	4.7	10	Sulphite 30% & Groundwood 70%
14	Mimeograph	458	None	1 X 2$\frac{1}{4}$	14	0.0037	5.12	10	Sulphite
4	Groundwood Pulp	459	None	1 X 3	15	----	---	8.2	Groundwood
29	Toilet Tissue	460	None	1 X 3	12	0.0025	5.3	10	Sulphite 75% & Groundwood 25%

TABLE 2. (Continued)

No.	Name	Ignition Temp., ° F.	Extra Exothermic Reaction, ° F.	Size, Dia. & Length, Inches	Rate of Temp. Rise, ° F./Hr.	Thickness, Inches	Moisture by Wt., %	Wt., Grams	Pulp Process
11	Toilet Tissue	462	None	1 X 3	15	0.0026	4.3	10	Sulphite
15	Bond	462	None	1 X 2¼	14	0.0035	5.0	10	Sulphite
19	Envelope	462	None	1 X 2¼	17	0.0039	4.7	10	Sulphite
6	Kraft Bag	462	None	1 X 2¼	17	0.0041	5.3	10	Kraft
20	Bond	464	None	1 X 2¼	20	0.0024	5.3	10	Sulphite
18	Bond	465	None	1 X 2¼	14	0.0032	5.3	10	Sulphite
23	Fruit Wrap	465	None	1 X 2½	13	0.0018	4.3	10	Sulphate
7	Paper Bag	466	None	1 X 2½	16	0.0037	5.4	10	Sulphite
31	Fruit Wrap	468	None	1 X 2¼	15	0.0016	6.8	10	Sulphite 98% & Groundwood 2%
5	Sulphite Pulp	472	None	1 X 2¼	15	----	---	15	Sulphite
22	Sulphate Pulp	474	None	1 X 2½	15	----	---	7	Sulphate
10	Waxed Kraft Paper	610	461	1 X 2¼	15	0.0038	---	10	Kraft

TABLE 2. (Continued)

No.	Name	Ignition Temp., ° F.	Extra Exothermic Reaction, ° F.	Size, Dia. & Length, Inches	Rate of Temp. Rise, ° F./Hr.	Thickness, Inches	Moisture by Wt., %	Wt., Grams	Pulp Process
3	Oiled Fruit Wrap	610	468	1 X 2¼	16	0.0011	4.7	10	Sulphite
33	Oiled Fruit Wrap	620	460	1 X 2¼	25	0.0013	6.2	10	Sulphite 98% & Groundwood 2%
--	Yellow Copy Paper with Linseed Oil	675	None	1 X 3	12	----	---	10*	----
16	Bleached Grease Proof	679	None	1 X 2¼	12	0.0019	6.2	10	Sulphite
17	Bleached Manifold Parchment	679	None	1 X 2¼	15	0.0020	6.5	10	Sulphite
28	Toweling with Linseed Oil	699	None	1 X 3	13	----	---	10*	Groundwood Sulphite
9	Laminated Kraft	700	None	1 X 2	16	0.0087	2.4	10	Kraft

* Weight of paper only.

TABLE 2. (Continued)

No.	Name	Sizing	Filler	Bleach	Finish	Coloring	Special Treatments
12	Laminator Dust	Rosin-Alum.	None	None	Machine	Anilines	Dust from Slitters & Saws Asphalt Laminator
	Newspaper	---	---	---	---	---	None
13	Bluewhite Newsprint	None	None	Zinc Hydro-sulphite on Groundwood	Machine	Anilines	None
21	Pulp Dust	Collects on dry end of paper machine dryers					Dirty & Oily
30	Newsprint	None	None	None	Calendered	Anilines	None
2	Oiled Fruit Wrap	Rosin-Alum.	None	None	Machine	Anilines	White Oil
32	Corrugating Box Board	None	None	---	Calendered	Bismark Brown Chorsiodine	None
	Yellow Copy	---	---	---	---	---	---
24	Waxed Paper	14#/1000# Resin	20#/1000 Titanox	Hypochlorite	Waxed	Rodamine 0.4 oz/1000# Blue R 0.25 oz/1000#	Wax Added

TABLE 2. (Continued)

No.	Name	Sizing	Filler	Bleach	Finish	Coloring	Special Treatments
27	Meat Wrap	10# Paracol 3# Lime 55# Size 42# Alum. per 1500#	None	None	Calendered	Red Fibers	None
26	Toilet Tissue	None	None	---	Creped & Embossed	None	None
1	Paper Dust	None	None	None	Machine	Anilines	Waste from Saws
28	Toweling	None	None	None	Creped	Auromine 2 oz/1500# Chrysiodine 1 1/8 oz/1500#	None
14	Mimeograph	Rosin	Clay	Hypochlorite	Regular	---	None
4	Groundwood Pulp	None	None	None	---	---	---
29	Toilet Tissue	None	None	None	Creped	None	None
11	Toilet Tissue	None	None	None	Machine	Anilines	None

TABLE 2. (Continued)

No.	Name	Sizing	Filler	Bleach	Finish	Coloring	Special Treatments
15	Bond	Rosin-Starch	Clay-Rayox	Hypochlorite	Regular	---	None
19	Envelope	2% Size	5.5% Talc 3.6% Alum.	None	---	Solar Blue	---
6	Kraft Bag	Rosin-Alum. 2% Size	None	None	Machine	Anilines	Starch Adhesive
20	Bond	2% Size	3% Talc 3.9% Alum.	None	None	Solar Blue	None
18	Bond	2% Size	8.3% Talc 3.9% Alum.	None	---	Solar Blue	None
23	Fruit Wrap	None	None	None	---	None	2.5# Mineral Oil Per Ream
7	Paper Bag	Rosin-Alum.	None	None	Machine	Anilines	Starch Adhesive
31	Fruit Wrap	7# Size 2# Sodium Carbonate 15# Alum. per 1500# Air Dry	None	None	Calendered	Anilines	

TABLE 2. (Continued)

No.	Name	Sizing	Filler	Bleach	Finish	Coloring	Special Treatments
5	Sulphite Pulp	None	None	None	Machine	None	Dried by Forming & Beating
22	Sulphate Pulp	None	None	None	---	None	None
10	Waxed Kraft Paper	Rosin-Alum.	None	None	Machine	Anilines	Waxed on Machine
3	Oiled Fruit Wrap	Rosin-Alum.	None	Hypochlorite	Machine	Anilines	Oiled
33	Oiled Fruit Wrap	7# Size 2# Sodium Carbonate 15# Alum. per 1500# Air Dry	None	None	Calendered	Anilines	Oiled
	Yellow Copy	Plus Linseed Oil					
16	Bleached Greaseproof	0.7% Size	2.3% Alum. 1% Rayox	None	---	Solar Blue	None
17	Bleached Manifold Parchment	0.7% Size	2.3% Alum.	None	---	Solar Blue Lemon Ochre	None

TABLE 2. (Continued)

No.	Name	Sizing	Filler	Bleach	Finish	Coloring	Special Treatments
28	Toweling with Linseed Oil	None	None	None	Creped	Auromine Chrysiodine	Linseed Oil
9	Laminated Kraft	Rosin-Alum.	None	None	Machine	Anilines	Laminated with Asphalt

TABLE 2. (Continued)

Paper Data

General

Air flow rate 0.05 cu. ft./min. Air velocity past specimen and large wire rack at 0.05 cu. ft./min.=10.4 ft./min. Paper rolled tightly and placed in wire rack. Dust tamped into wire rack. Pulp cut into strips and put into rack, except sulphite which was rolled.

Color Reactions Noted

300° F. -- Normal

350° F. -- Normal to Tan

400° F. -- Tan to Brown

450° F. -- Brown to Black (if not ignited)

500° F. -- Black (if not yet ignited)

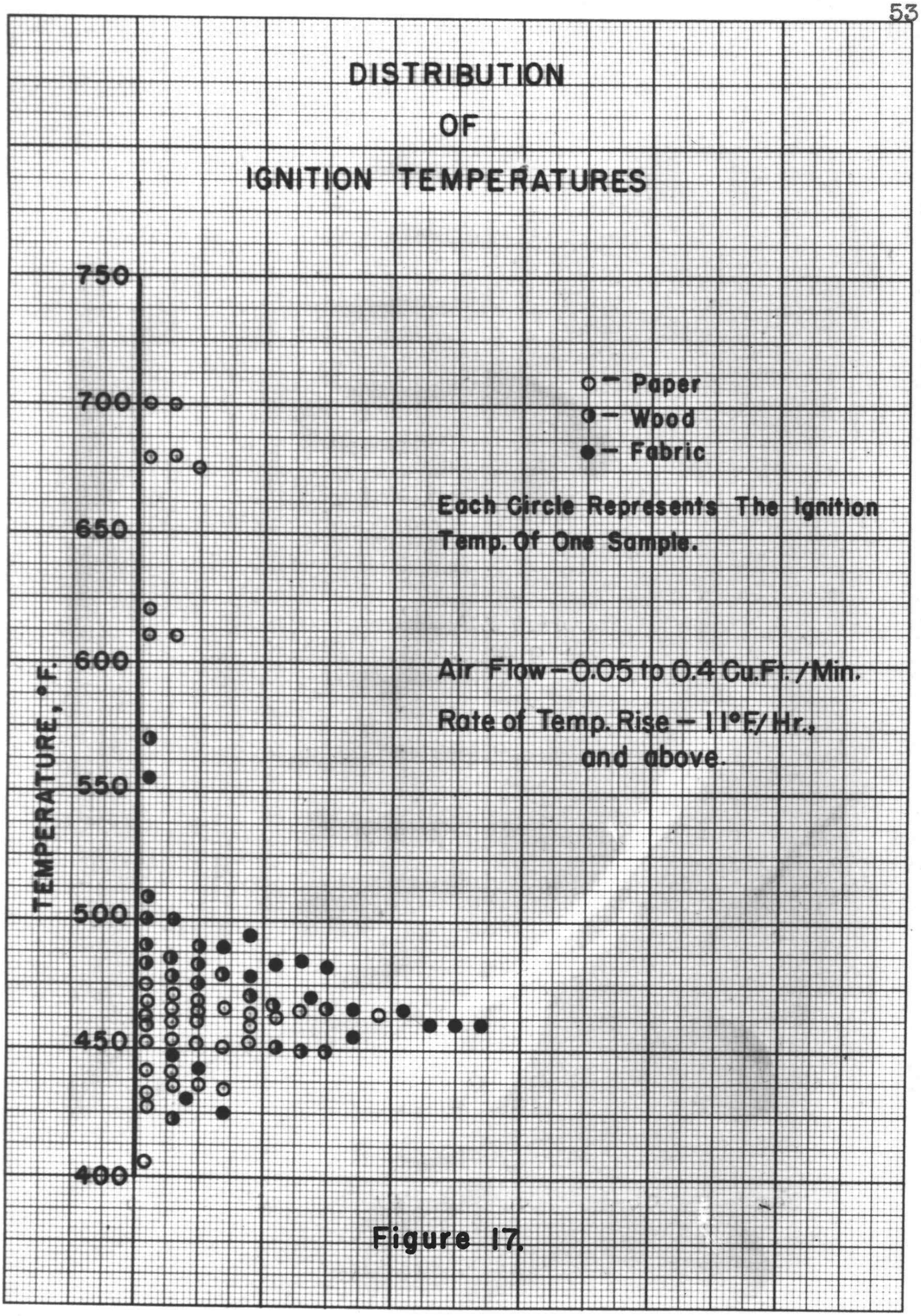

DISTRIBUTION
OF
IGNITION TEMPERATURES
750
700
650
600
550
500
450
400
TEMPERATURE, °F.
o – Paper
◐ – Wood
● – Fabric
Each Circle Represents The Ignition Temp. Of One Sample.
Air Flow – 0.05 to 0.4 Cu.Ft./Min.
Rate of Temp. Rise – 11°F/Hr., and above.

Figure 17.

left a solid black ash which was probably the incombustible clay filler.

The recorded time-temperature curves (Figures 7, 8, and 9) show the phenomenon of ignition to be the result of an exothermic reaction which may or may not generate sufficient heat to carry the process to completion. The temperature at the beginning of this exothermic reaction has been designated as the ignition temperature (if combustion results). The results of using this temperature have thus far been consistent.

Following are examples of the more interesting and unpredictable results obtained. Oiled fruit wraps (Samples Nos. 3 and 33) and waxed kraft paper (Sample No. 10) showed marked exothermic reactions at temperatures between 460° F. and 470° F., but the ultimate ignition reaction took place at temperatures slightly above 600° F. Evidently the oil or wax in the papers caused them to char or blacken with heat given off but not to ignite until a much higher temperature was reached. However, to illustrate the inconsistency, oiled fruit wrap (Sample No. 2), laminator dust which contained asphalt (Sample No. 12), and waxed paper (Sample No. 24) all ignited between 400° F. and 450° F. No reason for the difference was apparent except that the laminator dust was finely divided which may have caused its low ignition temperature. This effect was also noted with the dirty, oily sulphate pulp dust (Sample No. 21) which ignited at a temperature 40 degrees lower than the solid sulphate pulp. An insufficient number of tests was run, however, to draw any definite conclusions on the effect of finely dividing the paper tested. Some of the papers, bleached manifold parchment (Sample No. 17), bleached greaseproof (Sample No. 16), kraft paper laminated with asphalt (Sample No. 9), toweling soaked in linseed oil (Sample No. 28), and yellow copy paper soaked in linseed oil, turned black without a definite exothermic reaction between 450° F. and 500° F. but did not ignite until temperatures close to 700° F. were reached.

As can be seen from Table 2, small differences in moisture content made little difference in the ignition temperature. The reaction range was noted to be over 300° F.; consequently, most of the samples were probably completely dry before the reaction leading to ignition began*. The normal changes in the humidity of the air used also apparently had little effect on the ignition

---

* These reactions mentioned are the more rapid ones noted in these experiments. Slower reactions take place ordinarily, even at room temperatures.

temperature as shown by Table 5. The small differences noted could have been due to small changes in heating rate or to inhomogeneities in the samples themselves. Exhaustive tests with intentional large changes in humidity would be necessary if the trends present, if any, were to be found. If relative humidity is to be a pertinent factor, it is difficult to perceive how it could affect reactions at 400° F. unless excess moisture were introduced at the higher temperature, possibly in the form of superheated steam. Air saturated at 100° F. would have a relative humidity of only 0.38 percent if the temperature were raised to 400° F.

Summarizing, most papers ignite within a given temperature range, other conditions being equal, the individual ignition temperatures depending on the individual paper characteristics. The ignition phenomenon was the result of an exothermic reaction with the critical or ignition temperature designated at the beginning of this reaction. The ignition temperature so designated showed consistent variation with air flow rate, heating rate, and sample weight while the effect of humidity, moisture content, and thickness appeared to be negligible under normal conditions. The technique of testing gave satisfactory results and was used further on wood and fabric samples.

VII.
TESTS OF WOOD

TESTS OF WOOD

The procedure with wood as with paper was to run a more or less complete set of tests on one particular sample in order to find the approximate conditions for minimum ignition temperatures of all woods. It was found, however, that this was not a reliable procedure.

Ponderosa pine (sapwood) was chosen for the first tests because it was common and plentiful. The samples were prepared by cutting the wood into pieces slightly larger in diameter than matches and $2\frac{1}{4}$ inches long and stacking them into a large wire rack (see Figure 10). With this arrangement, there was sufficient air flow to permit ignition and it was possible to standardize the sample. One solid cylinder was tried for possible use as a sample, but ignition did not proceed to completion. There was an exothermic reaction, and the wood charred, blackened, and shrunk in volume but did not ignite.

Curves were plotted from the data as shown in Figures 18 and 19. The trend as with newspaper and yellow copy paper was toward higher ignition temperatures at higher air flow rates, but the curve was of a slightly different form than that obtained from the paper experiments. Minimum ignition temperatures were noticed at rates of air flow ranging from 0.05 to 0.4 cubic feet per minute with little

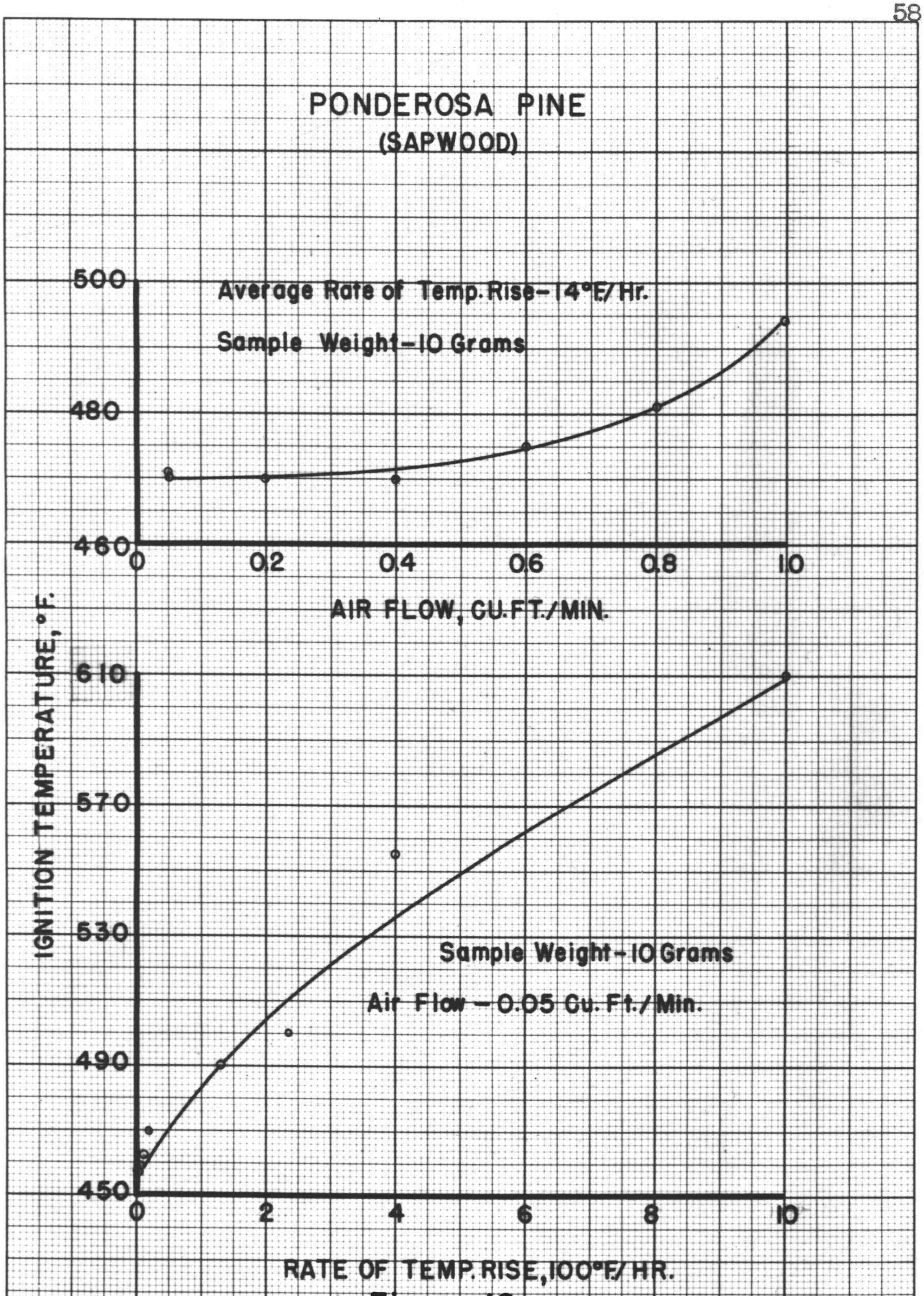

PONDEROSA PINE
(SAPWOOD)
Average Rate of Temp. Rise-14°F/Hr.
Sample Weight-10 Grams
500
480
460
0
0.2
0.4
0.6
0.8
1.0
AIR FLOW, CU.FT./MIN.
IGNITION TEMPERATURE, °F.
610
570
530
490
450
Sample Weight-10 Grams
Air Flow-0.05 Cu. Ft./Min.
0
2
4
6
8
10
RATE OF TEMP. RISE, 100°F/HR.

Figure 18.

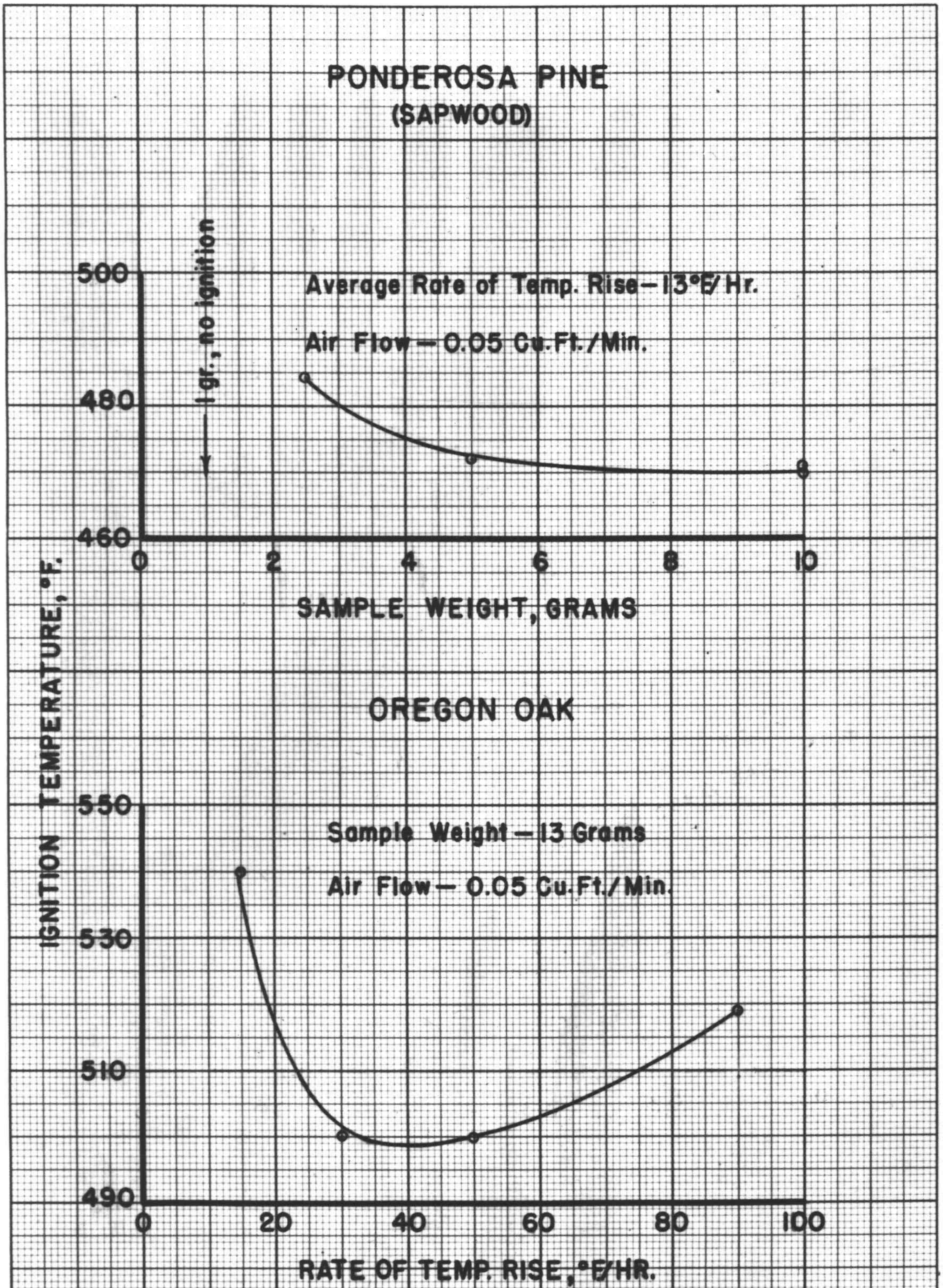

PONDEROSA PINE
(SAPWOOD)
Average Rate of Temp. Rise—13°F/Hr.
Air Flow—0.05 Cu.Ft./Min.
1 gr., no ignition
500
480
460
0
2
4
6
8
10
SAMPLE WEIGHT, GRAMS
IGNITION TEMPERATURE, °F.
OREGON OAK
Sample Weight—13 Grams
Air Flow—0.05 Cu.Ft./Min.
550
530
510
490
0
20
40
60
80
100
RATE OF TEMP. RISE, °F/HR.

Figure 19.

change noticeable below 0.4 cubic feet per minute.

The lowest ignition temperatures were again observed at low heating rates, but no minimum point on the curve was noted even at rates as low as 4° F. per hour. At fast heating rates, a considerable volume of combustible gases was given off just before ignition. These gases ignited readily when a flame was applied.

When testing for the effect of sample size on ignition temperature, some interesting results were recorded which clearly indicated the interdependence of sample weight, air flow rate, and heating rate in the determination of the ignition temperature. The lowest temperatures were noticed, as usual, with the heaviest samples (10 grams), but the smaller samples ignited only with difficulty and sometimes not at all. At an air flow rate of 0.05 cubic feet per minute, a 2½ gram sample ignited while a 1 gram sample did not but merely appeared to slowly turn black and evaporate. At an air flow rate of 0.2 cubic feet per minute or more a 2½ gram sample would not ignite. These tests were at slow heating rates close to 14° F. per hour. The heating rate was increased to 45° F. per hour, and the 2½ gram sample ignited when 0.2 cubic feet of air per minute was used. This indicated that samples of smaller mass, tested at slow heating rates and high air flow rates, permitted an excessive amount of combustible material to escape into the air with the result that instead of ignition a slow gasification and carbonization took place. The faster heating rate gave less time for combustible vapors and gases to escape while lower air flow rates carried less away. When the larger samples were used, there was enough material present to cause ignition even at low heating rates and high air flow rates.

Table 3 gives the tabulated results on ponderosa pine.

For a comparison with paper, the other wood samples were tested at 0.05 cubic feet per minute air flow rate and a 13° F. to 17° F. per hour rate of temperature rise unless a higher rate was required. The sample size was held constant at 1 inch diameter and 2¼ inches length, the weight varying with the density of the wood. The distribution chart (Figure 17) shows that most of the woods ignited between 450° F. and 500° F. which is slightly higher than for paper. The actual ignition temperatures and the conditions of test are given in Table 4. The hard woods, which actually burn more slowly because of their greater density, tended to have lower ignition temperatures than the soft woods.

Some of the specific tests require special comment as several of the woods deviated from the supposedly general results obtained from ponderosa pine (sapwood). As with

TABLE 3.

Ponderosa Pine (sapwood)

Run No.	Wt. of Sample, Grams	Air Flow Rate, Cu.Ft./Min.	Rate of Temp.Rise, °F./Hr.	Ignition Temp., °F.
133	10	0.05	13	470
134	10	0.05	13	471
135	10	0.2	17	470
136	10	0.4	12	470
137	10	0.6	17	475
138	10	0.8	14	469*
139	10	1.0	15	494
140	2½	0.05	12	484
141	5	0.05	12	472
142	2½	0.6	14 approx.	**
143	2½	0.6	14 approx.	**
144	1	0.05	14 approx.	***
145	10	0.05	1000	610
146	10	0.05	400	555
147	10	0.05	235	500
148	2½	0.4	14 approx.	**
149	2½	0.2	14 approx.	**

* Reason for lower temperature unknown--see Run No. 157.

** No ignition.

*** No ignition up to 560°--specimen charred and shrunk.

Ponderosa Pine (continued)

Run No.	Wt. of Sample, Grams	Air Flow Rate, Cu.Ft./Min.	Rate of Temp.Rise, ° F./Hr.	Ignition Temp., ° F.
150	10	0.05	52 (?)	470
151	2½	0.2	43	496
152	10	0.05	20	470
154	10	0.05	11	462
155	10	0.05	6	459
156	10	0.05	4	457
157	10	0.8	15	481*
158	10**	0.05	17	***
162	10	0.05	40	475
164	10	0.05	130	490

* Retest of Run No. 138.

** Solid cylinder.

*** No ignition up to 500° F.

Preparation of Sample

Sticks slightly larger than match sticks put into wire rack. Size of samples: 2 1/4 inches length X 1 inch diameter. Pine was thoroughly air dried, less than 7 percent moisture present.

TABLE 4.

Data on Woods Tested

Name	Class	Ignition Temp., °F.	Weight, Grams	Rate of Temp.Rise, °F./Hr.	Air Flow, Cu.Ft./Min.	Moisture by Wt., %	Size, Dia.&Length, Inches
Oregon Big Leaf Maple	Hard	423	10	16	0.05	Less than 7	1 X $2\frac{1}{4}$
Tan Bark Oak	Hard	448	12	15	0.05	Less than 7	1 X $2\frac{1}{4}$
Oregon Ash	Hard	450	13	13	0.05	Less than 7	1 X $2\frac{1}{4}$
Red Alder	Hard	450	10	16	0.05	Less than 7	1 X $2\frac{1}{4}$
Ponderosa Pine (Sapwood)	Soft	457	10	4*	0.05	7	1 X $2\frac{1}{4}$
Redwood	Soft	467	8	18	0.05	7	1 X $2\frac{1}{4}$
Western Red Cedar	Soft	468	7	17	0.05	Less than 7	1 X $2\frac{1}{4}$
Ponderosa Pine (Sapwood)	Soft	470	10	13*	0.05	Less than 7	1 X $2\frac{1}{4}$
Lodge Pole Pine	Soft	475	9	19	0.05	Less than 7	1 X $2\frac{1}{4}$

* Two different heating rates used.

TABLE 4. (Continued)

Name	Class	Ignition Temp., °F.	Weight, Grams	Rate of Temp. Rise, °F./Hr.	Air Flow, Cu.Ft./Min.	Moisture by Wt., %	Size, Dia.&Length, Inches
Western Hem-lock	Soft	477	10	16	0.05	Less than 7	1 X 2¼
Western White Pine (2nd growth)	Soft	479	10	12	0.05	Less than 7	1 X 2¼
Sitka Spruce	Soft	482	9	16	0.05	Less than 7	1 X 2¼
Sugar Pine	Soft	482	9	18	0.05	Less than 7	1 X 2¼
True Fir	Soft	485	9	18	0.05	Less than 7	1 X 2¼
Douglas Fir	Soft	489	10	16	0.05	7	1 X 2¼
Western White Pine (Old growth)	Soft	490	8½	25	0.20	Less than 7	1 X 2¼
Ponderosa Pine (Heartwood)	Soft	500	8	24	0.05	Less than 7	1 X 2¼
Oregon Oak	Hard	500	13	30	0.05	Less than 7	1 X 2¼
Western White Pine (Pitchy 2nd growth)	Soft	508	15	28	0.05	Less than 7	1 X 2¼

TABLE 4. (Continued)

Name	Class	Ignition Temp., °F.	Weight, Grams	Rate of Temp.Rise, °F./Hr.	Air Flow, Cu.Ft./Min.	Moisture by Wt., %	Size, Dia.&Length, Inches
Western Larch	Soft	570	11	26	0.2	Less than 7	1 X 2¼

TABLE 5.

Effect of Relative Humidity of the Air on Ignition Temperature

Sample	Ignition Temp., °F.	Relative Humidity at End of Test, %
	Paper	
Newspaper	428	50.4
*	428	45.0
Mimeograph	460	43.0
*	457	43.0
White Bond (No. 15)	460	26.4
*	465	38.5
White Bond (No. 18)	465	43.2
*	465	37.8
Oiled Fruit Wrap (No. 2)	434	53.7
*	435	32.6
	Wood	
Sitka Spruce	483	43.5
*	481	48.5
Western Red Cedar	466	39.0
*	470	49.5
True Fir	484	40.6
*	486	42.6
Sugar Pine	484	48.5
*	480	39.5

* Same conditions of test for comparison.

TABLE 5. (Continued)

	Ignition Temp., °F.	Relative Humidity at End of Test, %
Wood (Continued)		
Lodge Pole Pine	480	38
*	470	49.5
Western White Pine	480	45.5
*	478	40.7

* Same conditions of test for comparison.

Note: No attempt was made to produce large variations of humidity. Normal humidity changes produced no consistent variation of the ignition temperature as noted above.

paper, several of the woods exhibited extra exothermic reactions which did not lead to ignition, but this should have been expected, for exothermic reactions are common in the destructive distillation of wood. At a slow rate of temperature rise (13° F. to 17° F. per hour), ponderosa pine (heartwood) showed a slight exothermic reaction with accompanying fumes and blackening of the specimen at a temperature just below 500° F., but no ignition at that temperature. The rate of temperature rise was increased with the thought that ignition close to 500° F. might be possible if the exothermic reaction were boosted slightly with oven heat and the volatile gases had less time to escape. At a heating rate of 24° F. per hour, the wood ignited at 500° F. and burned. This indicates that with certain woods there is a distinct minimum heating rate at which ignition can be obtained or at which a low ignition temperature can be obtained. The same result was obtained with western white pine (old growth) which reacted exothermically at 500° F. when the 13° F. to 17° F. per hour heating rate was employed. The heating rate was increased to 25° F. per hour and ignition took place at 490° F. A series of tests on these woods would probably give a heating rate-temperature curve with a distinct minimum point or range.

Lodge pole pine and Douglas fir gave quite similar but erratic results. Approximately half the tests of these woods (15° F. to 20° F. per hour and 0.05 cubic feet per minute) gave ignition temperatures from 470° F. to 490° F. while the other half yielded a light exothermic reaction just below 500° F. and much higher ignition temperatures. There was no immediately apparent reason for the difference in the tests. The conditions for a low ignition temperature for those woods were evidently very critical.

Figure 19 shows the curve obtained from tests of Oregon oak. This is the best example obtained so far of a minimum range in the heating rate-temperature curve. The ignition temperature was slightly higher than for other woods and was minimum at a heating rate of 30° F. to 50° F. per hour. Testing of western larch showed the same effect with the minimum ignition temperature of 570° F. coming at a heating rate of 26° F. per hour. The temperature, 570° F., was the highest value of minimum ignition temperature obtained from the woods tested.

A small quantity of pitchy western white pine (2nd growth) was available. This was tested but gave inconsistent results. One ignition (no exothermic reaction noticed) was obtained at 660° F. while another was obtained at 508° F. when gases at the end of the tube were ignited with a flame. This indicates that it would be possible to obtain definite flash and fire points for some of the woods similar to those obtained with petroleum products.

Summing up the results of the tests of wood, the ignition temperature was again seen to be an individual property of the specific material, even more so than with the paper. One particular wood was seen to be not wholly representative of the entire class of material. More exhaustive tests (which time did not permit) of each specimen would undoubtedly show more clearly the trends effected by changes in the conditions of test. Nevertheless, most of the woods ignited within a certain temperature range so that results, in general, were similar. Variations with air flow rate, heating rate, and sample weight were noted similar to those obtained with paper, but some individual woods had distinct minimums in their heating rate-temperature curves. Humidity of the air and moisture content of the specimens again had no apparent consistent affect on the ignition temperatures obtained. (See Tables 4 and 5).

VIII.
TESTS OF FABRICS

TESTS OF FABRICS

The procedure used in testing fabrics was somewhat more abbreviated than that used in testing paper and wood. This was due to the lack of time, the small amount of some samples available, and the relatively great area of fabrics required to make a large sample 1 inch in diameter and 2½ inches long. Small samples approximately 5/8 inches in diameter and 1½ inches long were used for preliminary tests of each major type of fabric. The effect of air flow rate and rate of temperature rise on the small samples was noted and a larger sample was tested at the conditions indicated for a minimum ignition temperature. By this method, an approach to the minimum was accomplished with a saving in time and material. Single runs were made on other specimens of the same major types of fabric after the general trends and conditions for a minimum were found.

Table 6 and Figures 20, 21, 22, and 23 give the complete results of the fabric tests. The results on each major type of fabric will be described separately.

White cotton flannel, which was probably as nearly pure cellulose as any sample tested, showed trends very much like yellow copy paper and ponderosa pine (Figure 20). The ignition temperature decreased with increase of

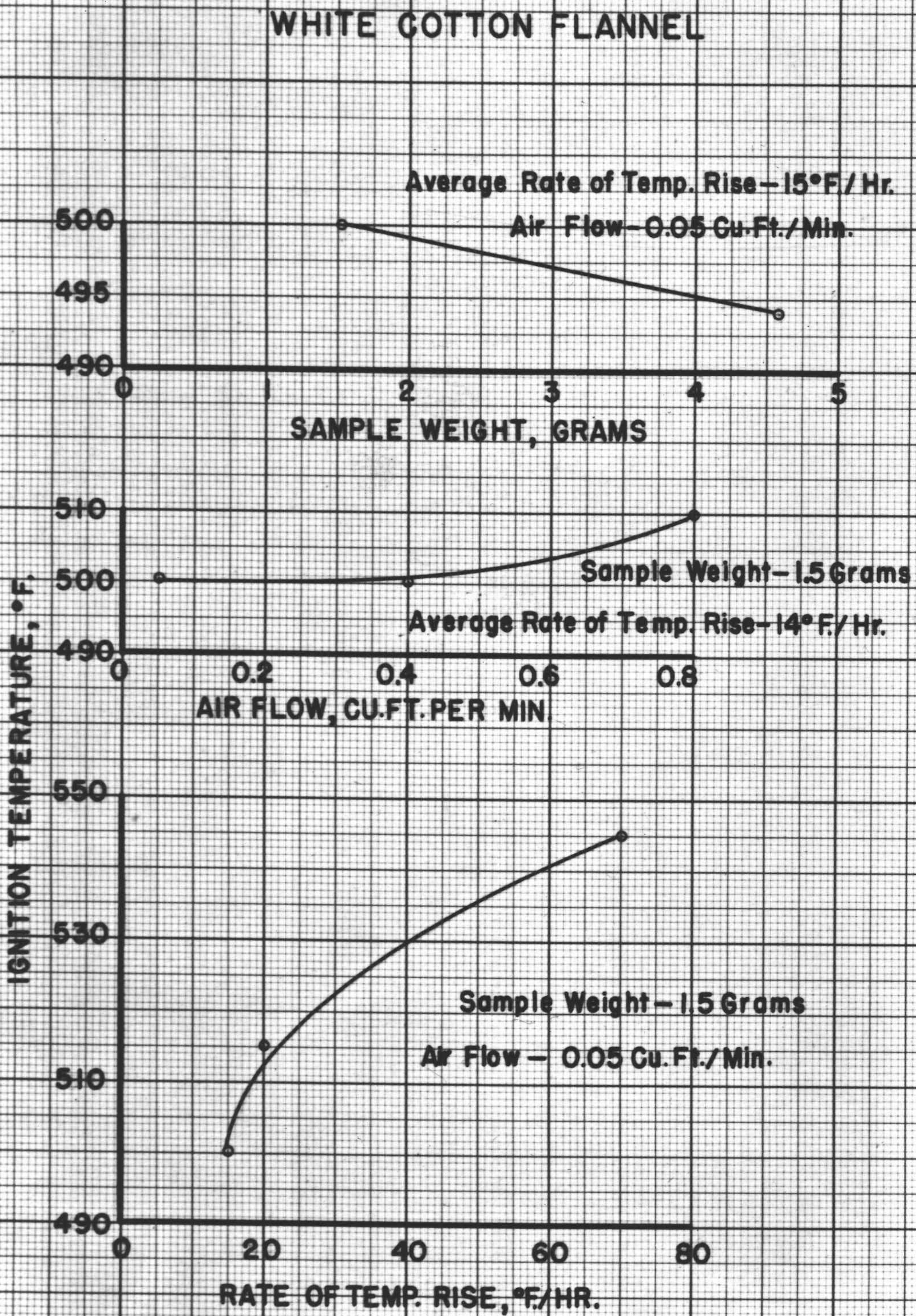

WHITE COTTON FLANNEL
Average Rate of Temp. Rise – 15°F./Hr.
Air Flow – 0.05 Cu.Ft./Min.
500
495
490
0
1
2
3
4
5
SAMPLE WEIGHT, GRAMS
510
500
490
Sample Weight – 1.5 Grams
Average Rate of Temp. Rise – 14° F./Hr.
0
0.2
0.4
0.6
0.8
AIR FLOW, CU.FT. PER MIN.
IGNITION TEMPERATURE, °F.
550
530
510
490
Sample Weight – 1.5 Grams
Air Flow – 0.05 Cu.Ft./Min.
0
20
40
60
80
RATE OF TEMP. RISE, °F/HR.

Figure 20.

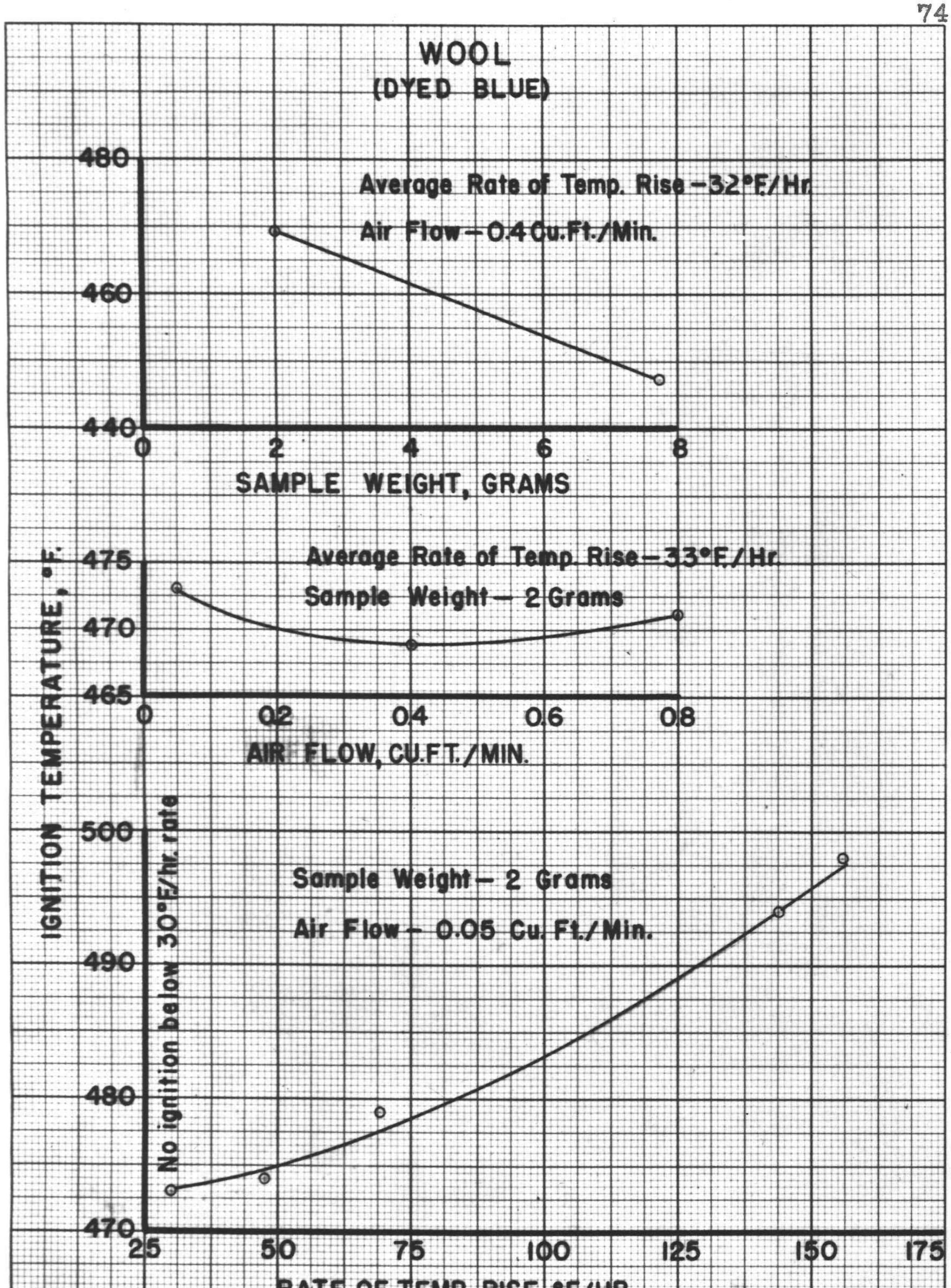

WOOL
(DYED BLUE)
Average Rate of Temp. Rise — 32°F./Hr.
Air Flow — 0.4 Cu.Ft./Min.
480
460
440
0
2
4
6
8
SAMPLE WEIGHT, GRAMS
Average Rate of Temp. Rise — 33°F./Hr.
Sample Weight — 2 Grams
475
470
465
0
0.2
0.4
0.6
0.8
AIR FLOW, CU.FT./MIN.
IGNITION TEMPERATURE, °F.
No ignition below 30°F./hr. rate
Sample Weight — 2 Grams
Air Flow — 0.05 Cu. Ft./Min.
500
490
480
470
25
50
75
100
125
150
175
RATE OF TEMP. RISE, °F./HR.

Figure 21.

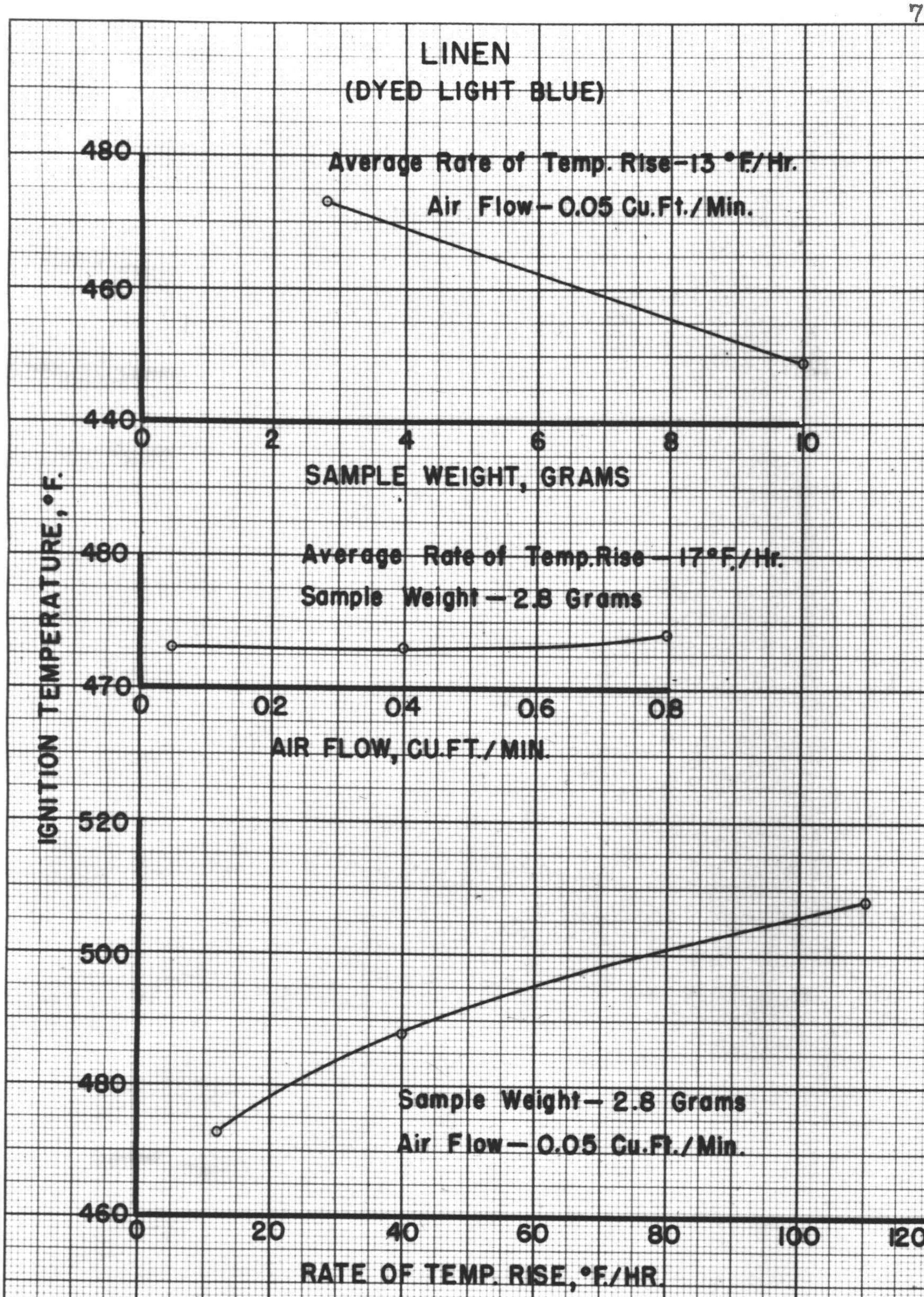

LINEN
(DYED LIGHT BLUE)
Average Rate of Temp. Rise-13 °F./Hr.
Air Flow-0.05 Cu.Ft./Min.
480
460
440
0
2
4
6
8
10
SAMPLE WEIGHT, GRAMS
Average Rate of Temp.Rise-17°F./Hr.
Sample Weight-2.8 Grams
480
470
0
0.2
0.4
0.6
0.8
AIR FLOW, CU.FT./MIN.
IGNITION TEMPERATURE, °F.
520
500
480
460
Sample Weight-2.8 Grams
Air Flow-0.05 Cu.Ft./Min.
0
20
40
60
80
100
120
RATE OF TEMP. RISE, °F./HR.

Figure 22.

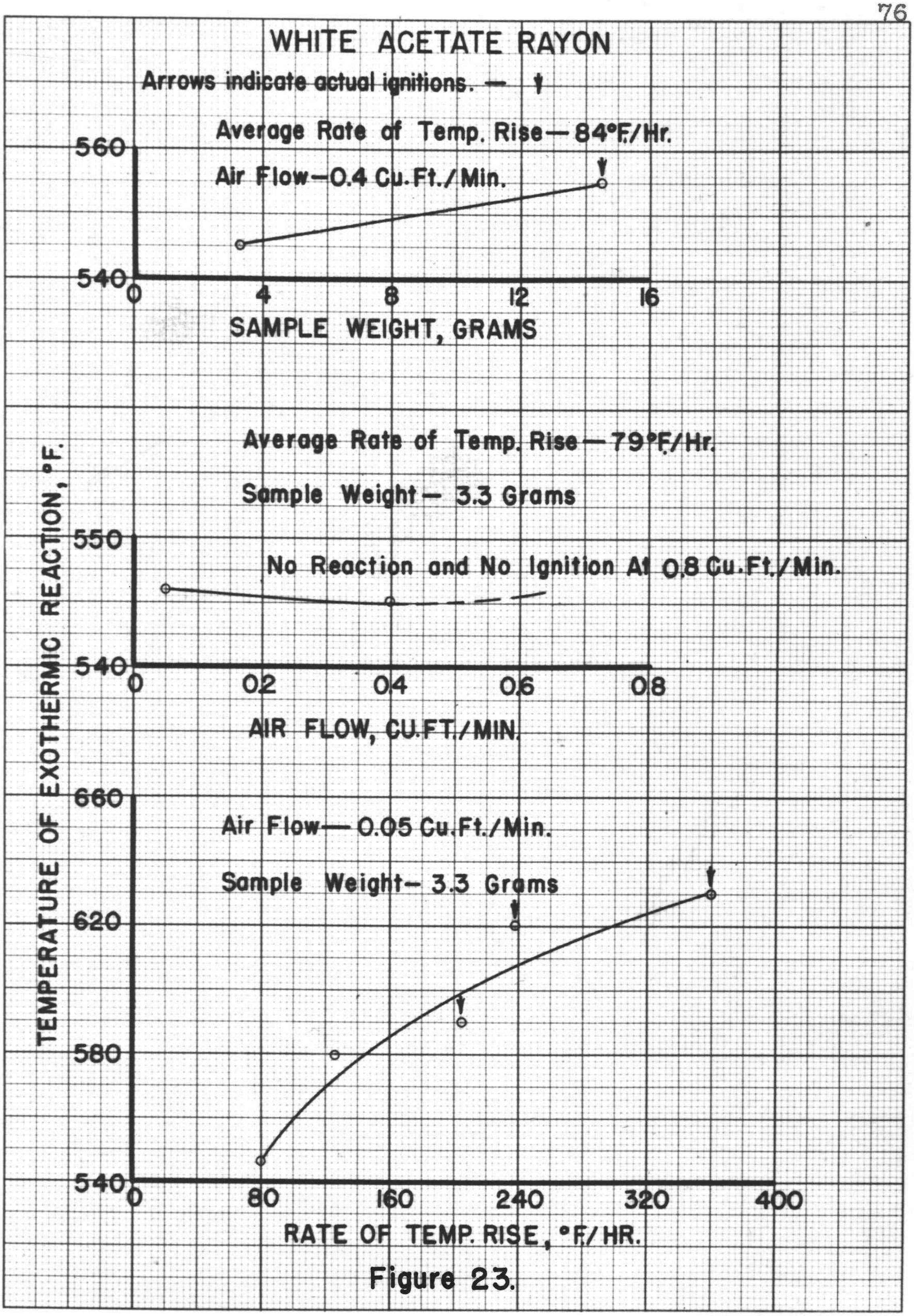

WHITE ACETATE RAYON
Arrows indicate actual ignitions. —
Average Rate of Temp. Rise — 84°F./Hr.
Air Flow — 0.4 Cu. Ft./Min.
560
540
0
4
8
12
16
SAMPLE WEIGHT, GRAMS
Average Rate of Temp. Rise — 79°F./Hr.
Sample Weight — 3.3 Grams
No Reaction and No Ignition At 0.8 Cu. Ft./Min.
550
540
0
0.2
0.4
0.6
0.8
AIR FLOW, CU. FT./MIN.
TEMPERATURE OF EXOTHERMIC REACTION, °F.
Air Flow — 0.05 Cu. Ft./Min.
Sample Weight — 3.3 Grams
660
620
580
540
0
80
160
240
320
400
RATE OF TEMP. RISE, °F./HR.

Figure 23.

TABLE 6.

Data From Fabric Tests

Run No.	Material	Sample Wt., Grams	Rate of Air Flow, Cu.Ft./Min.	Rate of Temp.Rise, °F./Hr.	Color	Extra Exothermic Reaction, °F.	Ignition Temp., °F.
242	Acetate Rayon	3.15	0.05	360	White	None	630
243	"	3.15	0.05	238	"	"	620
244	"	3.3	0.05	205	"	"	591
245	"	3.3	0.05	127	"	580	None
246	"	3.3	0.05	80	"	546	"
247	"	3.3	0.4	83	"	545	"
248	"	3.3	0.8	74	"	None	"
249	"	13.88	0.4	110	"	"	580
252	"	14.45	0.4	89	"	"	555
259	Cotton Canvas Awning	10.95	0.05	15	White & Green	"	459
217	Cotton Corduroy	6.32	0.05	17	Blue	"	489
211	Cotton Flannel	1.52	0.05	15	White	"	500
212	"	1.43	0.4	13	"	"	500

TABLE 6. (Continued)

Run No.	Material	Sample Wt., Grams	Rate of Air Flow, Cu.Ft./Min.	Rate of Temp.Rise, °F./Hr.	Color	Extra Exothermic Reaction, °F.	Ignition Temp., °F.
213	Cotton Flannel	1.5	0.8	15	White	None	510
214	"	1.45	0.05	20	"	"	515
214a	"	1.45	0.05	70	"	"	5.47
215	"	4.59	0.05	14	"	"	494
216	"	4.45	0.05	5	"	"	465
261	Cotton Mesh Curtain	7.0	0.05	12	"	"	484
255	Cotton and Silk	12.3	0.05	12	Green	"	455
258	"	10.0	0.05	12	Red & White	"	478
262	"	10.57	0.05	14	Maroon & White	"	460
232	Linen	2.82	0.05	16	Light Blue	"	473
234	"	2.71	0.4	18	"	"	473
235	"	2.76	0.05	40	"	"	488
236	"	2.7	0.05	110	"	"	508
237	"	2.78	0.8	19	"	"	474

TABLE 6. (Continued)

Run No.	Material	Sample Wt., Grams	Rate of Air Flow, Cu.Ft./Min.	Rate of Temp.Rise, °F./Hr.	Color	Extra Exothermic Reaction, °F.	Ignition Temp., °F.
238	Linen	10.11	0.05	11	Light Blue	None	445
239	"	10.33	0.03	11	"	"	441
256	"	13.6	0.05	15	Unbleached	"	463
265	"	18.15	0.05	15	White	"	482
254	Nylon Hose	9.0	0.05	12	Tan	461	None
266	Regenerated Rayon	10.71	0.05	15*	Blue & White	None	Below 440
267	Regenerated Rayon Hose	11.47	0.05	17	Tan	"	460
257	Rug Material (Jute, Wool, and Cotton)	11.22	0.05	15	Cotton-White Jute-Tan Wool-Grey	"	470
250	Silk	2.6	0.05	13	Green & White	"	468
251	"	9.8	0.05	14	"	"	431

* Approximately.

TABLE 6. (Continued)

Run No.	Material	Sample Wt., Grams	Rate of Air Flow, Cu.Ft./Min.	Rate of Temp.Rise, °F./Hr.	Color	Extra Exothermic Reaction, °F.	Ignition Temp., °F.
263	Pure Dye Silk	8.60	0.05	11	White	None	425
264	Weighted Silk	4.45	0.05	12	"	"	None
218	Wool	2.05	0.05	15*	(#1) Blue	"	None up to 600
219	"	2.0	0.05	600	"	"	800
220	"	2.0	0.05	30*	"	"	None up to 650
221	"	2.0	0.05	156	"	"	498
222	"	2.0	0.05	138	"	"	494
223	"	2.0	0.05	69	"	"	479
224	"	2.0	0.05	45	"	"	474
225	"	2.0	0.05	30	"	"	473
226	"	2.0	0.05	20*	"	"	None up to 630

* Approximately.

TABLE 6. (Continued)

Run No.	Material	Sample Wt., Grams	Rate of Air Flow, Cu.Ft./Min.	Rate of Temp.Rise, °F./Hr.	Color	Extra Exothermic Reaction, °F.	Ignition Temp., °F.
228	Wool	2.0	0.4	37	(#1) Blue	None	469
229	"	2.0	0.8	32	"	"	471
231	"	7.73	0.4	28	"	"	447
233	"	9.23	0.4	33	White	431	None
253	"	7.42	0.4	18	(#2) Blue	None	431
260	Wool and Cotton	4.24	0.05	14	White	"	482

sample weight, decrease of air flow, and decrease of heating rate. No absolute minimum was reached in any of the curves although very little change was noted with air flow changes from 0.05 cubic feet per minute to 0.4 cubic feet per minute. The use of No. 1/3 cam (heating rate 5° F. per hour) produced an ignition temperature 30° F. lower than that obtained with No. 1 (heating rate 14° F. per hour). This was a more marked decrease than noted before under the same conditions. Blue cotton corduroy and white mesh cotton curtain had ignition temperatures within 10 degrees of the ignition temperature of the flannel while the cotton awning canvas ignited at a temperature 35 degrees lower. Evidently the dye or paint in the canvas caused the ignition to proceed to completion at a lower temperature. No peculiar reactions were noted with cotton fabrics.

Wool, the first animal fiber tested, gave slightly different results. Ignition was obtained at heating rates of 30° F. per hour and over, but not at lower rates. At the rates below 30° F. per hour, the wool samples appeared to char and shrink with a relatively incombustible pellet left as the residue. The pellet was of a black honeycomb structure inside indicating that some sort of a reaction had taken place. No definite exothermic reaction was noted, however. With increase of the heating rate above the lower limit, the ignition temperature increased as noted before (Figure 21).

The air flow-temperature curve showed a definite, although slight, minimum at 0.4 cubic feet per minute. Such slight minimums were noted by Brown (3) in some of his experiments. A larger sample was tested at 0.4 cubic feet per minute and approximately 30° F. per hour with a resulting lower ignition temperature of 447° F. Two other wool specimens were then tested. One ignited at 431° F. while the other exhibited a marked exothermic reaction at 431° F., but ignition did not proceed to completion. Specimens of the same major type of fabric did not all show quite the same ignition characteristics.

The curves obtained from the linen tests were well defined and very similar to those obtained from the yellow copy paper and ponderosa pine tests. (See Figure 22). Higher ignition temperatures were experienced with increases in air flow and heating rate and decreases in sample size. The average ignition temperature obtained at a heating rate of 11° F. per hour and 0.05 cubic feet per minute air flow rate was 442° F. Two other specimens were tested with resulting ignitions at 482° F. and 463° F. at a heating rate of 15° F. per hour. The composition of the specimens undoubtedly caused the wide variation in results as the slight increase in heating rate could not cause much change in the ignition temperature.

Acetate rayon was the last major type of fabric on which a set of curves was obtained. The information on the reactions obtained was more individualistic than that obtained from any of the other materials, the rayon being actually a type of plastic. There was a distinct chain of different reactions. At a temperature of 425° F. to 475° F., the specimens shrunk and darkened in color with no exothermic or endothermic reaction apparent. At a temperature above 500° F., strong acetic acid fumes were given off and the specimen turned black and swelled to approximately its original size. At the point of swelling, a slight endothermic reaction was noticed with the larger specimens. The inside of the specimens appeared honeycombed and porous. At some time after the swelling took place, an exothermic reaction began which, with larger specimens and faster heating rates, resulted in an actual ignition. With smaller samples at the slower heating rates, the reactions were not vigorous enough to cause actual ignition and in some cases failed to show any change in the recorded temperature curve. A slight minimum was again noticed in the air flow-temperature curve at 0.4

cubic feet per minute. At 0.8 cubic feet per minute, no ignition or exothermic reaction took place. The lowest ignition temperature obtained was 555° F. with a sample weight of 14.5 grams, a heating rate of 89° F. per hour, and an air flow rate of 0.4 cubic feet per minute.

The remaining specimens were available in small quantities only, and the results are of one or two runs only. Table 6 gives the conditions of the tests.

Regenerated rayon acted more like the vegetable cellulose base materials. It ignited readily and apparently with no complicated chain of reactions as experienced with acetate rayon. One specimen ignited at 460° F. while the other ignited below 440° F. (the exact temperature was not obtained).

Three samples of silk were tested. Two of these, which were ordinary pure silk, ignited at 431° F. and 425° F. The other sample was a weighted silk (metallic weighting). It ignited with difficulty if a flame was applied, but the burning stopped when the flame was taken away. In the oven, the specimen turned black, but no exothermic reaction was recorded.

The one sample of nylon hose tested yielded no ignition. There was a slight exothermic reaction at 461° F. Above that temperature, the specimen merely turned black and appeared to melt. No ignition was noted up to 800° F., although heavy gases were given off which could be ignited with a flame.

Several combination materials were tested. Three combination cotton and silk specimens ignited at 455° F., 478° F., and 460° F. These temperatures were approximately half way between those yielded by pure cotton and pure silk under the same conditions. One wool and cotton combination was tried. It ignited at 482° F. which was closer to the ignition temperature for cotton than that for wool. This should be expected, however, as the conditions of the test were those ideal for cotton and not for wool. A combination jute, cotton, and wool rug material ignited at 470° F. which again seems to be near the center of the most common ignition range.

The tests of fabrics gave the widest variation of results of any of the major classes of materials, but the variation in the materials themselves also was wide. Nevertheless, the majority of the ignition temperatures were in the range 425° F. to 500° F. which is approximately the same as the range for paper and wood. Most of the values (Figure 17) tended to group themselves in this one range, even though some of the materials were animal, some vegetable, and some plastic. As with paper and wood, marked variations of ignition temperatures with air flow rate, sample weight, and rate of temperature rise were noticed although the individual amounts and direction of variation were not all the same.

It was impossible in the short time available to cover all fabric possibilities. The magnitude of such possibilities is indicated partially by the amount of variation experienced in this abbreviated set of tests.

IX.
CONCLUSIONS

CONCLUSIONS

It has been found impossible to cover the field of organic materials completely in the amount of time that could be spent in these experiments. There are many different materials available; materials of even the same class may have different ignition characteristics; each test took approximately 12 to 18 hours to complete; and finally, the conditions of the tests may be varied over a very large range. With some materials, as much as two months could be spent on one single specimen in order to get complete curves and data. Consequently, the attempt has been made to approach values of minimum ignition temperatures for the materials tested by noting trends and by testing the materials under the most favorable conditions possible with the equipment used. The conditions which were thought to have the most effect on the ignitions temperature were varied. These were: air flow rate, sample weight, rate of temperature rise, and composition of sample. General trends of variation were established and are shown in the accompanying tables and curves. Values close to minimum ignition temperatures under natural conditions have been found and should prove useful in safety and fire prevention work.

The ignition phenomenon has been seen to be the result of an exothermic reaction which may or may not cause ignition, depending on the amount of heat evolved and the nature of the material. Although the exact point of ignition is difficult to designate, the definition used in this thesis (page 3), that of the temperature at the beginning of the exothermic reaction, has given consistent results.

Probably the most useful conclusion which can be drawn from these tests is this: The approximate minimum ignition temperature of the majority of papers, woods, and fabrics falls within a definite temperature range. With the apparatus and conditions used in these tests, this range covered temperatures from 400° F. to 500° F. with the peak coming close to 460° F. Some materials have ignition temperatures outside of this range, but these temperatures tend to be higher rather than lower. Discoloration of samples, indicating some initial reactions taking place, began at temperatures between 300° F. and 400° F.

The variation of ignition temperature with sample weight, in all cases recorded, showed a decrease with an increase of sample weight. No optimum size or weight of sample was reached as the dimensions of the equipment limited the weight of samples which could be tested. The curves obtained were in general of a concave upward form (see curve sheets).

The variation of ignition temperature with air flow rate was also consistent when tightly packed or rolled samples were used. As long as sufficient air to support ignition was supplied, the ignition temperature increased in general with increase in air flow. At the lower air flow rates, the curves showed a distinct flattening and in some cases a slight minimum. The curves were again of general concave upward form.

The variation of ignition temperature with rate of temperature rise yielded a variety of different forms of curves. There were three prominent curve forms: (1) Concave downward with no minimum point or range (Figures 12, 18, 20, 22, and 23); (2) Concave upward with no minimum point or range (Figure 21); (3) Concave upward with a definite minimum point or range (Figure 19).

Absolute minimum ignition temperatures were not obtained in all the tests. There were two reasons for this. One, the sample weight was limited by apparatus dimensions, as mentioned before. Two, heating rates lower than 5° F. to 15° F. per hour were impractical with the equipment used. Tests of newspaper at a heating rate of 17° F. per hour produced ignition at 428° F. while a test at a heating rate of 6° F. per hour produced ignition at 427° F. If this is considered representative, the ignition temperatures of paper closely approached the minimum. Ponderosa pine showed a difference of 13° F. in ignition temperature when the heating rate was decreased from 13° F. to 4° F. per hour. With cotton flannel, the ignition temperature decreased 29 degrees when the heating rate was decreased from 14° F. to 5° F. per hour. With some of the other materials (oak, wool, acetate rayon), the minimum ignition temperature apparently was reached. In spite of this discrepancy, it is believed that the values obtained approach the minimum with useful accuracy, for it is doubtful if the most ideal conditions for ignition would ever be attained under natural or normal conditions of storage of the combustible materials. The type of minimums recorded varied some also. Some were shown as actual minimums of the curves, as indicated above, while others were minimum heating rates at which ignition was possible and below which only a slow oxidation and evaporation resulted. The general trend was toward higher ignition temperatures at higher heating rates. This showed distinctly the dependence of ignition temperature on time and that the phenomenon was not merely an event in time.

The composition of the samples caused the ignition temperature to vary throughout the distribution range. The majority of the samples tested were of a vegetable or cellulose base and would be expected to fall within a general range, but some of the other materials which were not of a vegetable cellulose nature also had ignition temperatures in this range. The composition of most of the samples was complicated enough to discourage any attempt at correlating ignition temperature with composition. The ignition temperature is distinctly an individual characteristic.

The tests made by Brown (3) yielded values which do not all agree with these experiments. Some of his values are 487° F. for filter paper and 443° F. for absorbent cotton which are within the range shown in this thesis. However, he recorded some values as low as 378° F. for western red cedar and 363° F. for newsprint which are much lower than the values indicated herein. These values were obtained at heating rates above 100° F. per hour which are much higher than the heating rates at minimums indicated in Tables I, III, and VI. Undoubtedly, the exact conditions of test, arrangement of the equipment, and the composition of specimens made the differences. This again stresses the importance of standardization of method and equipment and the need for more complete investigation of the whole ignition question.

There is much room for additional original investigations which could include:

1) More complete tests of materials already tested.

2) Tests of building materials.

3) Tests of fireproofed and other specially treated materials.

4) Tests with changes in atmosphere and relative humidity of the atmosphere used.

5) Investigation of ignition phenomenon by use of analyses of specimens at various points in the reaction range.

It is hoped that this set of tests may prove useful in the fire prevention field and may form the basis for further experiments as suggested above.

X.
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XI.
APPENDIX I - OVEN CURVES

OVEN

TIME-TEMPERATURE

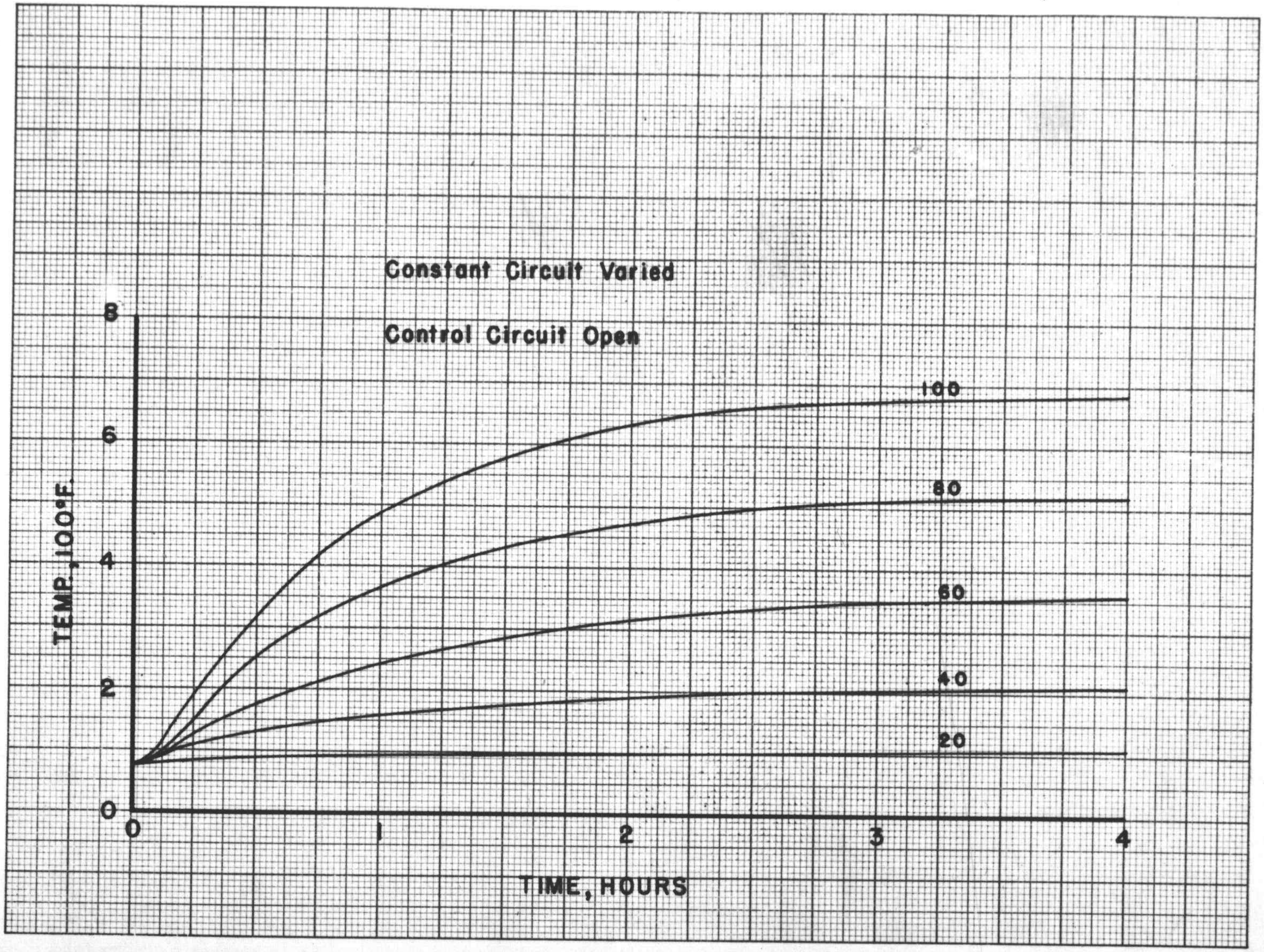
CURVES

for

Various

Constant and Control Circuit

Variac Settings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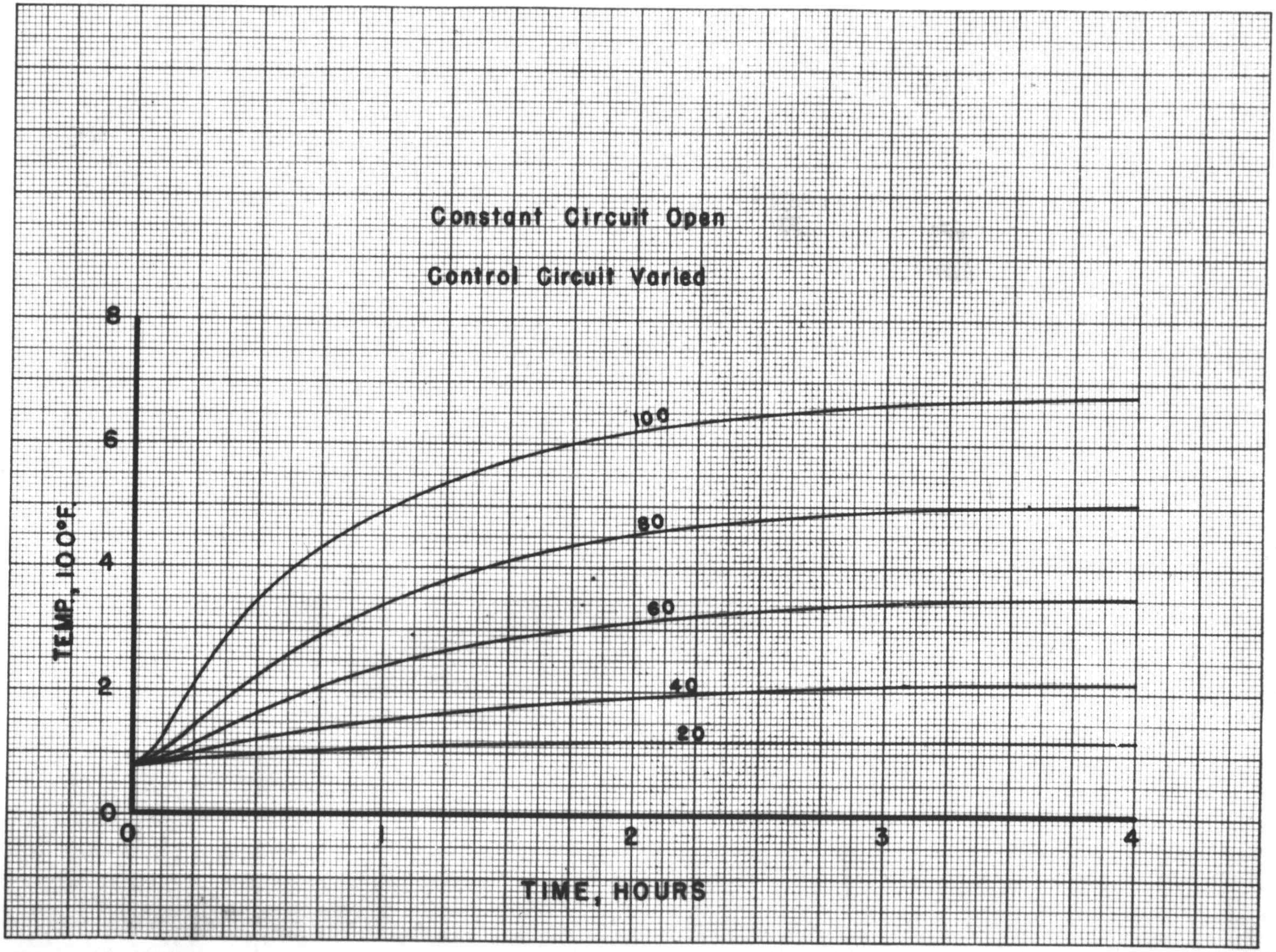
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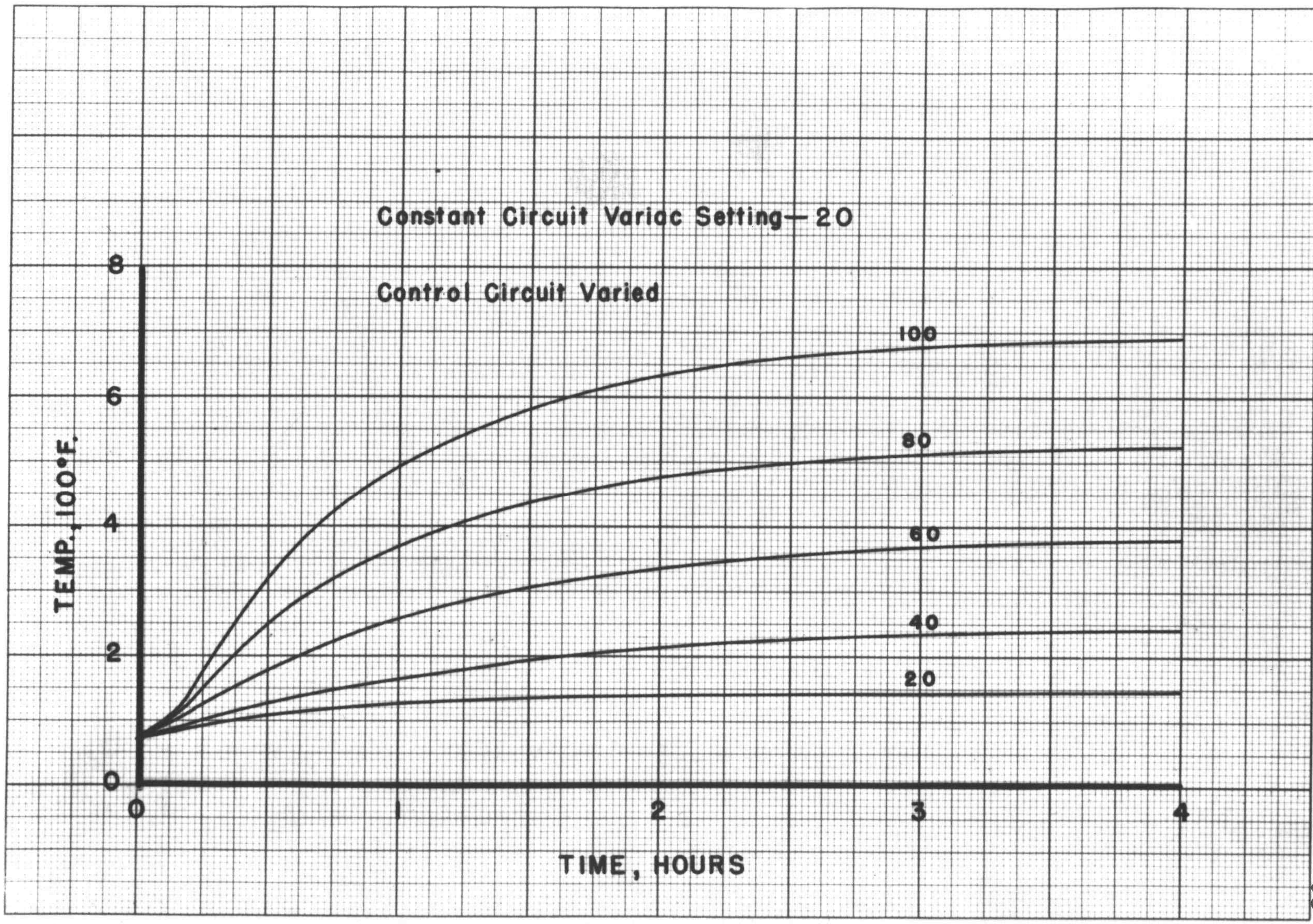

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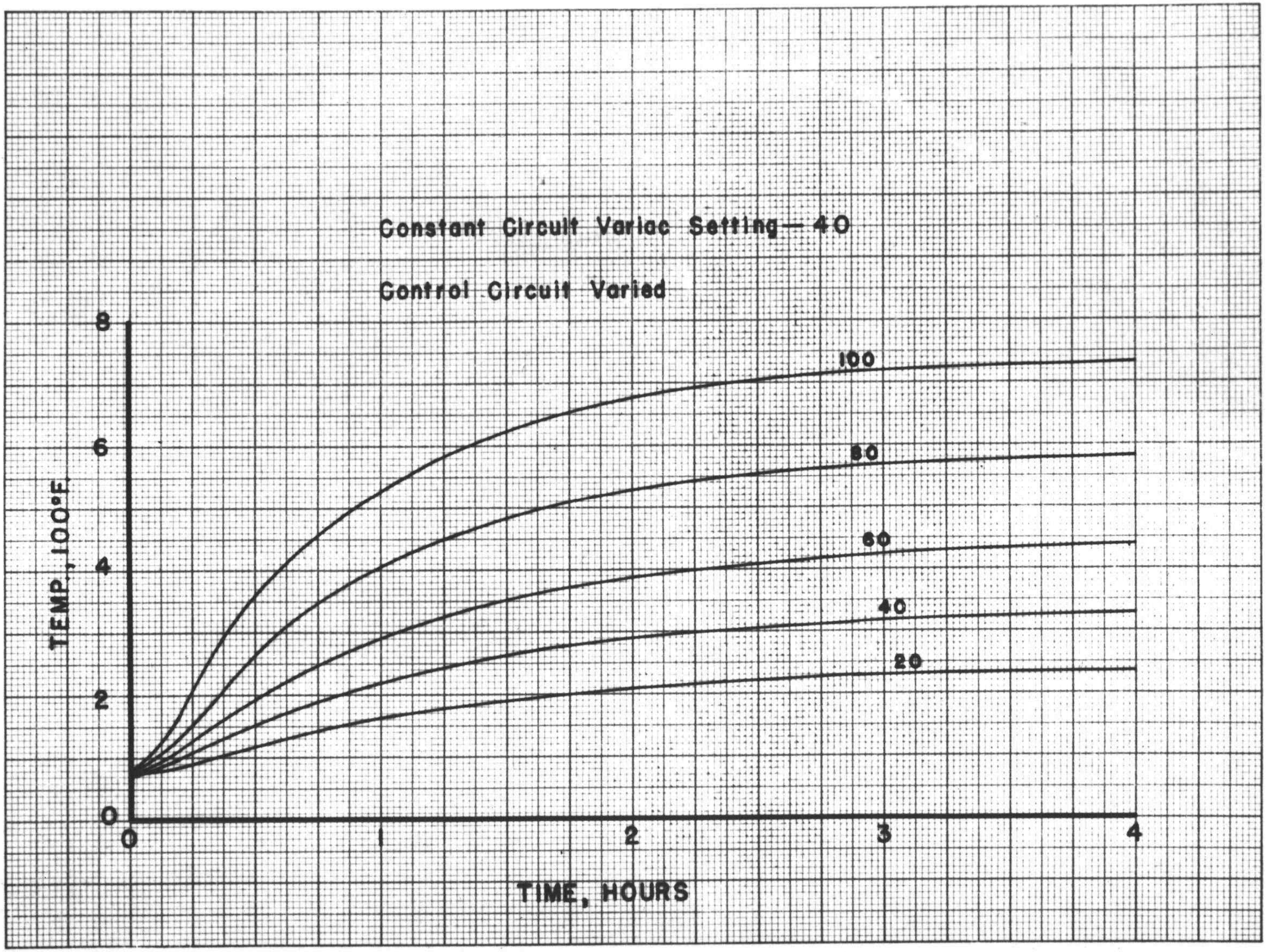
TIME, HOURS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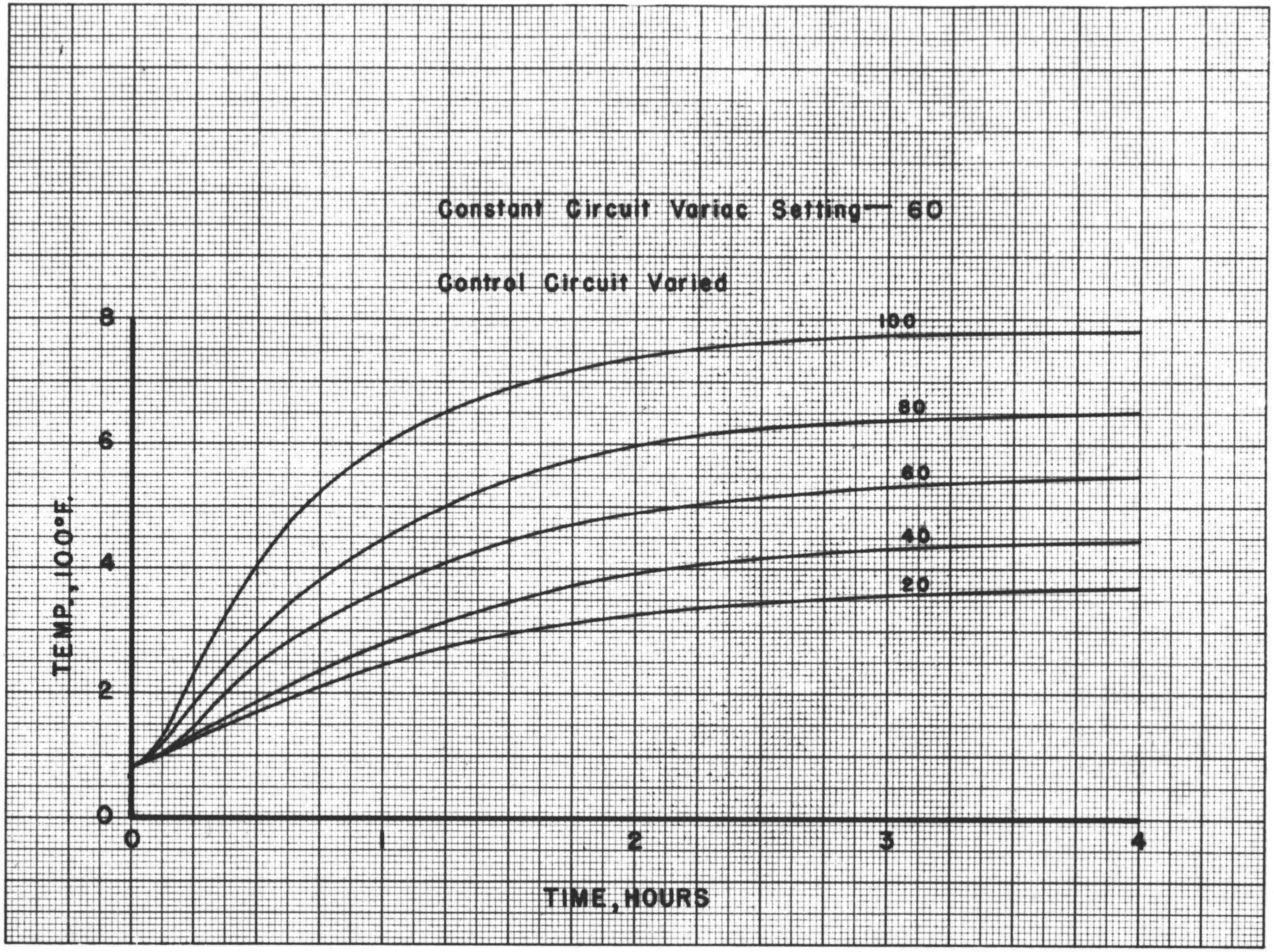
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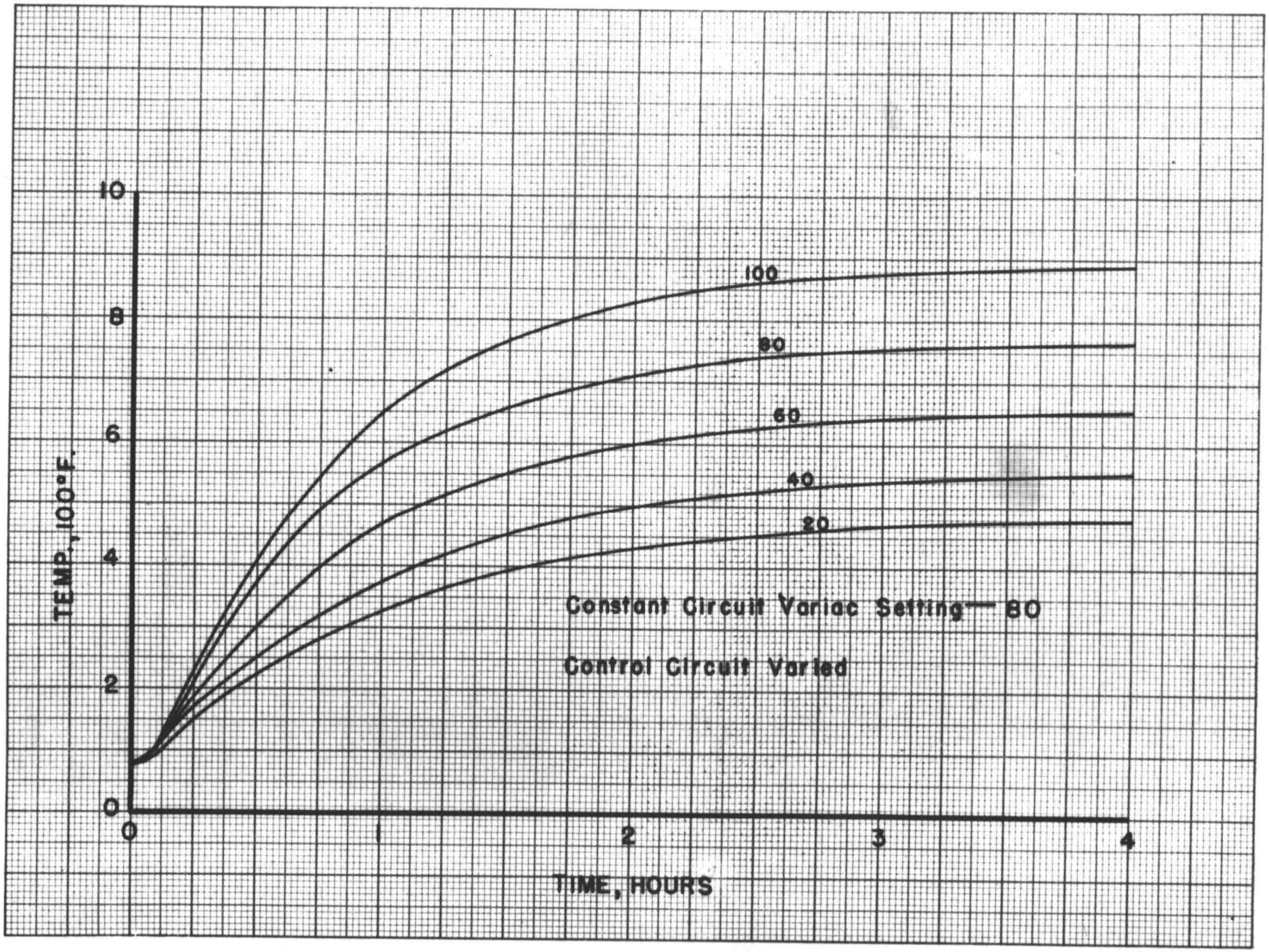
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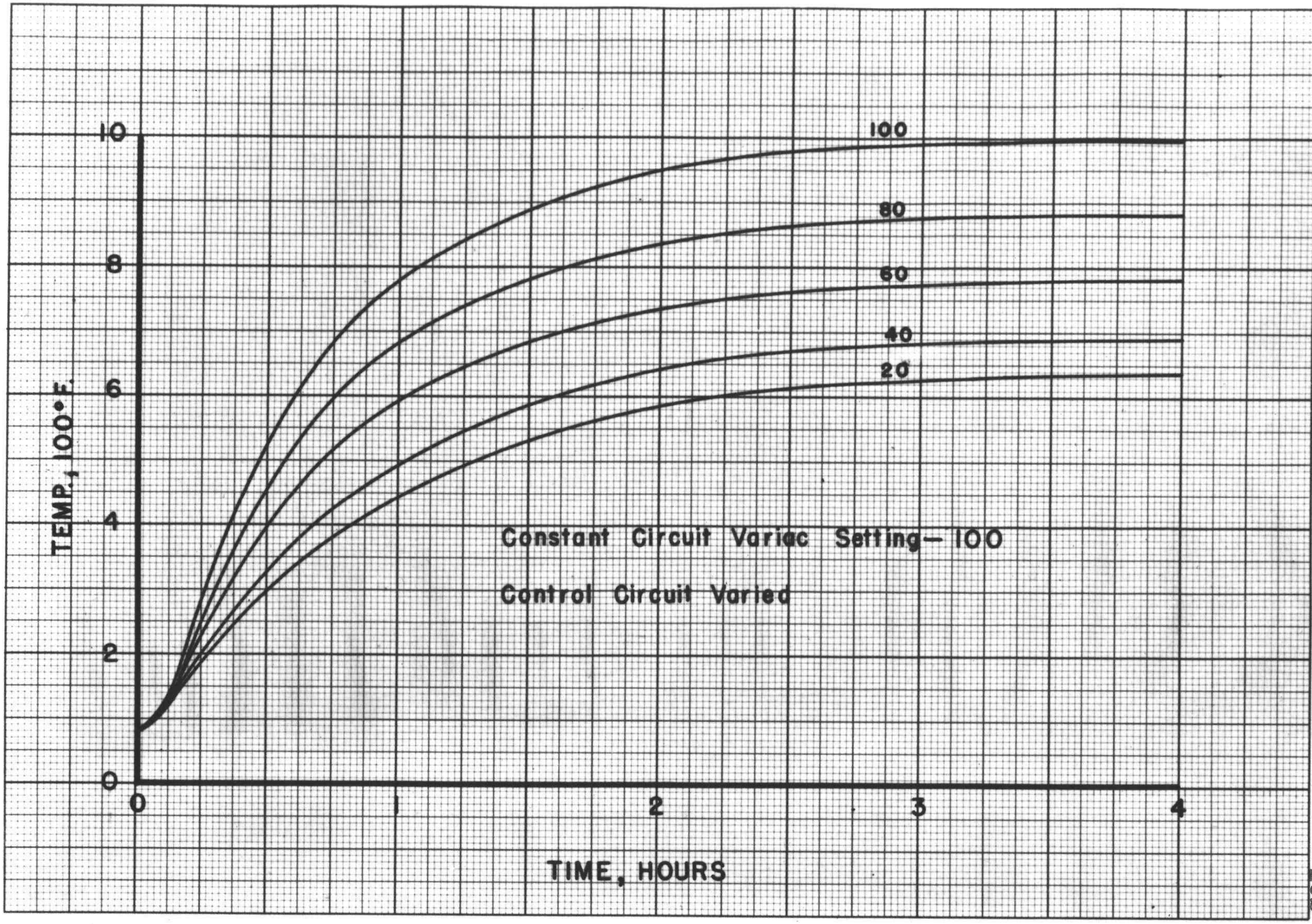
Control Circuit Varied



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Control Circuit Varied

OVEN

HEATING RATE-TEMPERATURE

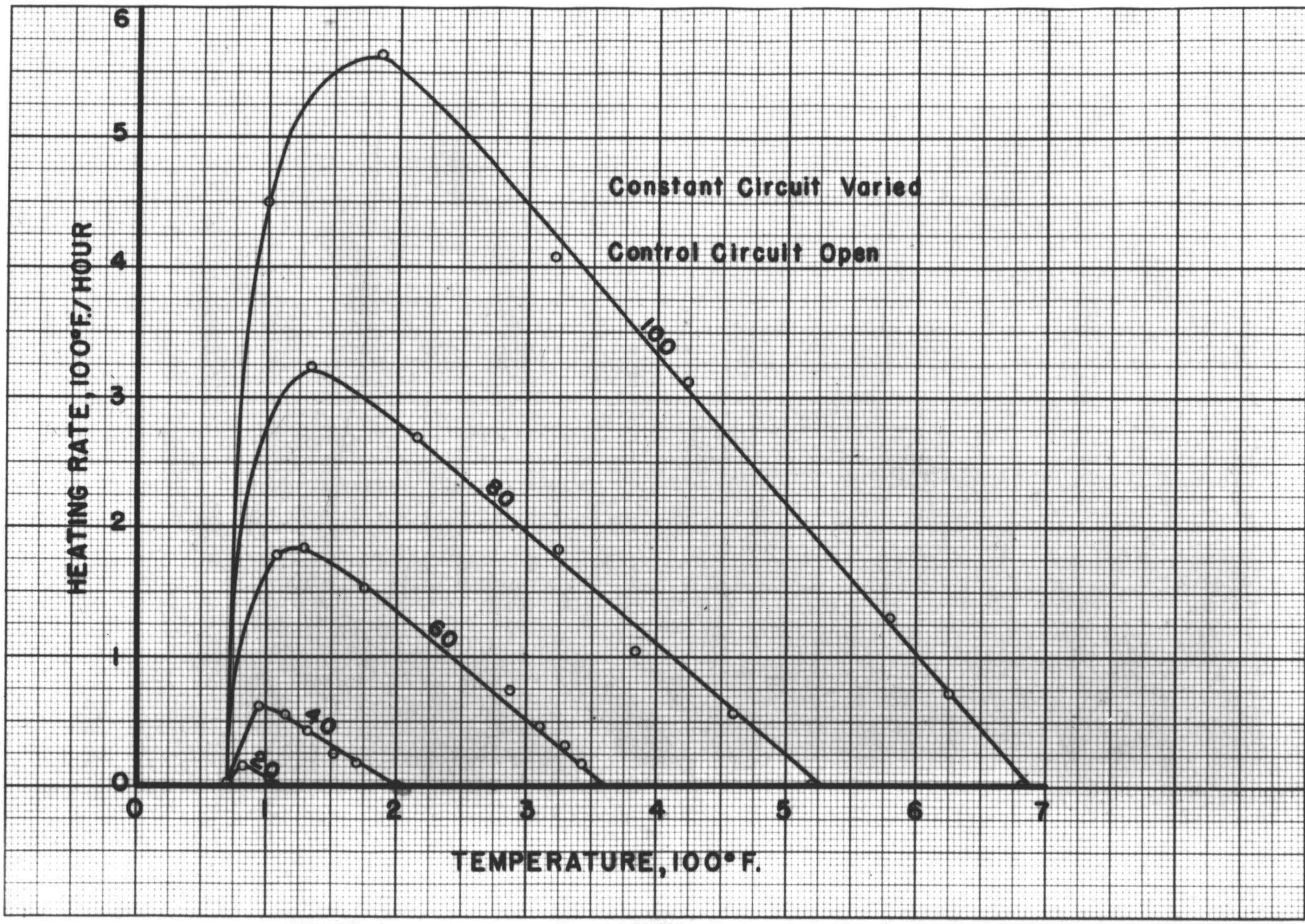
CURVES

for

Various

Constant and Control Circuit

Variac Settings



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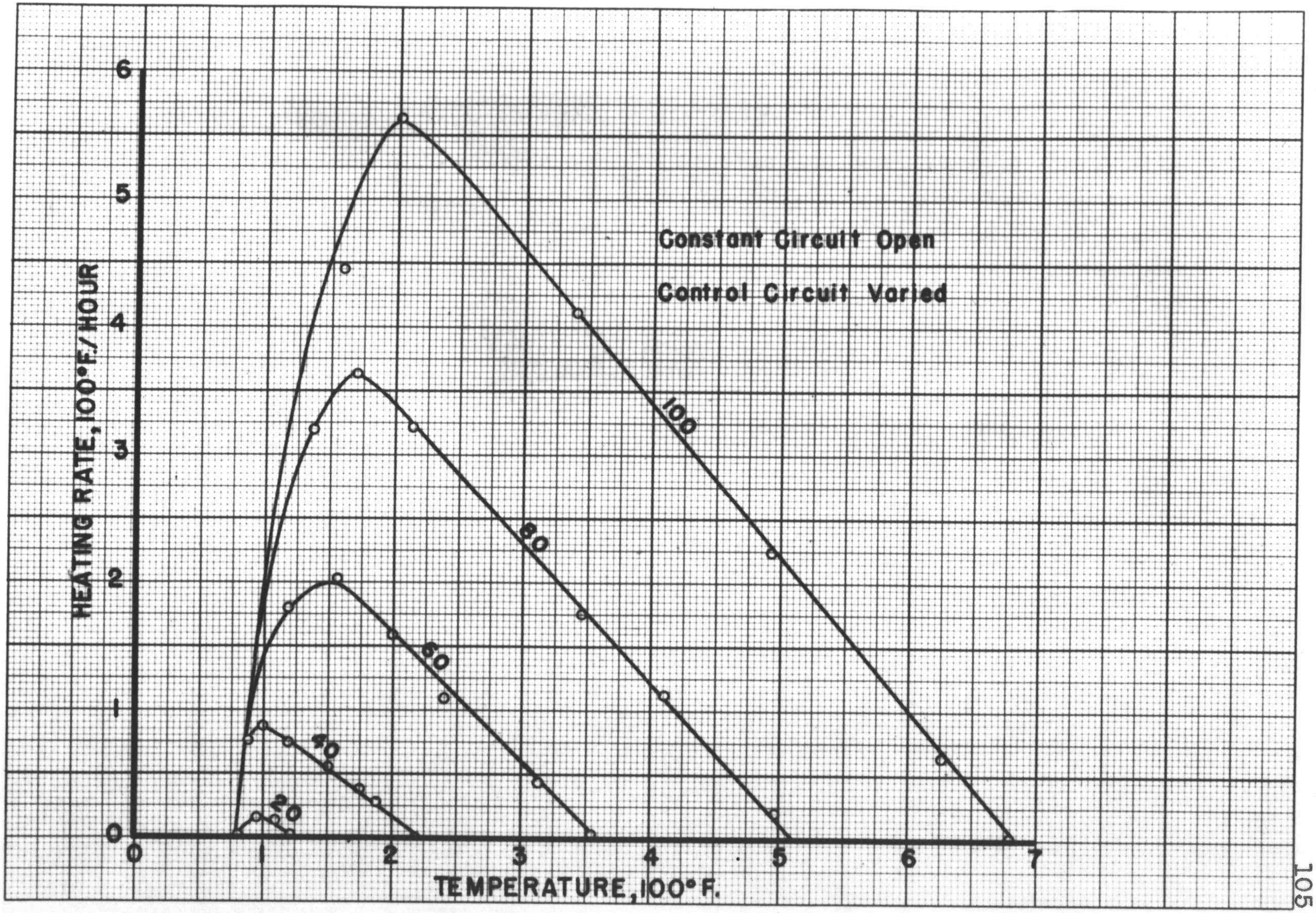

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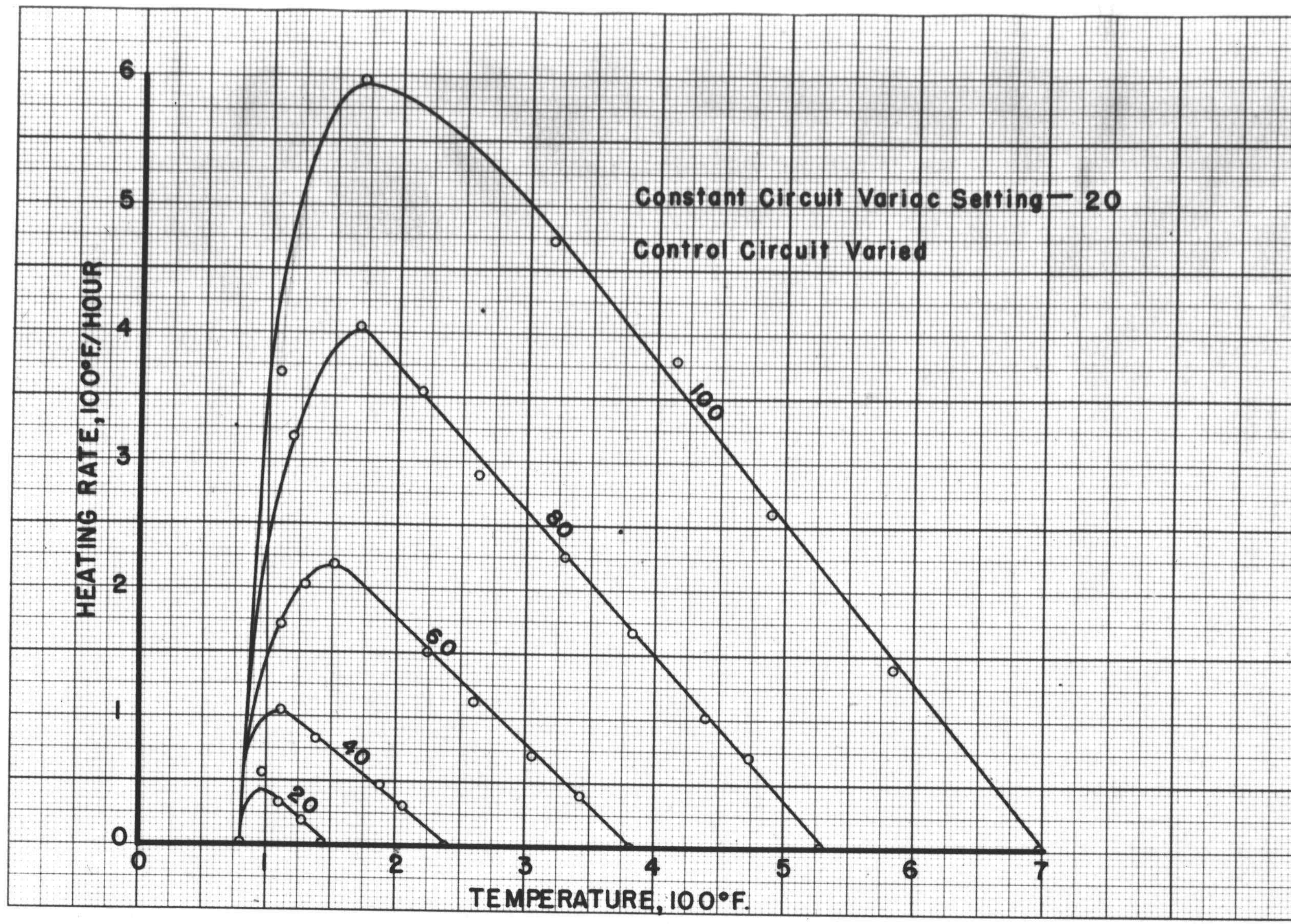
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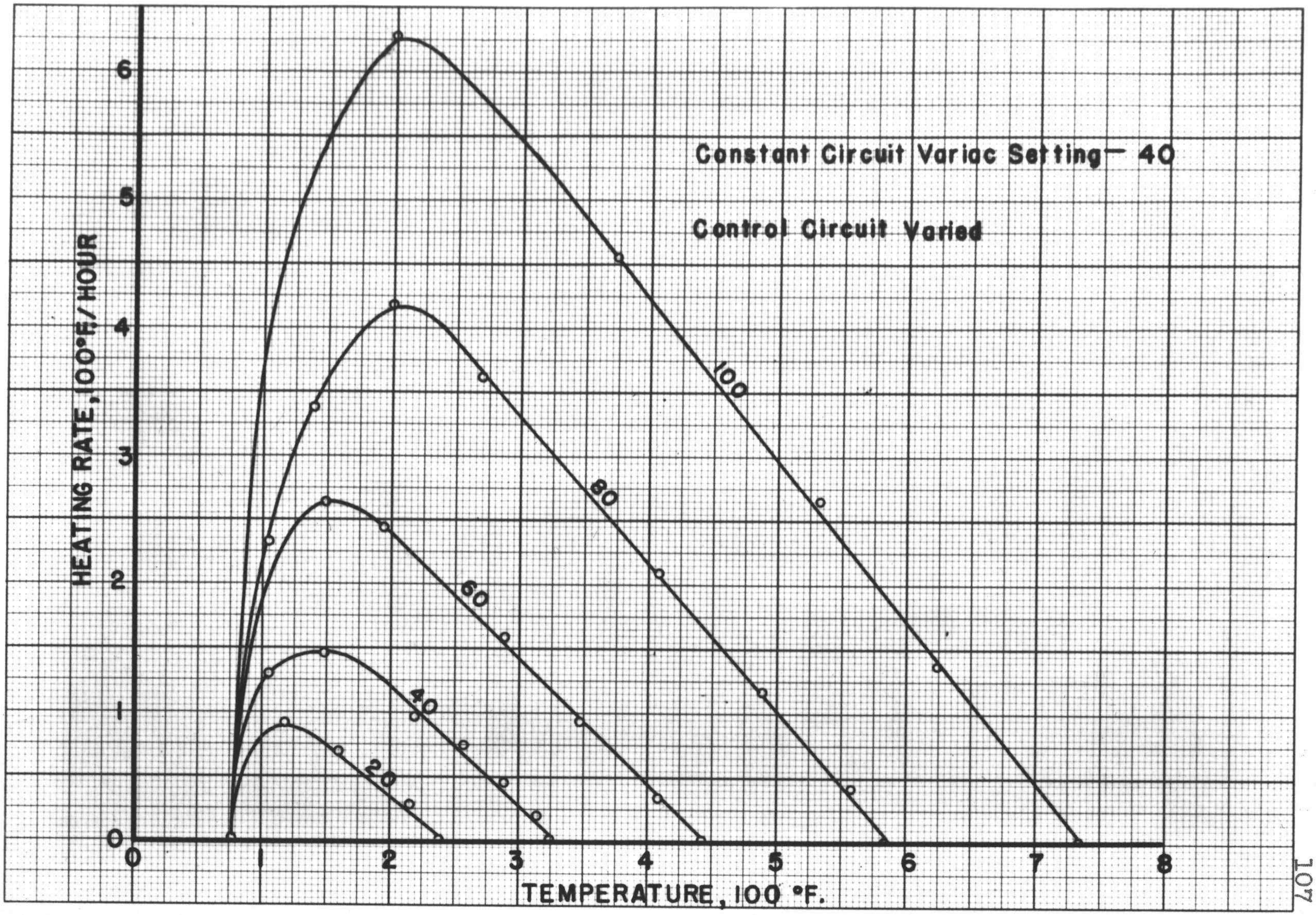
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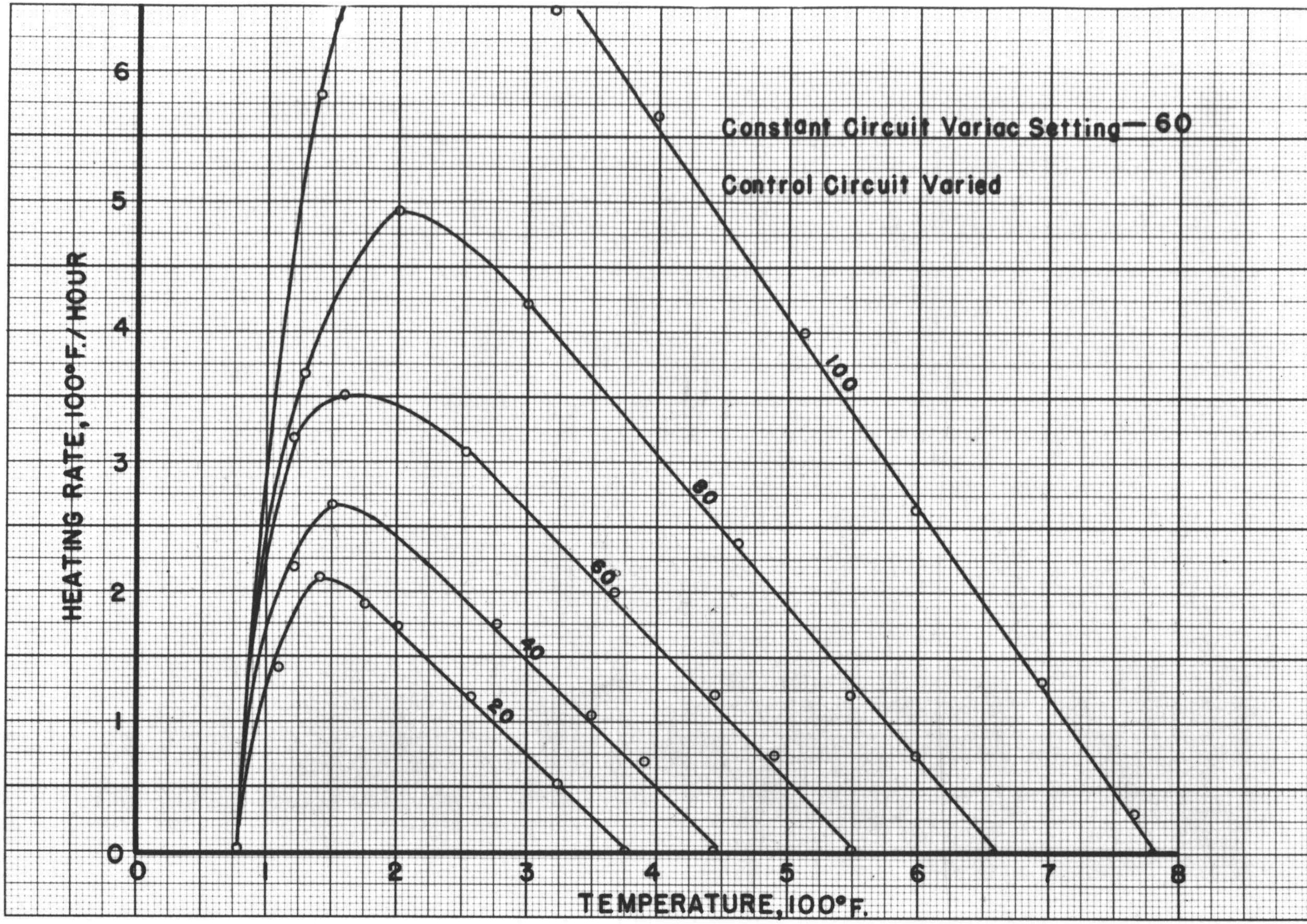

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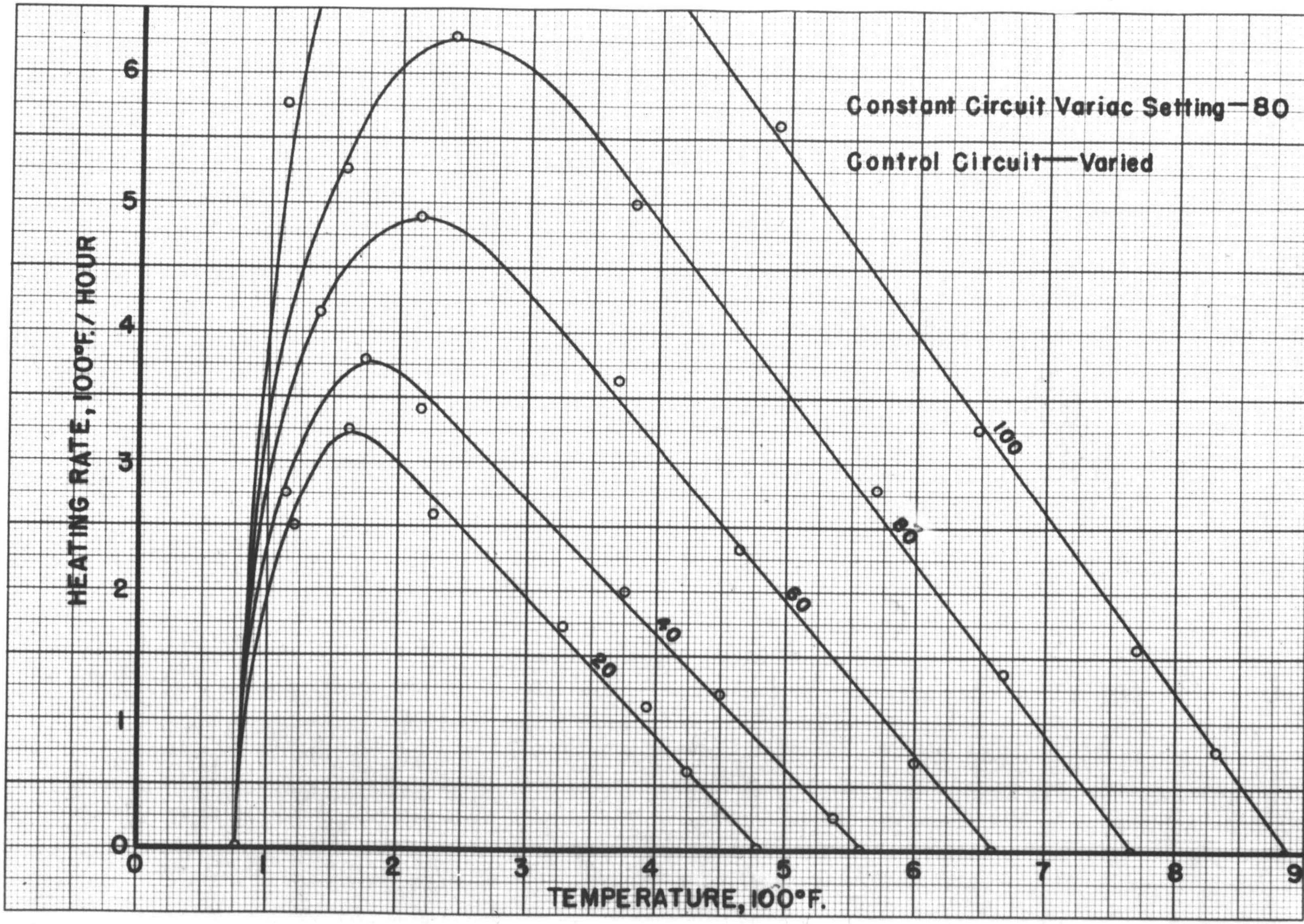
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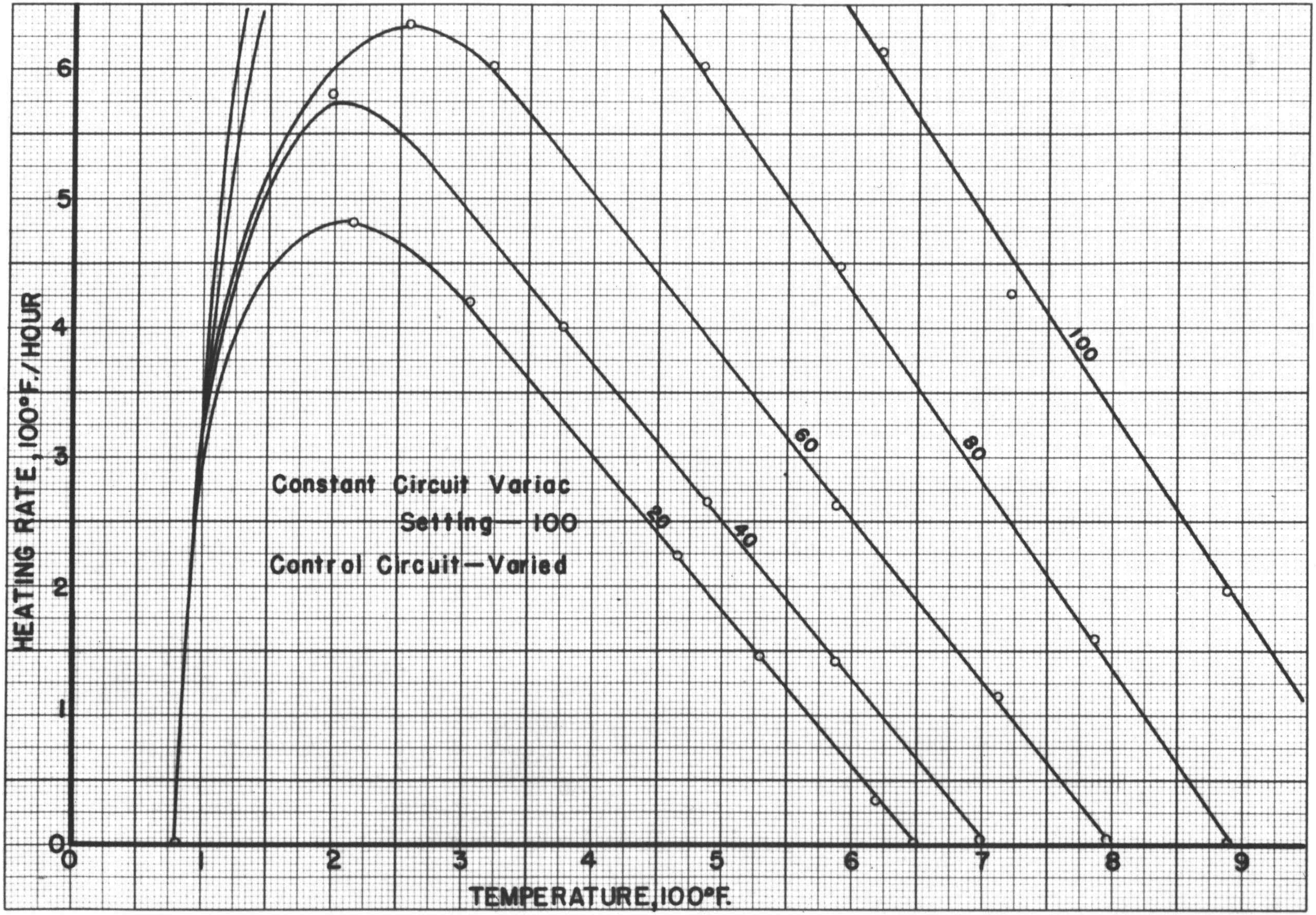
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XII.
APPENDIX II - PAPER SAMPLES

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Pulp. (Sample not included)

Sample No. 22

Raw material Hemlock.

Pulp process Sulphate.

Sizing None.

Filler None.

Bleaching process None.

Surface or finish None.

Coloring None.

Special treatments, or remarks None.

Percent moisture by weight Undetermined.

Thickness Undetermined.

Rate of temperature rise 15° F./hour.

Size of sample 1 X 2½ inches.

Weight of sample 7 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 474° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Groundwood Pulp.(Sample not included)

Sample No. 4

Raw material Wood fibre.

Pulp process Groundwood.

Sizing None.

Filler None.

Bleaching process None.

Surface or finish None.

Coloring None.

Special treatments, or remarks None.

Percent moisture by weight Undetermined.

Thickness Undetermined.

Rate of temperature rise 15° F./hour.

Size of sample 1 X 3 inches.

Weight of sample 8.2 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 459° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample: Pulp dust. (Sample not included)

Sample No.: 21

Raw material: Hemlock, spruce, and red fir.

Pulp process: Sulphate.

Sizing: None.

Filler: None.

Bleaching process: None.

Surface or finish: None.

Coloring: None.

Special treatments, or remarks: This is composed of fibers and is undoubtedly the greatest cause of our fires in the paper machine dryers. It settles loosely on all parts of the dry end; and when oil treatment is being made on the calenders, it mixes in with this too. To prevent fires, this dust is removed by means of air pressure to the front side of the machine and hosed with water into the sewers.

Percent moisture by weight: Undetermined.

Thickness: Undetermined.

Rate of temperature rise: 16° F./hour.

Size of sample: 1 X 2 inches.

Weight of sample: 7.4 grams.

Rate of air flow: 0.05 cubic feet/minute.

Extra exothermic reaction: None.

Ignition temperature: 434° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Laminator paper dust.(Sample not included)

Sample No. 12

Raw material Cellulose fibre.

Pulp process Kraft.

Sizing Rosin-alum.

Filler None.

Bleaching process None.

Surface or finish Machine Finish.

Coloring Anilines.

Special treatments, or remarks Dust from slitters and saws used in converting laminated kraft paper.

Percent moisture by weight Undetermined.

Thickness Undetermined.

Rate of temperature rise 14° F./hour.

Size of sample 1 X 2 inches.

Weight of sample 8.7 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 405° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Paper dust from converting plant.
(Sample not included)

Sample No. 1

Raw material Wood.

Pulp process Sulphite-groundwood.

Sizing None.

Filler None.

Bleaching process None.

Surface or finish Machine finish.

Coloring Anilines.

Special treatments, or remarks Waste from cut-off and trim saws in converting plant. Saws were running on blue white toilet tissue when sampled.

Percent moisture by weight Undetermined.

Thickness Undetermined.

Rate of temperature rise 14° F./hour.

Size of sample 1 X 2 inches.

Weight of sample 5.2 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 452° F.

Data on Paper Sample and Conditions and Results of Test

Common name of sample Fruit wrap. (Sample not included)

Sample No. 23

Raw material Spruce.

Pulp process Sulphate.

Sizing None.

Filler None.

Bleaching process None.

Surface or finish Mineral oil 2.5#/ream.

Coloring None.

Special treatments, or remarks None.

Percent moisture by weight 4.3 percent.

Thickness 0.0018 inches.

Rate of temperature rise 13° F./hour.

Size of sample 1 X 2½ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 465° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample: Wax paper.

Sample No.: 24

Raw material: Red fir.

Pulp process: Sulphate.

Sizing: 14#/1000# stock resin.

Filler: 30# titanox/1000# stock.

Bleaching process: Single stage hypochlorite.

Surface or finish: Waxed.

Coloring: Rodamine 2/5 oz./1000# stock, blue R $\frac{1}{4}$ oz./1000#.

Special treatments, or remarks:

Wax added 4 to 5 pounds/ream.

Percent moisture by weight: 4.9 percent.

Thickness: 0.0024 inches.

Rate of temperature rise: 15° F./hour.

Size of sample: 7/8 X $2\frac{1}{2}$ inches.

Weight of sample: 10 grams.

Rate of air flow: 0.05 cubic feet/minute.

Extra exothermic reaction: None.

Ignition temperature: 450° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Toilet tissue.

Sample No. 11

Raw material Cellulose fibre.

Pulp process Sulphite.

Sizing None.

Filler None.

Bleaching process None.

Surface or finish Machine finish.

Coloring Anilines.

Special treatments, or remarks None.

Percent moisture by weight 4.3 percent.

Thickness 0.0026 inches.

Rate of temperature rise 15° F./hour.

Size of sample 1 X 3 inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 462° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Oiled Canary Citrus (fruit wrap).

Sample No. 3

Raw material Cellulose fibre.

Pulp process Sulphite.

Sizing Rosin-alum.

Filler None.

Bleaching process Hypochlorite.

Surface or finish Machine finish.

Coloring Anilines.

Special treatments, or remarks Oiled with paraffin oil on the calender stack.

Percent moisture by weight 4.7 percent.

Thickness 0.0011 inches.

Rate of temperature rise 16° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction 468° F.

Ignition temperature 610° F.

Data on Paper Sample and Conditions and Results of Test

Common name of sample Lemon Crownoil Fruit (fruit wrap).

Sample No. 2

Raw material Cellulose fibre.

Pulp process Sulphite.

Sizing Rosin-alum.

Filler None.

Bleaching process None.

Surface or finish Machine finish.

Coloring Anilines.

Special treatments, or remarks Oiled with paraffin (white oil) on the calender stack.

Percent moisture by weight Undetermined.

Thickness 0.0016 inches.

Rate of temperature rise 16° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 434° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Waxed kraft paper.

Sample No. 10

Raw material Cellulose fibre-paraffin.

Pulp process Kraft.

Sizing Rosin-alum.

Filler None.

Bleaching process None.

Surface or finish Machine finish.

Coloring Anilines.

Special treatments, or remarks Waxed on a special machine to a total ream weight of thirty-eight pounds.

Percent moisture by weight Undetermined.

Thickness 0.0038 inches.

Rate of temperature rise 15° F./hour.

Size of sample 1 X 2¼ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction 461° F.

Ignition temperature 610° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample: Laminated kraft.

Sample No.: 9

Raw material: Cellulose fibre-asphalt.

Pulp process: Kraft.

Sizing: Rosin-alum.

Filler: None.

Bleaching process: None.

Surface or finish: Machine finish.

Coloring: Anilines.

Special treatments, or remarks: Two sheets of 30# kraft paper, laminated with enough asphalt to bring the total ream weight (500 count) to 112 pounds.

Percent moisture by weight: 2.4 percent.

Thickness: 0.0087 inches.

Rate of temperature rise: 16° F./hour.

Size of sample: 1 X 2 inches.

Weight of sample: 10 grams.

Rate of air flow: 0.05 cubic feet/minute.

Extra exothermic reaction: None.

Ignition temperature: 700° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Otter Kraft Bag (paper bag).

Sample No. 6

Raw material Cellulose fibre.

Pulp process Kraft.

Sizing Rosin-alum.

Filler None.

Bleaching process None.

Surface or finish Machine finish.

Coloring Anilines.

Special treatments, or remarks Adhesive used in bag manufacture is a starch product.

Percent moisture by weight 5.3 percent.

Thickness 0.0041 inches.

Rate of temperature rise 17° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 462° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Golden Gate Bag (paper bag).

Sample No. 7

Raw material Cellulose fibre.

Pulp process Sulphite.

Sizing Rosin-alum.

Filler None.

Bleaching process None.

Surface or finish Machine finish.

Coloring Anilines.

Special treatments, or remarks Starch adhesives used in manufacture of bags.

Percent moisture by weight 5.4 percent.

Thickness 0.0037 inches.

Rate of temperature rise 16° F./hour.

Size of sample 1 X $2\frac{1}{2}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 466° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample	White Columbiair Bond 9#.
Sample No.	20
Raw material	
Pulp process	Sulphite.
Sizing	2 percent.
Filler	3% talc and 3.9% alum.
Bleaching process	None.
Surface or finish	None.
Coloring	Solar blue.
Special treatments, or remarks	None.
Percent moisture by weight	5.3 percent.
Thickness	0.0024 inches.
Rate of temperature rise	20° F./hour.
Size of sample	1 X 2¼ inches.
Weight of sample	10 grams.
Rate of air flow	0.05 cubic feet/minute.
Extra exothermic reaction	None.
Ignition temperature	464° F.

Data on Paper Sample and Conditions and Results of Test

Common name of sample ______ White Bond 16#.

Sample No. ______ 18

Raw material ______

Pulp process ______ Sulphite.

Sizing ______ 2 percent.

Filler ______ 8.3% talc and 3.9% alum.

Bleaching process ______ None.

Surface or finish ______ None.

Coloring ______ Solar blue.

Special treatments, or remarks ______ None.

Percent moisture by weight ______ 5.3 percent.

Thickness ______ 0.0032 inches.

Rate of temperature rise ______ 14° F./hour.

Size of sample ______ 1 X $2\frac{1}{4}$ inches.

Weight of sample ______ 10 grams.

Rate of air flow ______ 0.05 cubic feet/minute.

Extra exothermic reaction ______ None.

Ignition temperature ______ 465° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample White Wove Envelope 24#.

Sample No. 19

Raw material

Pulp process Sulphite.

Sizing 2 percent.

Filler 5.5% talc and 3.6% alum.

Bleaching process None.

Surface or finish None.

Coloring Solar blue.

Special treatments, or remarks None.

Percent moisture by weight 4.7 percent.

Thickness 0.0039 inches.

Rate of temperature rise 17° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 462° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Bleached Manifold Parchment 18#.

Sample No. 17

Raw material

Pulp process Sulphite.

Sizing .7 percent.

Filler 2.3% alum.

Bleaching process None.

Surface or finish None.

Coloring Solar blue and lemon ochre.

Special treatments, or remarks None.

Percent moisture by weight 6.5 percent.

Thickness 0.0020 inches.

Rate of temperature rise 15° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 679° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample: Bleached Greaseproof 25#.

Sample No.: 16

Raw material:

Pulp process: Sulphite.

Sizing: .7 percent.

Filler: 2.3% alum and 1% rayox.

Bleaching process: None.

Surface or finish: None.

Coloring: Solar blue.

Special treatments, or remarks: None.

Percent moisture by weight: 6.2 percent.

Thickness: 0.0019 inches.

Rate of temperature rise: 12^{o} F./hour.

Size of sample: 1 X $2\frac{1}{4}$ inches.

Weight of sample: 10 grams.

Rate of air flow: 0.05 cubic feet/minute.

Extra exothermic reaction: None.

Ignition temperature: 679^{o} F.

Data on Paper Sample and Conditions and Results of Test

Common name of sample Purple oiled fruit wrap.

Sample No. 33

Raw material Sulphite 98% and groundwood 2%.

Pulp process

Sizing 7# size, 2# sodium carbonate, and 15# alum (per 1500# AD).

Filler None.

Bleaching process None.

Surface or finish Calendered.

Coloring Same as unoiled.

Special treatments, or remarks Weight 12.5# with about 2.2# of white oil per ream.

Percent moisture by weight 6.2 percent.

Thickness 0.0013 inches.

Rate of temperature rise 25° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction 460° F.

Ignition temperature 620° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Newsprint.

Sample No. 30

Raw material Wood.

Pulp process Sulphite 18% and groundwood 82%.

Sizing None.

Filler None.

Bleaching process None.

Surface or finish Calendered.

Coloring Practically none 1/16 oz./ton ethyl violet.

Special treatments, or remarks Weight 35#.

Percent moisture by weight Undetermined.

Thickness 0.0035 inches.

Rate of temperature rise 15^{o} F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 435^{o} F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Purple unoiled fruit wrap.

Sample No. 31

Raw material Wood (spruce and hemlock).

Pulp process Sulphite and groundwood.

Sizing 7# size, 2# sodium carbonate, and 15# alum (per 1500# air dry).

Filler None.

Bleaching process None.

Surface or finish Calendered.

Coloring Methyl violet DXX $5\frac{1}{2}$# safranine Y $7\frac{1}{2}$ oz. (per 1500# AD).

Special treatments, or remarks

Unbleached sulphite 98%.

Groundwood 2%.

Weight 12.5# per ream (500 count).

Percent moisture by weight 6.8 percent.

Thickness 0.0016 inches.

Rate of temperature rise 15° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 468° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Toilet tissue.

Sample No. 29

Raw material Sulphite 75% and groundwood 25%.

Pulp process

Sizing None.

Filler None.

Bleaching process None.

Surface or finish Creped.

Coloring None.

Special treatments, or remarks Weight 12.5#.

Percent moisture by weight 5.3 percent.

Thickness 0.0025 inches.

Rate of temperature rise 12° F./hour.

Size of sample 1 X 3 inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 460° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample: Embossed toilet tissue.

Sample No.: 26

Raw material: Sulphite 75% and groundwood 25%.

Pulp process:

Sizing: None.

Filler: None.

Bleaching process: None.

Surface or finish: Creped and embossed.

Coloring: Practically none.

Special treatments, or remarks: None.

Percent moisture by weight: 4.8 percent.

Thickness: 0.0024 inches.

Rate of temperature rise: 20° F./hour.

Size of sample: 1 X $3\frac{1}{4}$ inches.

Weight of sample: 10 grams.

Rate of air flow: 0.05 cubic feet/minute.

Extra exothermic reaction: None.

Ignition temperature: 452° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample ____ Sierra toweling.

Sample No. ____ 28

Raw material ____ Sulphite 30% and groundwood 70%.

Pulp process ____

Sizing ____ None.

Filler ____ None.

Bleaching process ____ None.

Surface or finish ____ Creped.

Coloring ____ 2 oz. auromine and 1 1/8 oz. chrysoidine (per 1500# AD).

Special treatments, or remarks ____ Weight 34.5#.

Percent moisture by weight ____ 4.7 percent.

Thickness ____ 0.0070 inches.

Rate of temperature rise ____ 15° F./hour.

Size of sample ____ 1 X 3 inches.

Weight of sample ____ 10 grams.

Rate of air flow ____ 0.05 cubic feet/minute.

Extra exothermic reaction ____ None.

Ignition temperature ____ 454° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample: Corrugating boxboard.

Sample No.: 32

Raw material: Groundwood and sulphite screenings and some broke.

Pulp process:

Sizing: None.

Filler: None.

Bleaching process: None.

Surface or finish: Calendered.

Coloring: 23 oz. bismark brown and 80 oz. chorsiodine Y (per 1500#)

Special treatments, or remarks: None.

Percent moisture by weight: 7.3 percent.

Thickness: 0.010 inches.

Rate of temperature rise: 15^{o} F./hour.

Size of sample: 1 X $2\frac{1}{4}$ inches.

Weight of sample: 10 grams.

Rate of air flow: 0.05 cubic feet/minute.

Extra exothermic reaction: None.

Ignition temperature: 440^{o} F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Cheviot meat wrap.

Sample No. 27

Raw material Sulphite 90% and groundwood 10%.

Pulp process

Sizing 10# paracol, 3# lime, 55# size, and 42# alum (per 1500# AD).

Filler None.

Bleaching process None.

Surface or finish Calendered.

Coloring 115# red fibers per 1500# AD.

Special treatments, or results Weight 40#.

Percent moisture by weight 5.6 percent.

Thickness 0.0037 inches.

Rate of temperature rise 15° F./hour.

Size of sample 1 X 2¼ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 452° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample ____ Bond paper.

Sample No. ____ 15

Raw material ____ Hemlock chips.

Pulp process ____ Sulphite.

Sizing ____ Rosin-starch.

Filler ____ Clay-rayox.

Bleaching process ____ Hypochlorite.

Surface or finish ____ Regular.

Coloring ____ White.

Special treatments, or remarks ____ None.

Percent moisture by weight ____ 5.0 percent.

Thickness ____ 0.0035 inches.

Rate of temperature rise ____ 14° F./hour.

Size of sample ____ 1 X $2\frac{1}{4}$ inches.

Weight of sample ____ 10 grams.

Rate of air flow ____ 0.05 cubic feet/minute.

Extra exothermic reaction ____ None.

Ignition temperature ____ 462° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample	Mimeograph paper.
Sample No.	14
Raw material	Hemlock chips.
Pulp process	Sulphite.
Sizing	Rosin.
Filler	Clay.
Bleaching process	Hypochlorite.
Surface or finish	Regular.
Coloring	White
Special treatments, or remarks	None.
Percent moisture by weight	5.12 percent.
Thickness	0.0037 inches.
Rate of temperature rise	14° F./hour.
Size of sample	1 X $2\frac{1}{4}$ inches.
Weight of sample	10 grams.
Rate of air flow	0.05 cubic feet/minute.
Extra exothermic reaction	None.
Ignition temperature	458° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample	Bluewhite newsprint 32#.
Sample No.	13
Raw material	Sulphite and groundwood pulps.
Pulp process	Sulphite and groundwood.
Sizing	None.
Filler	None.
Bleaching process	Zinc hydrosulphite on groundwood.
Surface or finish	Machine finish.
Coloring	Methyl violet and ethyl violet aniline dyes.
Special treatments, or remarks	None.

Percent moisture by weight	5.9 percent.
Thickness	0.0033 inches.
Rate of temperature rise	17° F./hour.
Size of sample	1 X $2\frac{1}{2}$ inches.
Weight of sample	10 grams.
Rate of air flow	0.05 cubic feet/minute.
Extra exothermic reaction	None.
Ignition temperature	432° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Machine dried unbleached sulphite pulp. (Sample not included)

Sample No. 5

Raw material Cellulose fibre.

Pulp process Sulphite.

Sizing None.

Filler None.

Bleaching process None.

Surface or finish Machine finish.

Coloring None.

Special treatments, or remarks Sulphite pulp dried by forming, pressing, and beating on a special machine.

Percent moisture by weight Undetermined.

Thickness Undetermined.

Rate of temperature rise 15° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 15 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 472° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Newspaper.

Sample No. Unknown.

Raw material Unknown.

Pulp process Unknown.

Sizing Unknown.

Filler Unknown.

Bleaching process Unknown.

Surface or finish Unknown.

Coloring Unknown.

Special treatments, or remarks Unknown.

Percent moisture by weight 7.8 percent.

Thickness 0.0037 inches.

Rate of temperature rise 18° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 428° F.

Data on Paper Sample
and
Conditions and Results of Test

Common name of sample Yellow copy paper.

Sample No. Unknown.

Raw material Unknown.

Pulp process Unknown.

Sizing Unknown.

Filler Unknown.

Bleaching process Unknown.

Surface or finish Unknown.

Coloring Unknown.

Special treatments, or remarks Unknown.

Percent moisture by weight 5.0 percent.

Thickness 0.0028 inches.

Rate of temperature rise 22° F./hour.

Size of sample 1 X $2\frac{1}{4}$ inches.

Weight of sample 10 grams.

Rate of air flow 0.05 cubic feet/minute.

Extra exothermic reaction None.

Ignition temperature 441° F.