FLASHOVER OF CYLINDRICAL INSULATORS IN HOMOGENEOUS ELECTRIC FIELDS WITH VARIABLE TEMPERATURE AND HUMIDITY

THESIS BY
JOHN W. THATCHER

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INTRODUCTION

Insulators are used to prevent a passage of power or current from a point of high potential to one of low potential. Necessarily then since air or some other dielectric medium such as oil must surround the insulator, the problem of insulation is, in whole or in part, that of two dielectrics in parallel in an electric field. Furthermore, many of these problems take the form of some solid dielectric in parallel with air.

From dielectric theory we know that at the surface of separation between two dielectrics the tangential component of the field intensity must be the same in both dielectrics. If one of the dielectrics is air and the other has a dielectric constant K, then the component of the field intensity normal to the surface in the air will be K times the intensity in the other dielectric. This means that the intensity in the air is increased at the surface of separation and that it is more nearly normal to the surface. Therefore, the air path along the surface of the dielectric is weakened, and the breakdown voltage will be noticeably less with a solid dielectric in the field than it otherwise would have been.

However, if one makes the surface of separation between air and the other dielectric tangential at all points to the flux lines there will be no normal component of intensity, the tangential component at the surface will be the same as if the dielectric wasn't there and the strength of the air path will be unchanged. This means that both the air and the dielectric will be worked to their fullest efficiency.

Experimentally it has been shown that many other factors enter into the flashover of a solid dielectric in parallel with air. When the surface of separation is tangential to the flux lines the flashover value is increased over what it would be if this were not the case, but it is not increased to the amount one would, at first thought, anticipate. Factors which apparently enter into this decrease in flashover voltage are: - 1. characteristics of the surface such as roughness, presence of some foreign substance such as dust, homogeneity and ability to absorb moisture; 2. temperature; 3. relative humidity of the air; 4. ohmic resistance; 5. shape, both of insulation and conductors; 6. pressure; 7. joints; 8. dielectric constant; 9. ionization.

The problem of insulator design is then that of modifying the shape of the insulator from always being tangential to the flux lines to one which will allow all the above factors to have a minimum effect and still follow as closely as possible to the theoretical design. The best insulation of course will be obtained when the flashover voltage equals the air puncture voltage.

The results of our experiment published herewith prove that the flashover voltage is generally much less than the air puncture voltage and that the humidity of the surrounding air affects the flashover voltage. In general the higher the humidity the lower the flashover value.

Our results are verified in Westinghouse's Special Publication #1690, "High Voltage Porcelain Insulators" page 27, where a theoretically designed hard rubber insulator had a flashover value of about 9.4 K.V. per cm. which is less than the 30 K.V. per cm. breakdown voltage of air as given by Peek. However, no decrease in flashover value of this insulator was found when it was very dirty, which is the opposite to what we would expect and to which our experiments point.

Rice (A.I.E.E. 1917, page 905) found no differences in flashover voltages of dry cylinders and cylinders exposed to the moisture of the air, while Littleton and Shaver, as reported in the Quarterly Transactions of the A.I.E.E. Vol. 47, page 438, found an increase in flashover voltage with an increase in relative humidity for Pyrex rods.

Schwaiger on the other hand found that glass and porcelain rods in a uniform tangential field showed a decrease in flashover voltage with an increase in humidity. Therefore, since different investigators show little agreement as to the effect of humidity on the flashover voltage of insulators in tangential uniform fields, it seemed worth while to determine, if possible, a qualitative relationship between humidity, temperature and flashover voltage on such insulators. In order to have the number of variable factors as few as possible all our work was done on cylinders in a uniform field with axes parallel parallel to the lines of force. The results thus obtained can then be extended to other shapes, if a law of performance is discovered.

DESCRIPTION OF APPARATUS

In order to obtain an electric field as homogeneous as possible, a plate gap was used. The plates were spun out of #12 gauge copper with a 12 inch flat portion extending into the edges which had a radius of curvature of four inches. This radius of curvature was found to be sufficient enough to cause all discharges to start in the flat portion of the plates.

The effective diameter of the plates, about 12 inches, was enough to give a uniform field with parallel flux lines when the plates were separated enough to hold the longest test specimen in stock. The plates were supported near the center with three screws so that the plates could be made perfectly parallel. The surface of each plate, however, was not a plane surface due to warping of the plate when the lug supporting the three screws was soldered on. This warping was not enough to appreciably affect the field flux though it was enough to make it impossible to perfectly fit the ends of the test pieces with the plate surface.

The stand for the plates was made of carefully dried maple surfaced on all four sides and varnished carefully to prevent absorption of moisture. No metal was used to construct the stand except two screws in the base pieces, which were not expected to give any trouble. The stand, together with the plate gap are shown in Figure 1. A sketch of the stand and gap is shown in Figure 2.

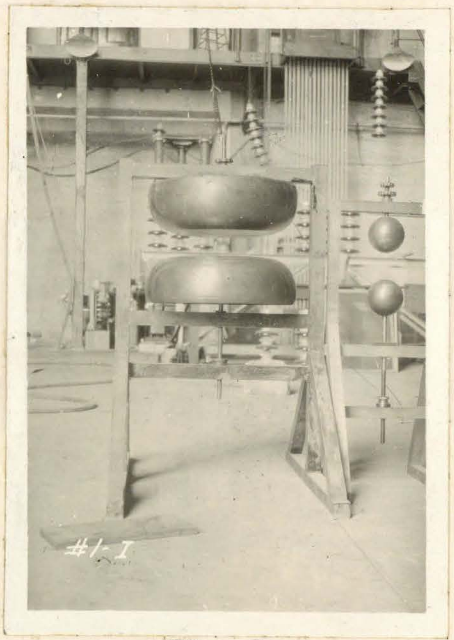


Fig. 1

In order to vary the surrounding atmospheric conditions of the test specimen, a test chamber was used which was large enough to hold the plate gap and stand. This chamber was made of wood about 5 x 5 feet square and 10 feet high. The walls, floor and roof were made hollow and filled with a diatomaceous earth of good heat insulating properties. Double glass observation windows all around the chamber except in the door, provided ample observation for the instruments and test piece inside. The test voltage was conducted through the roof by means of an Ohio Brass sixty K.V. porcelain wall bushing. The chamber was heated by strap heaters mounted

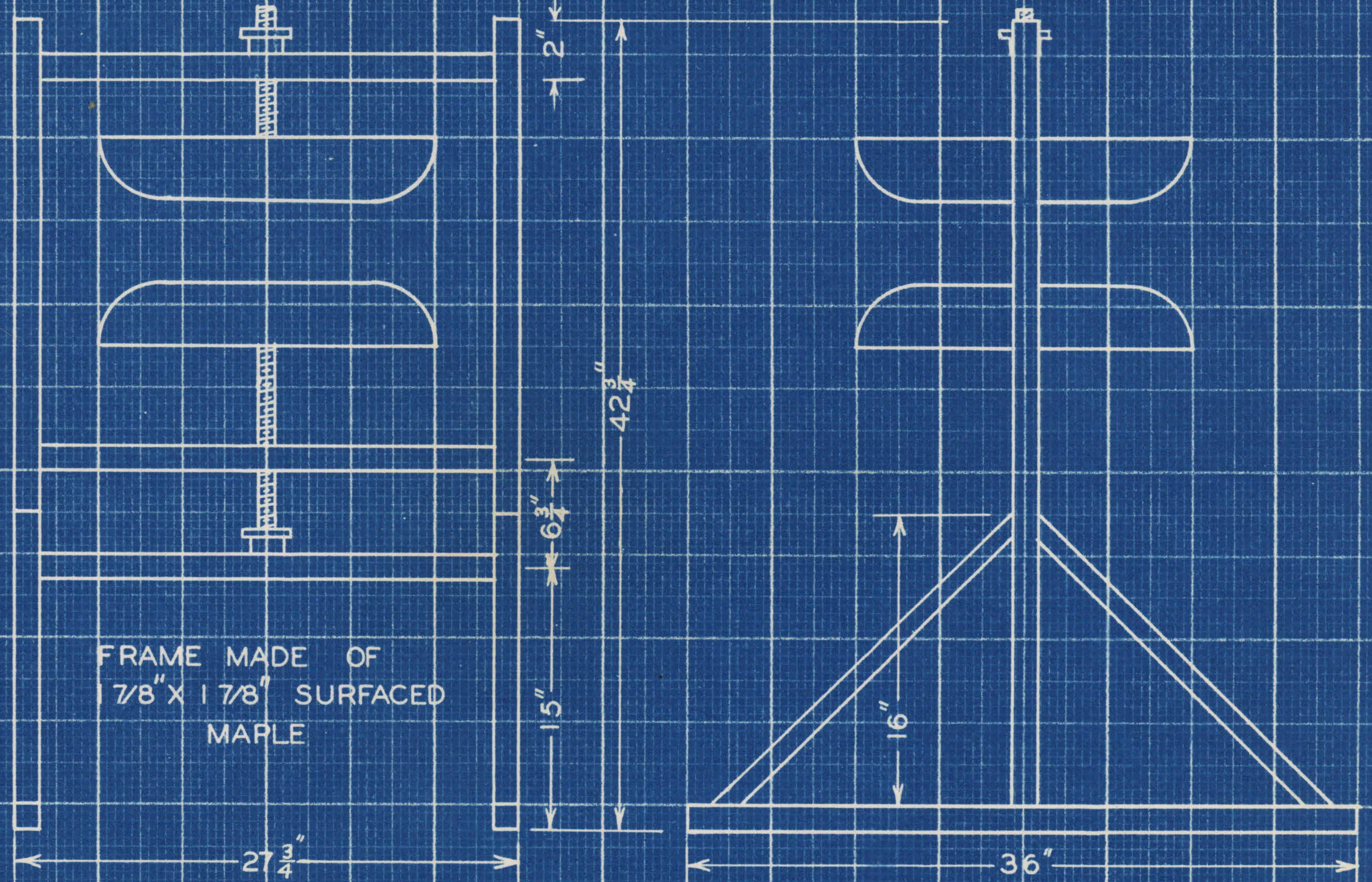


PLATE GAP

FIG. 2

on the inside wall and connected with switches so that all or part of the heaters could be controlled by hand or by thermostat. The heaters could be used in 220 watt steps and had a capacity of about two kilowatts. The humidity was varied by evaporating water over an electric heater which also was controlled from the outside. In order to determine the humidity, wet and dry bulb thermometers were placed close together inside the chamber near a window. An electric fan was placed inside and arranged to blow directly on the thermometers. Preliminary tests indicated that the resultant air circulation was sufficient to give accurate readings. The water for the evaporating pan and for the wet bulb thermometer was obtained through brass tubing leading to a reservoir fastened to the outside of the chamber. Valves in the tubing controlled the supply to each.

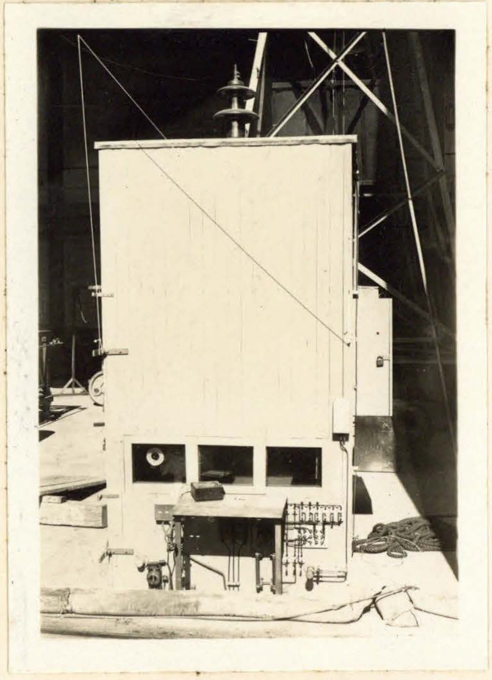


Fig. 3

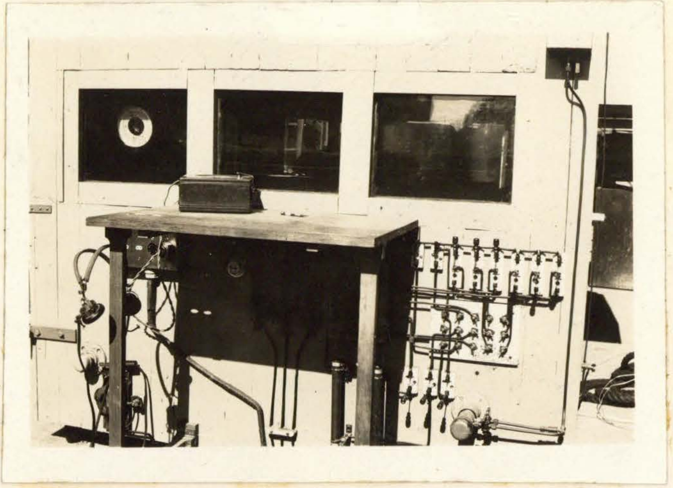


Fig. 4

Fig. 5

Figures 3, 4 and 5 show views of the chamber and control apparatus. With this apparatus the conditions inside the chamber could be controlled entirely from the outside. In this way inside disturbances were entirely eliminated and the only time it would be necessary to go inside the chamber would be to change specimens.

The air pressure was measured with an aneroid barometer suspended near a window.

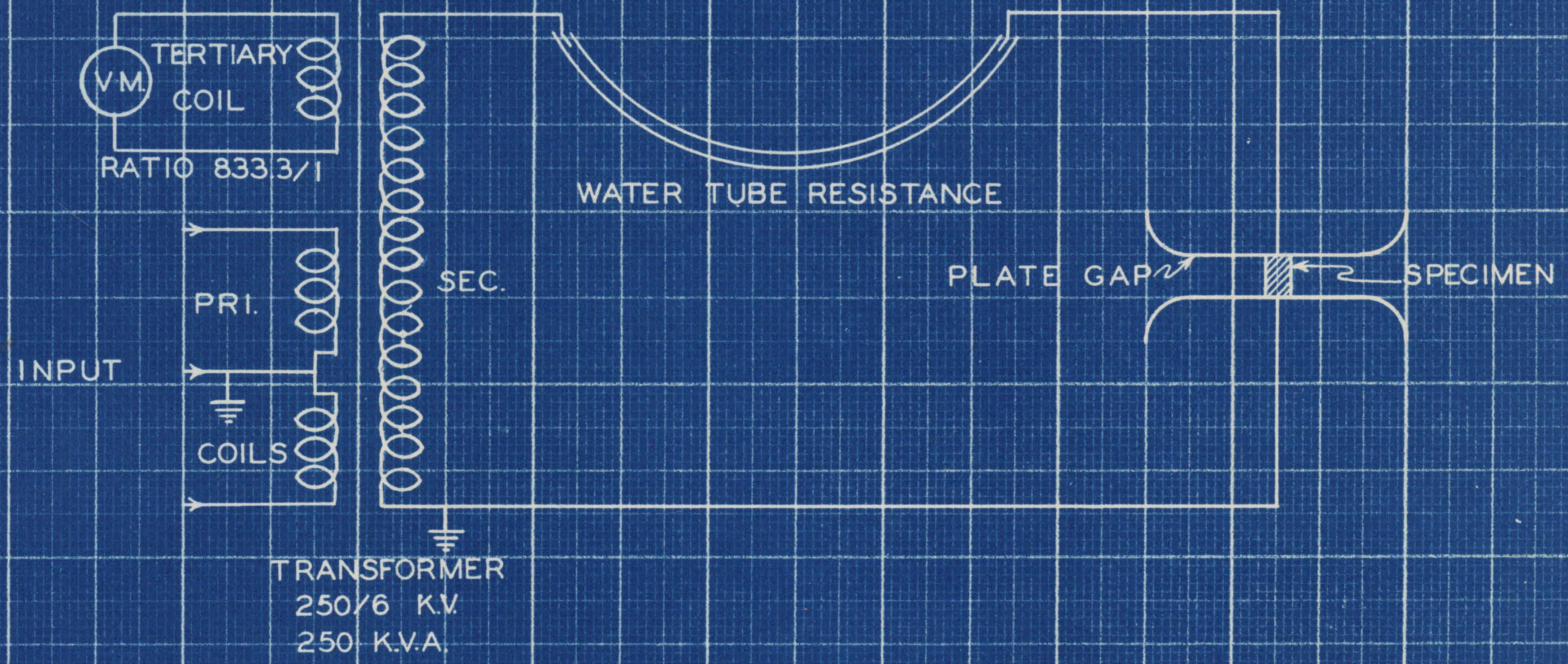
Voltage at flashover was measured with Weston model 155 instruments connected across the tertiary coil of the 250 K.V. transformer, and was supplied from the transformer to the chamber through a water resistance consisting of about 15 feet of 3/4 inch garden hose. The voltage was controlled with a motor operated voltage regulator connected in the primary of the 250 K.V. transformer.

PROBLEM AND PROCEDURE

The specific problem was to study the effect of temperature and humidity upon the flashover voltage of cylindrical insulators in a homogeneous electric field.

The test pieces were cleaned with alcohol, dried and placed carefully between the plates of the gap so as to obtain the best possible connection between the ends of the specimen and the surface of the plates.

The temperature and humidity were then brought up to their desired values. Voltage was applied to the test piece, increasing steadily from zero to flashover. The rate of increase of voltage was about 5 K.V. per second, though no accurate determinations were made of this since it varied from time to time. At the instant of flashover the voltage in the tertiary winding of the transformer was read. This winding had been previously calibrated with a 12.5 cm. sphere gap and so the actual flashover voltage was then found by referring to this experimentally determined curve between tertiary winding volts and actual voltage. At the same time the flashover voltage was read, readings of the wet and dry bulb temperatures, the barometric pressure and time were taken. The diagram of connections is shown in Figure 6. As is shown in the diagram, a water tube resistance about fifteen feet in length was used to protect the transformer upon flashover.



SCHEMATIC DIAGRAM OF CONNECTIONS

FIG. 6

For the large majority of data a time interval of ten minutes was allowed between each successive reading. However, even this length of time seemed too small and so some data was taken with time intervals of fifteen and twenty minutes. Instead of making the readings more uniform the greater length of time made them more irregular. It was also noticed that the first readings taken, after the piece had been standing for some time, were also irregular. These two effects are apparently caused by the same thing and are probably due to the surface resistance changing when allowed to stand after a flashover. This surface effect could be caused by an uneven distribution of dust and moisture which would collect between readings.

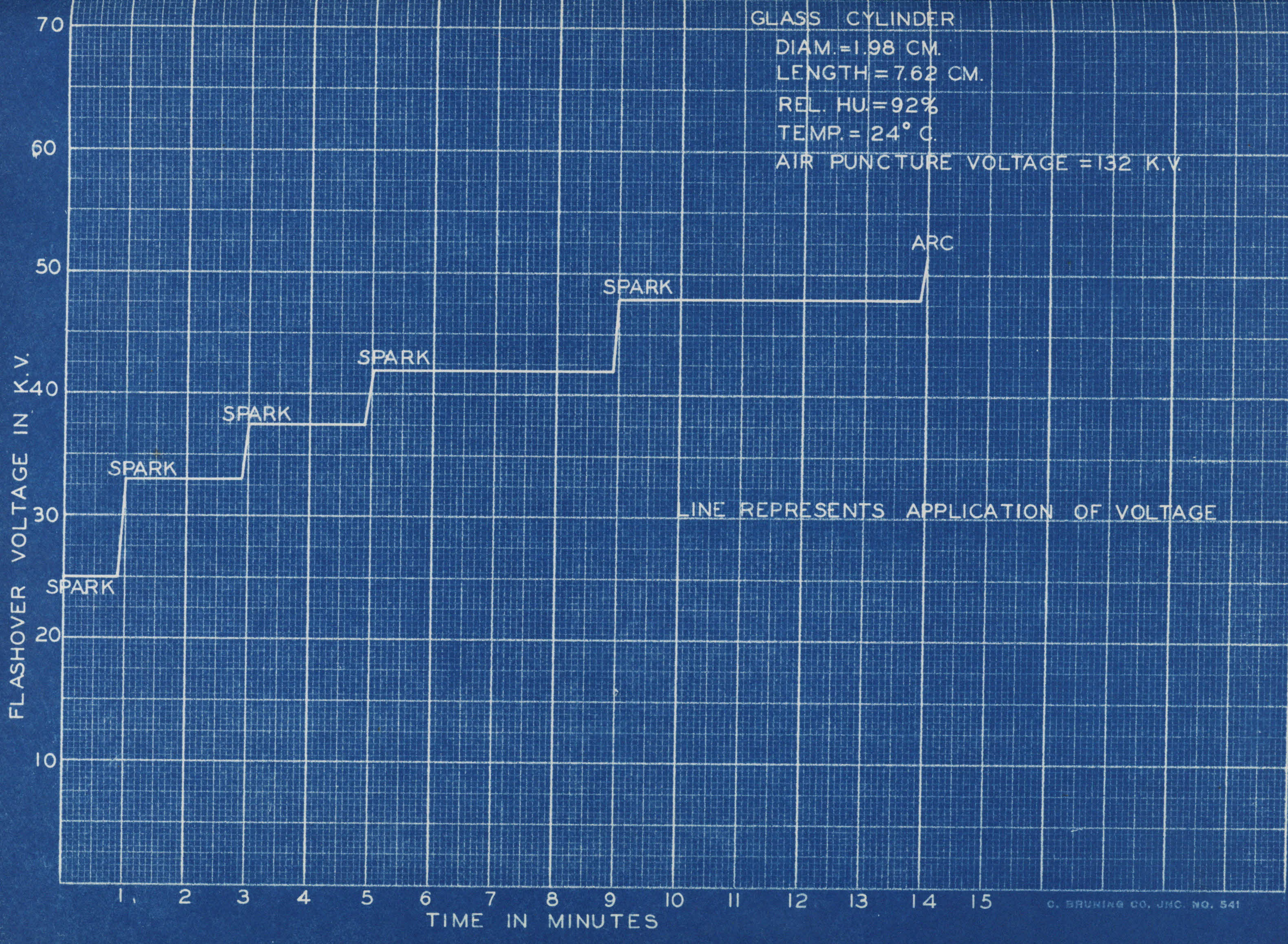
It was not known previous to these experiments whether temperature had any effect on the flashover of the specimens. It was found next to impossible to keep a constant temperature and vary the humidity. This meant that there would be three variables, temperature, humidity and flashover voltage, for any given set of readings. This was particularly the case when low temperatures and high humidities were desired because in evaporating the water in the chamber the temperature naturally increased. It was felt necessary then to take a great amount of data over widely ranging conditions of humidity and temperature and by collecting, from this mass of readings, sets of data with one of the variables constant, obtain the desired curves. This was done. After taking as much data as necessary for any given specimen, and calculating the relative humidity and the kilovolts of flashover, all the readings were collected in one set which did not have humidities varying over two per cent. In this way the relationship between temperature and flashover voltage for any given humidity was determined. And in the same way the relationship between the flashover voltage and the humidity for any given temperature was determined.

Since no curves could be found which gave values of relative humidity when the wet and dry bulb temperatures were known, it was found advantageous to make such a family of curves from data given in the Smithsonian tables. A copy of these curves is placed at the end of this report.

PRELIMINARY TESTS

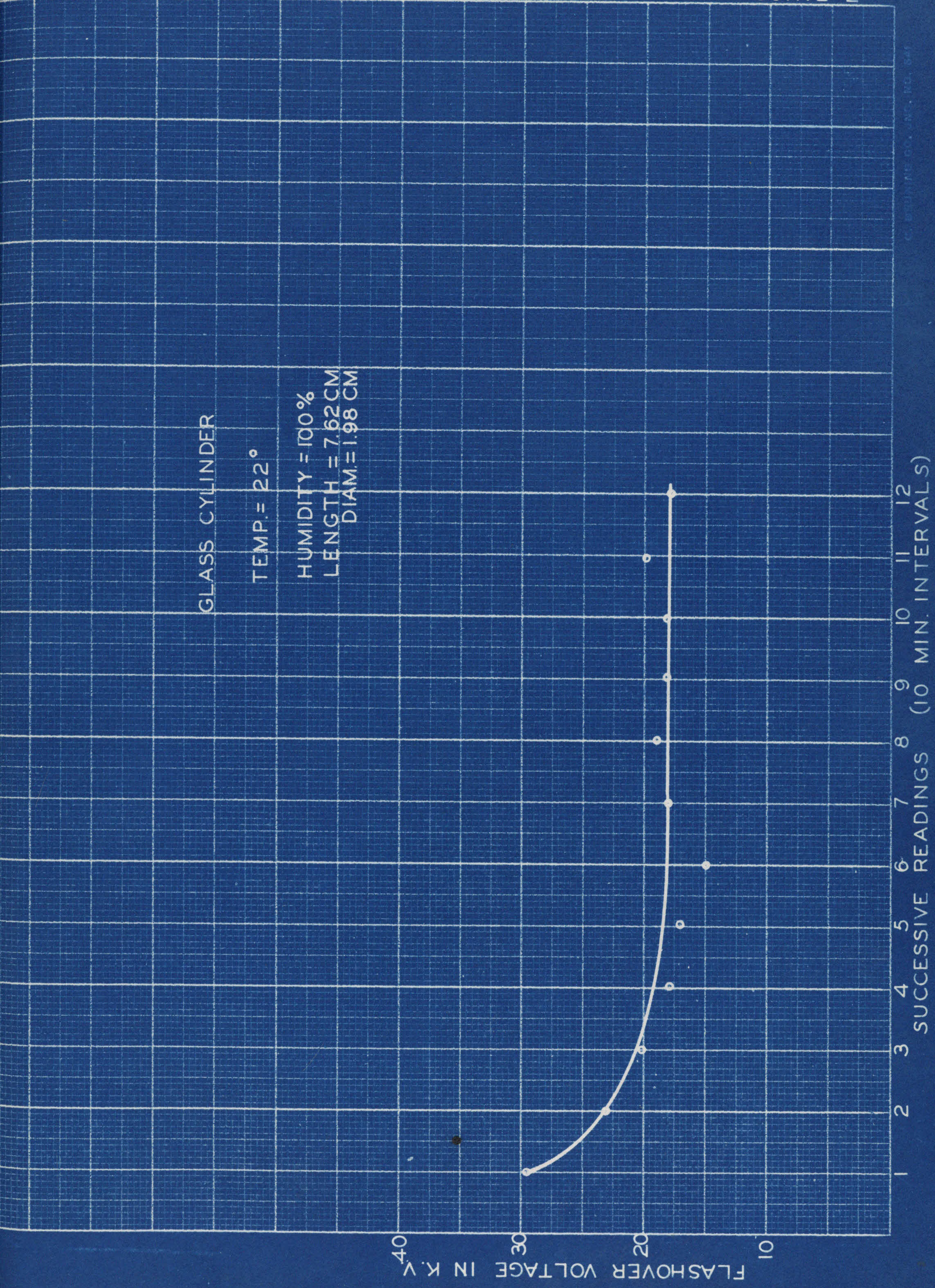
It was soon noticed in testing these cylinders that the condition of the surface of a cylinder seemed to change after having been flashed over and that it required a considerable length of time for the cylinder to return to a normal condition again. It was found that if the cylinder was flashed over soon after one discharge that the flashover voltage was invariably higher, and that if several discharges were made soon after each other the flashover voltage would continue to rise to a maximum which was somewhat lower than the air breakdown voltage for that spacing. This effect is graphically shown in Curve 1. A glass cylinder was used in this test. The voltage was brought up until the piece flashed over at 25 K.V. This voltage was held for one minute and then brought up to 33 K.V. where it flashed over again, but as before, the sparking soon stopped. In this way the voltage was raised five times before the maximum voltage of 51.5 K.V. was reached where the arc continued. This effect seemed to be more pronounced when the humidity was high. It is no doubt due to the fact that the spark destroys the path which it took either by drying up the moisture or by cleaning up any dirt in its path, and then in the next flashover it must seek a new path which would have a higher resistance than before, though still be the path of least resistance. It is important because of this phenomena that enough time be given between discharges so as to allow the specimen to return to its natural condition.

Another phenomena noticed was that the first two or three readings

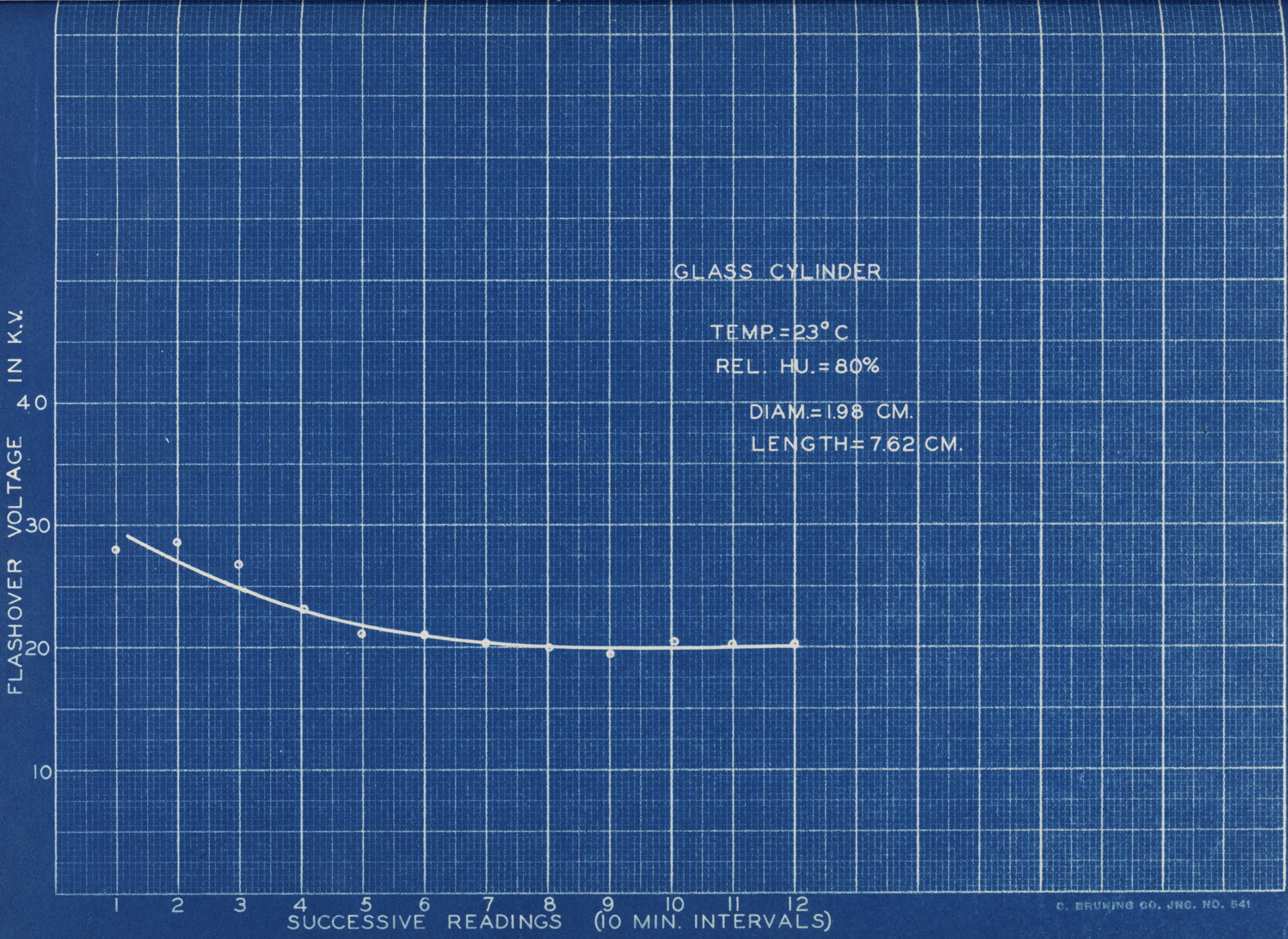

GLASS CYLINDER
DIAM.=1.98 CM.
LENGTH=7.62 CM.
REL. HU.=92%
TEMP.= 24° C.
AIR PUNCTURE VOLTAGE =132 K.V.
ARC
SPARK
SPARK
SPARK
SPARK
SPARK
LINE REPRESENTS APPLICATION OF VOLTAGE
FLASHOVER VOLTAGE IN K.V.
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TIME IN MINUTES

CURVE I

CURVE 2


GLASS CYLINDER
TEMP.= 22°
HUMIDITY = 100%
LENGTH = 7.62 CM
DIAM.= 1.98 CM
1
2
3
4
5
6
7
8
9
10
11
12
SUCCESSIVE READINGS (10 MIN. INTERVALS)
40
30
20
10
FLASHOVER VOLTAGE IN K.V.

CURVE 3


GLASS CYLINDER
TEMP.=23° C
REL. HU.=80%
DIAM.=1.98 CM.
LENGTH=7.62 CM.
FLASHOVER VOLTAGE IN K.V.
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
SUCCESSIVE READINGS (10 MIN. INTERVALS)

taken in testing the specimen were usually higher than normal or were irregular. Two graphs of this effect are shown in Curves 2 and 3. In each of these two cases the initial readings were higher than the succeeding readings indicated they should be. These curves are typical of any given set of readings. Such irregular readings were not used in making up the final curves.

Since it was not certain that the temperature correction factor as given by Peek for air breakdown voltage applied and as only qualitative results were sought for, no correction for temperature was made.

TEST RESULTS

The results obtained in this report are obtained from tests made on four different cylinders, two glass and two Pyrex.

In Curve 4 the results of a short test on a glass cylinder 1.55 cm. diameter and 5.00 cm. long are shown. This test was made at a temperature such that the heat added by evaporating water about balanced the heat lost by radiation. In this way it was possible to get varying humidities with nearly a constant temperature. The curve indicatés a straight line relationship between flashover voltages and relative humidities.

In Curve 5 the results of a great number of tests made on a glass cylinder 1.98 cm. diameter and 7.62 cm. long are given. In trying to obtain a relationship between temperature and flashover voltages for constant humidity on this cylinder, it was found that not enough data was taken to give any definite curve. However, from the tests made on the Pyrex insulators, it was found that temperature has little or no effect on the flashover value. Since the glass cylinder is very much like Pyrex, the points are plotted without respect to temperature, assuming that the temperature did not affect the flashover voltage. From experience and the data taken this assumption is believed to be nearly correct. This curve also shows nearly a straight line relationship between the flashover voltage and humidity, though the slope of this curve is steeper than that of Curve 4. Figure 7 shows a typical discharge for this cylinder.

Fig. 7

Curve 6 is plotted from data obtained for a Pyrex cylinder 10.24 cm. long and 3.89 cm. diameter. This data is also plotted without respect to temperature, since it was found that temperature seems to have no effect on the flashover of Pyrex insulators at least in the range of the tests. This curve is nearly horizontal for low humidities though the flashover rapidly decreases for higher humidities.

Curve 7 shows the resulta of data taken on a Pyrex insulator 2.62 cm. long and 3.89 cm. diameter. This insulator had the same diameter as the one used to determine Curve 6. The relationships between temperature and flashover voltage for constant humidities for this cylinder are shown in Curves 8 to 15 inclusive. While the data for these curves is quite irregular at times, it is quite definitely shown that temperature does not affect the flashover voltage. This result was determined over a range of temperature from 10^{o} to 70^{o} centigrade. The points for Curve 7 were obtained by taking the average values of flashover voltages for different humidities from the curves 8 to 15. Curve 7 indicates that the flashover voltage decreases directly with an increase in humidity. This curve does not agree in shape with that in Curve 6. However, the difference may be due to the change in length of the specimens. If such is the case it would mean that the dimensions of the insulator would affect the shape of the curve, and only by taking a great amount of data on insulators of different sizes can this be determined. Figures 8 and 9 show typical discharges for a Pyrex cylinder.

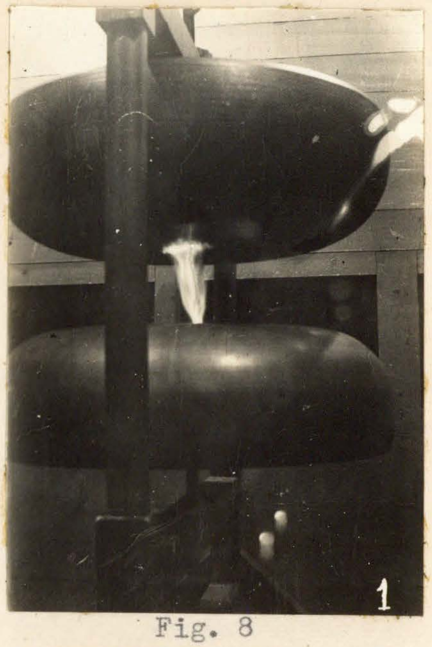


Fig. 8

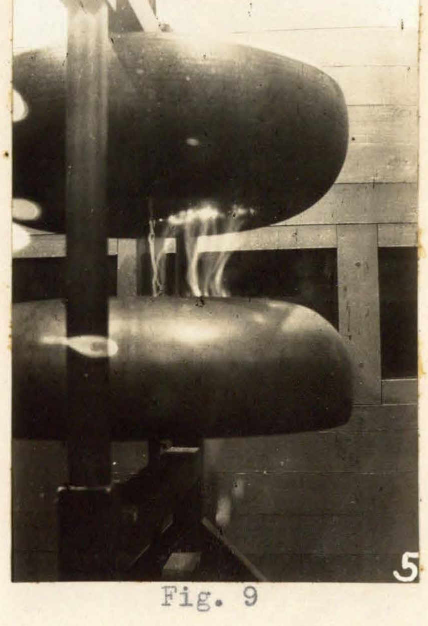


Fig. 9

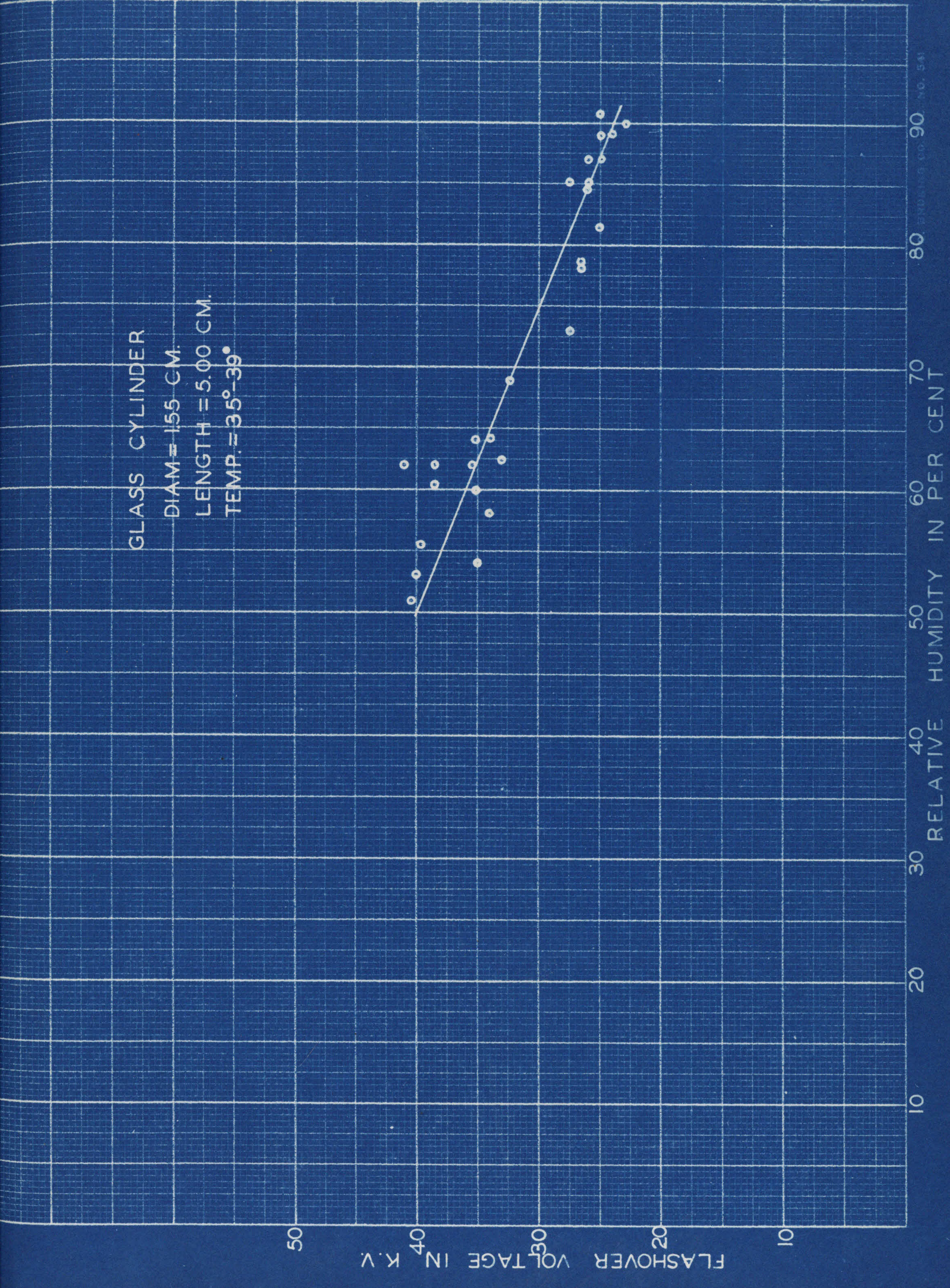
CONCLUSION

The results of this test very definitely show that the flashover voltage of glass and Pyrex insulators in a uniform field decreases with an increase in humidity; that for Pyrex, and very probably for glass, there is little or no change of flashover voltage with a change in temperature, and that, in general, with an increase in humidity the flashover voltage decreases more rapidly for glass insulators than Pyrex. This is exactly what one would be led to expect.

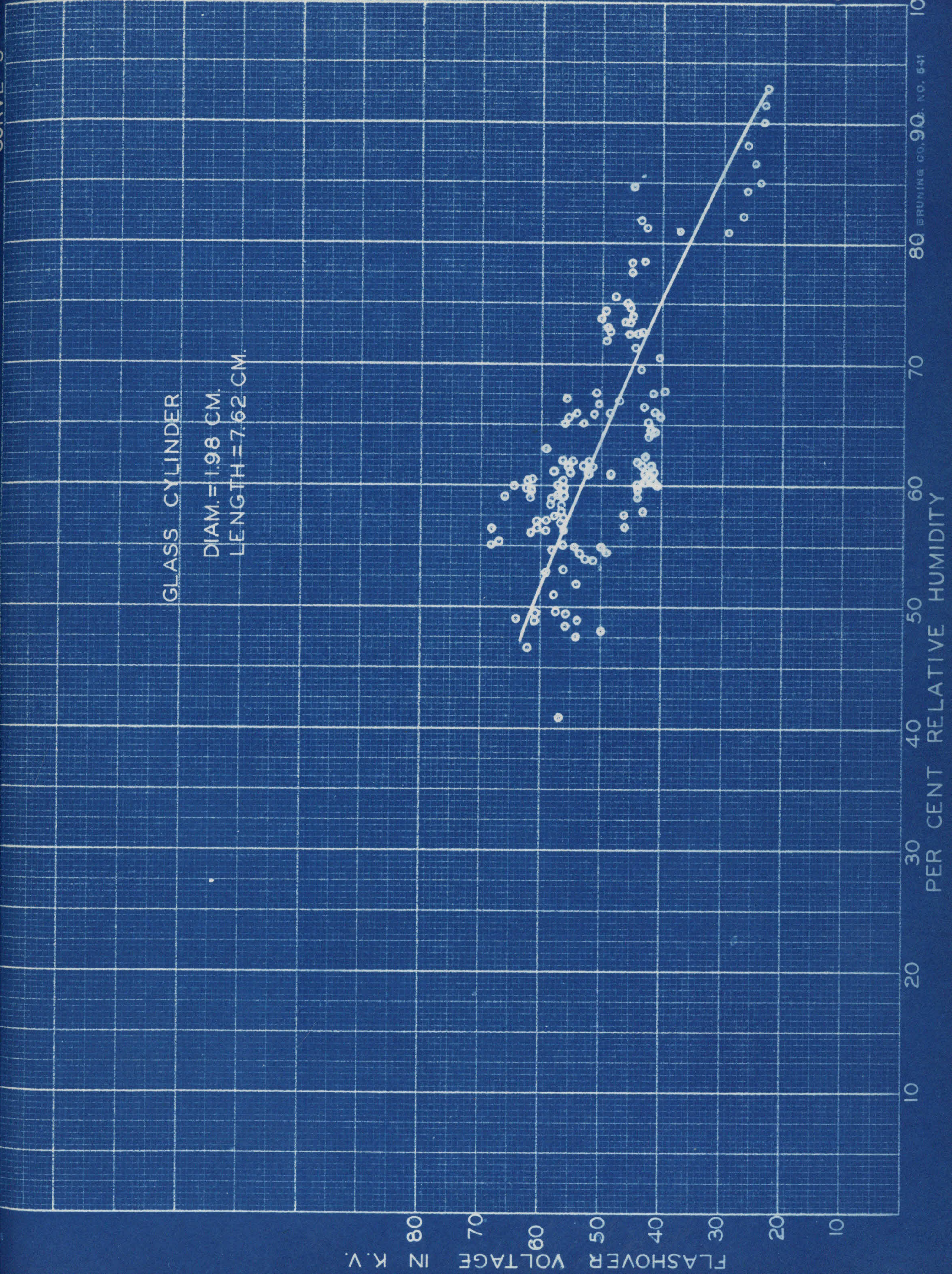
However, it is still uncertain whether the dimensions of the specimen will change the rate of decrease of flashover voltage at different humidities. Also readings at humidities below thirty per cent have not been made and the shape of the curve below that point is not known.

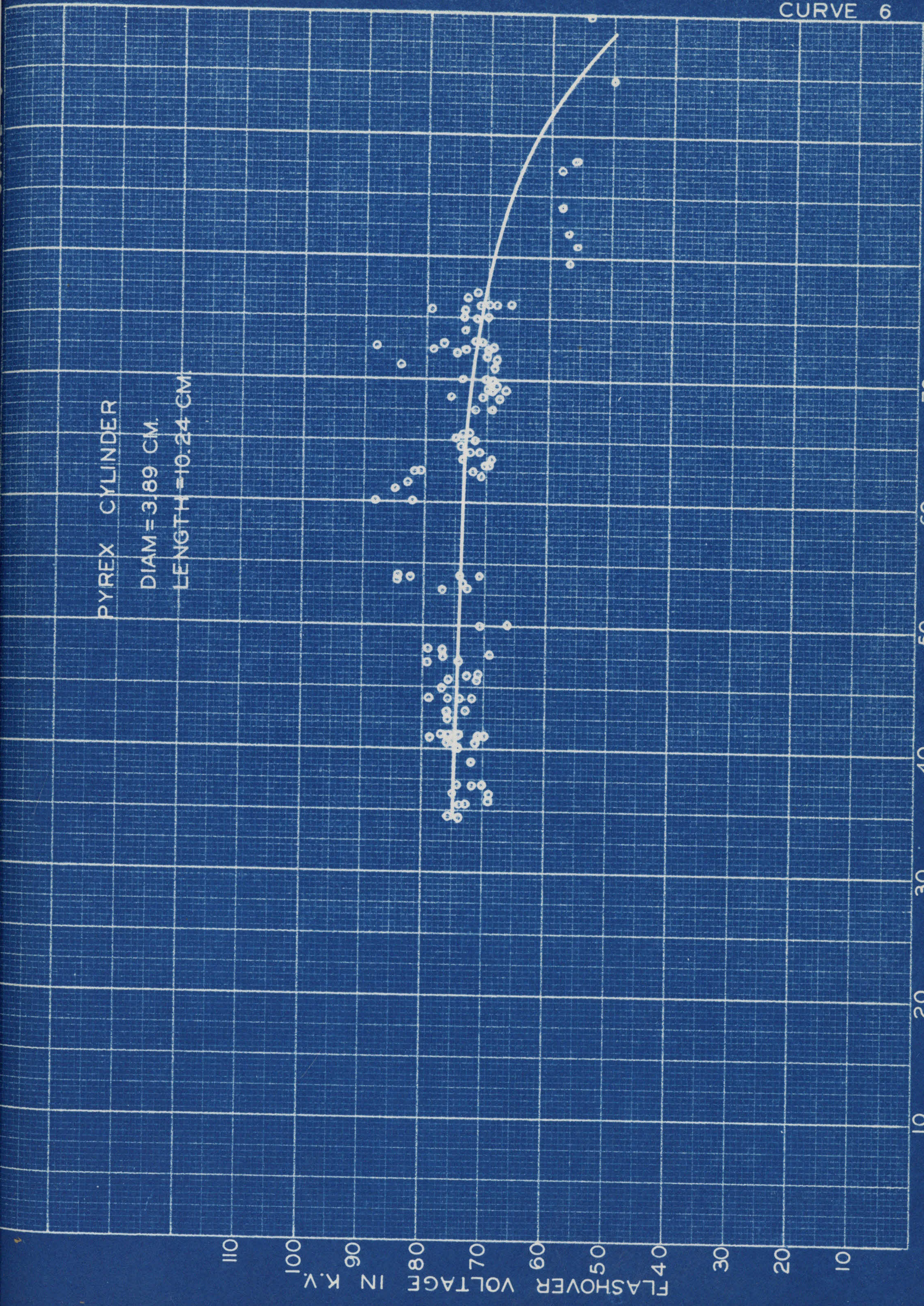
While it is definite from these tests that an increase of humidity will decrease the flashover potential for Pyrex and glass cylinders, quantitative measurements have not been made and only three possible variables have been considered. Therefore, while this report indicates the direction in which further work should be made, the final results are far from completion and there remain a great number of tests to be made before satisfactory conclusions can be drawn.

CURVE 4

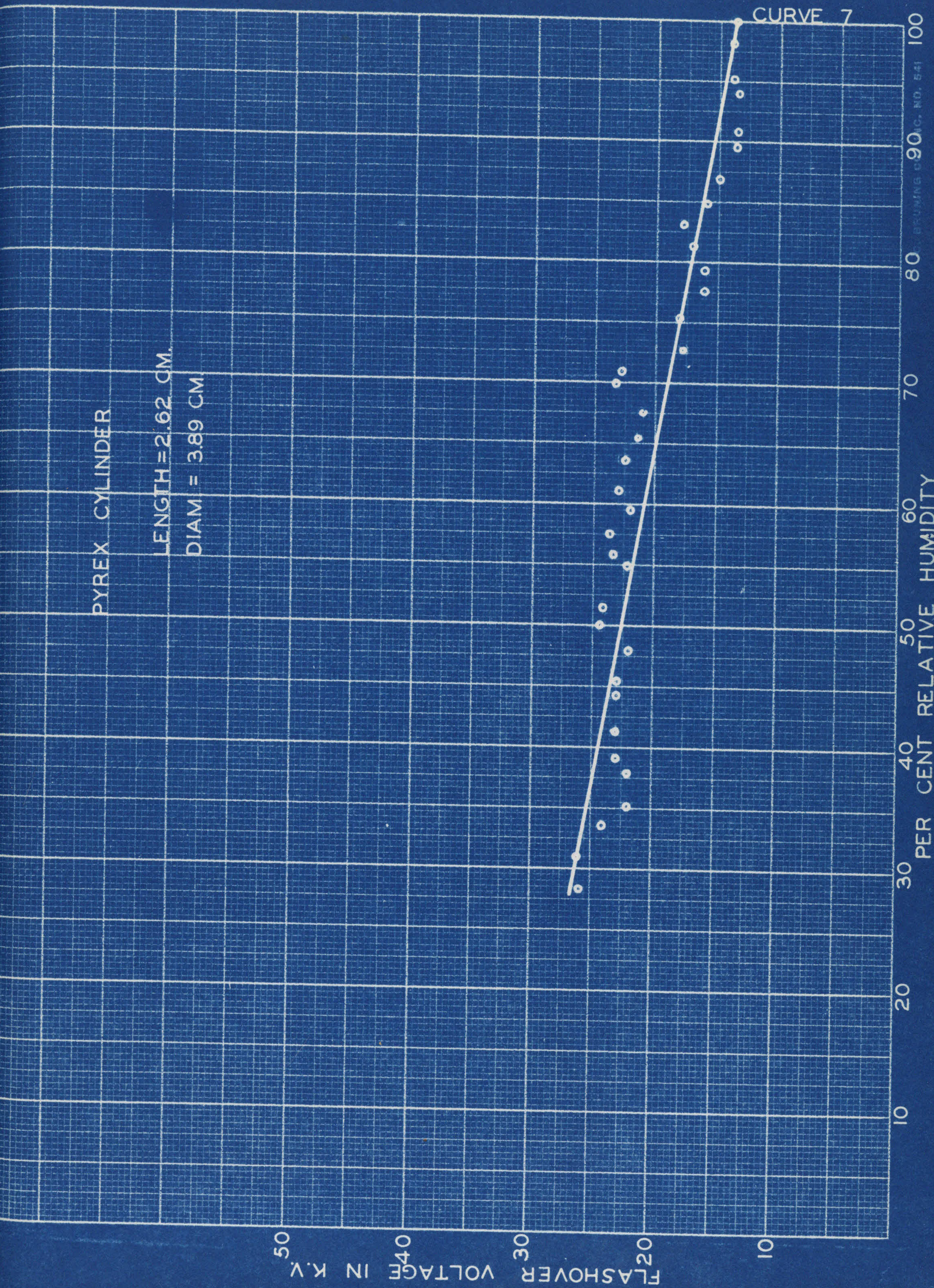

GLASS CYLINDER
DIAM = 1.55 CM.
LENGTH = 5.00 CM.
TEMP. = 35°-39°
RELATIVE HUMIDITY IN PER CENT
10
20
30
40
50
60
70
80
90
FLASHOVER VOLTAGE IN K.V.
50
40
30
20
10

CURVE 5

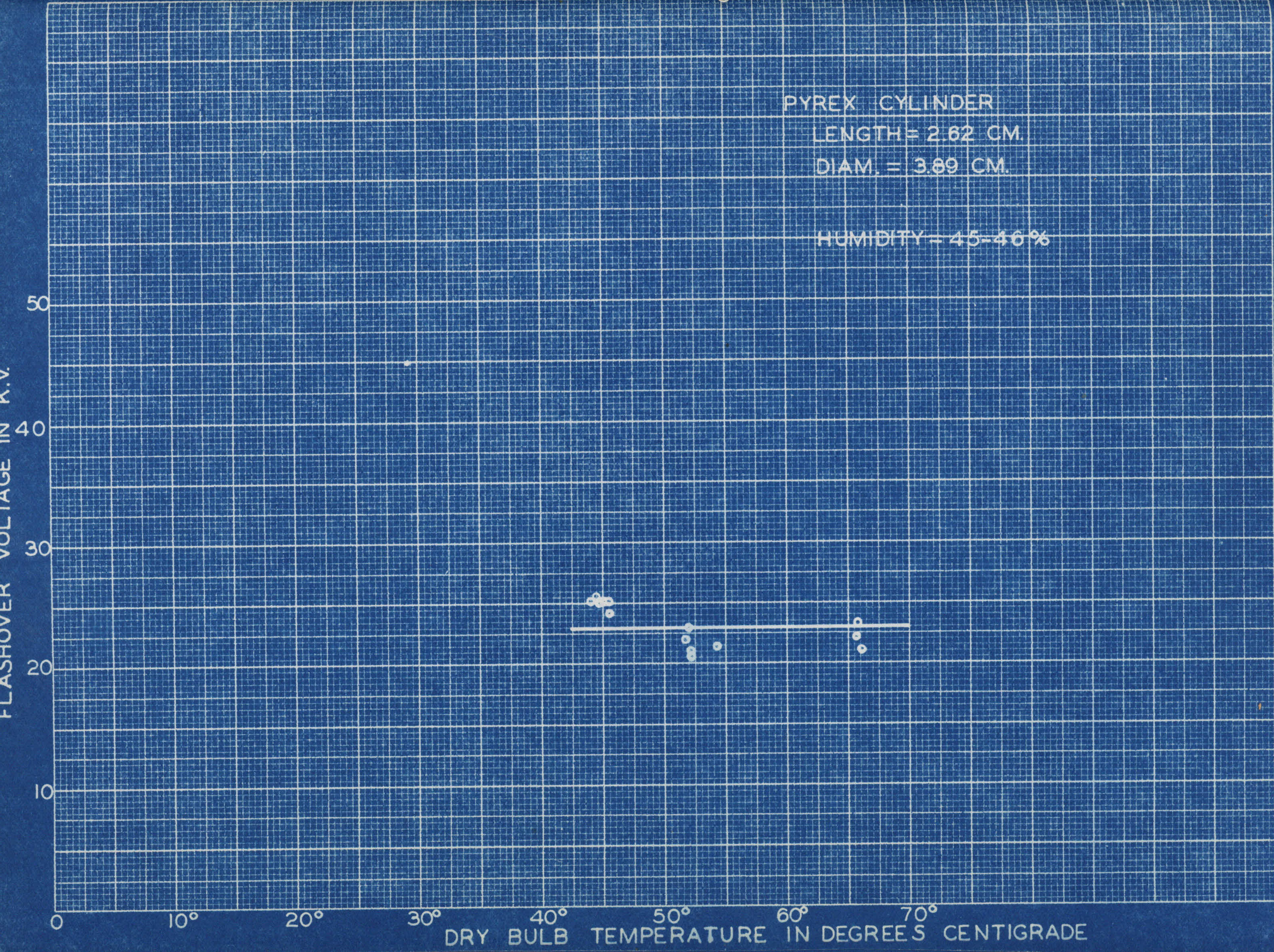

GLASS CYLINDER
DIAM.=1.98 CM.
LENGTH=7.62 CM.
PER CENT RELATIVE HUMIDITY
10
20
30
40
50
60
70
80
90
100
FLASHOVER VOLTAGE IN K.V.
10
20
30
40
50
60
70
80
BRUNING CO. NO. 541


CURVE 6
PYREX CYLINDER
DIAM = 3.89 CM.
LENGTH = 10.24 CM.
PER CENT RELATIVE HUMIDITY
10
20
30
40
50
60
70
80
90
100
FLASHOVER VOLTAGE IN K.V.
10
20
30
40
50
60
70
80
90
100
110
BRUNING CO. NO. 541

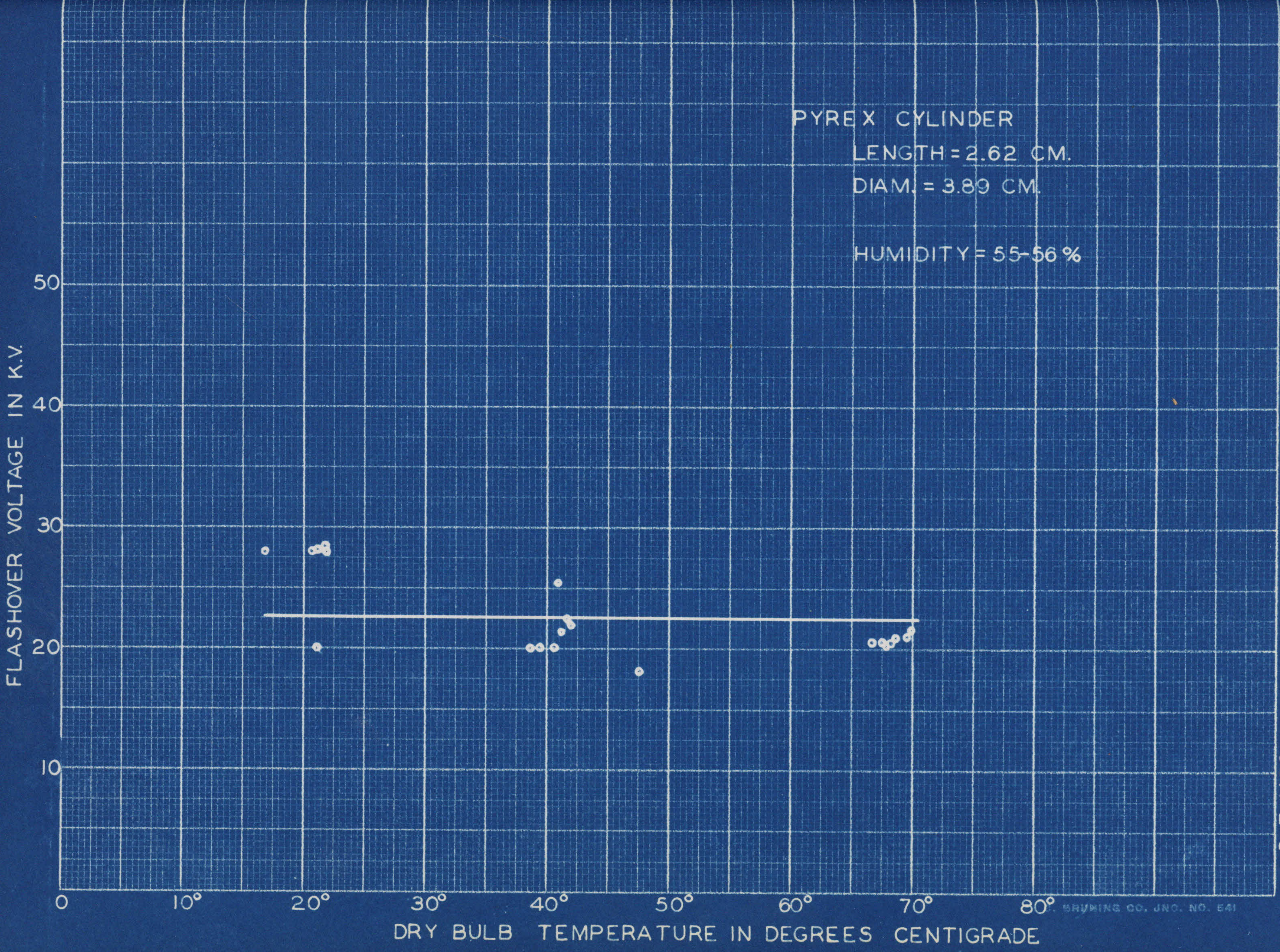
CURVE 7


PYREX CYLINDER
LENGTH = 2.62 CM.
DIAM = 3.89 CM.
PER CENT RELATIVE HUMIDITY
10
20
30
40
50
60
70
80
90
100
FLASHOVER VOLTAGE IN K.V.
10
20
30
40
50

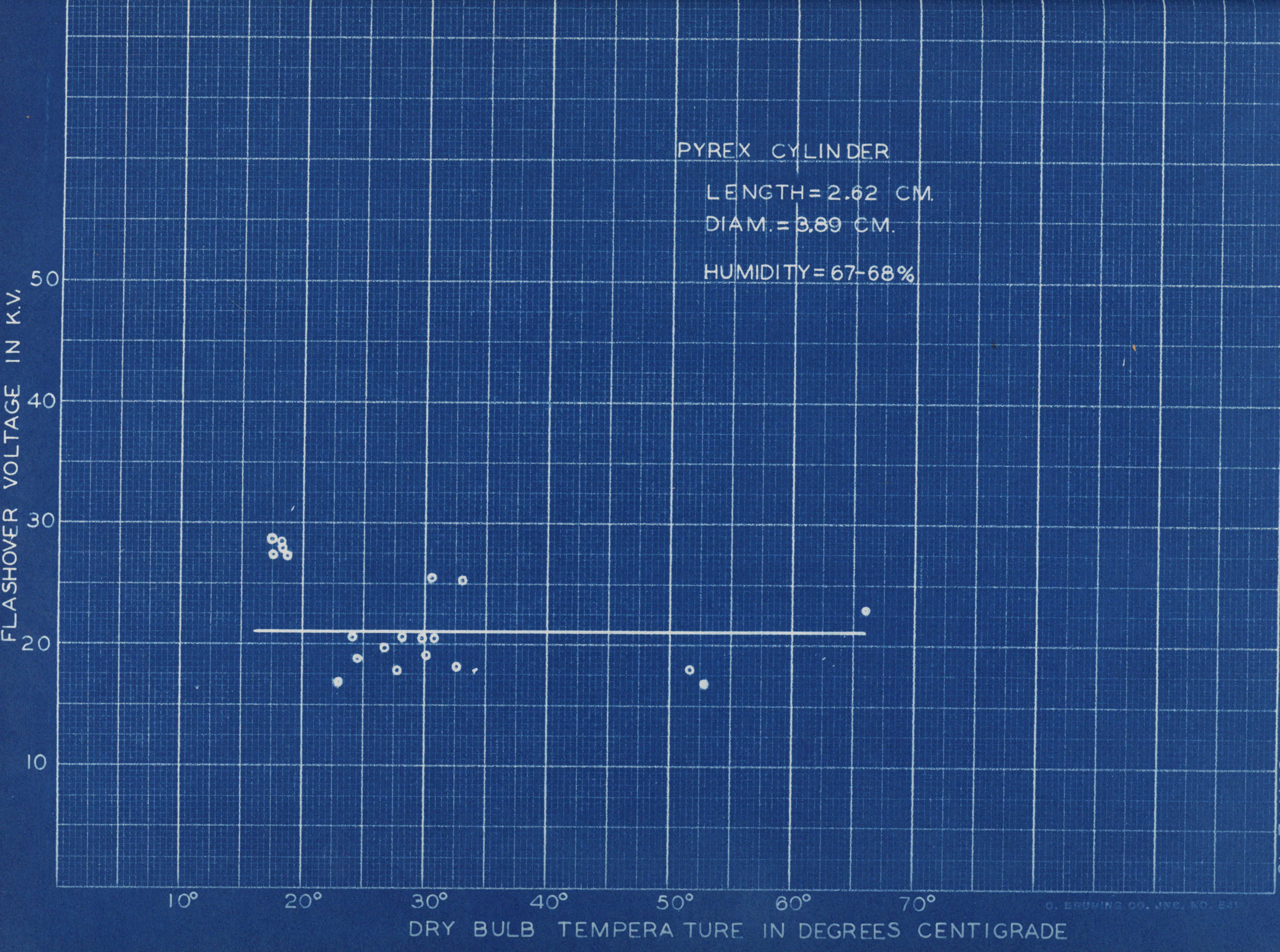
CURVE 8


PYREX CYLINDER
LENGTH = 2.62 CM.
DIAM. = 3.89 CM.
HUMIDITY = 45-46%
FLASHOVER VOLTAGE IN K.V.
10
20
30
40
50
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
0
10°
20°
30°
40°
50°
60°
70°

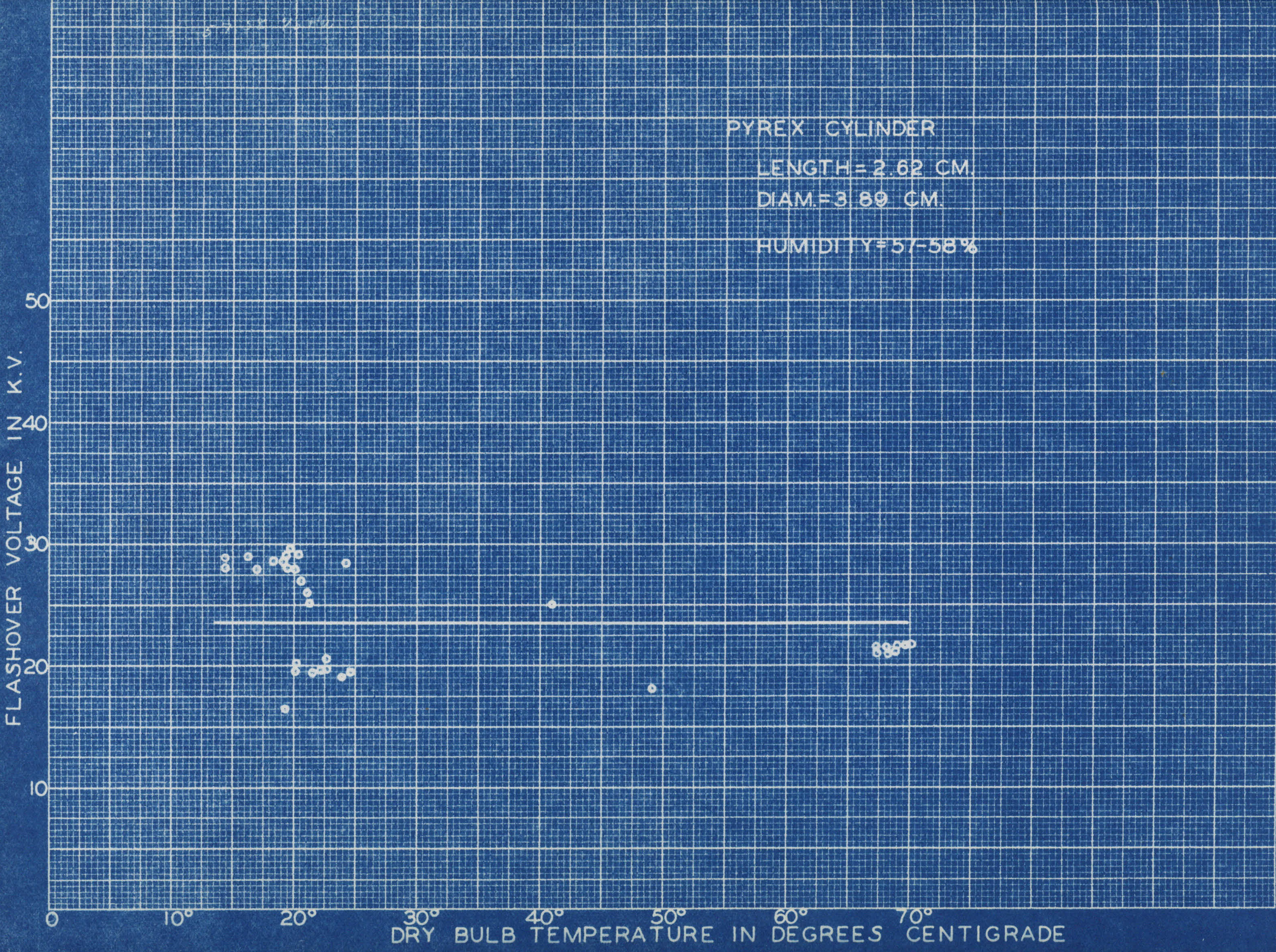
CURVE 9

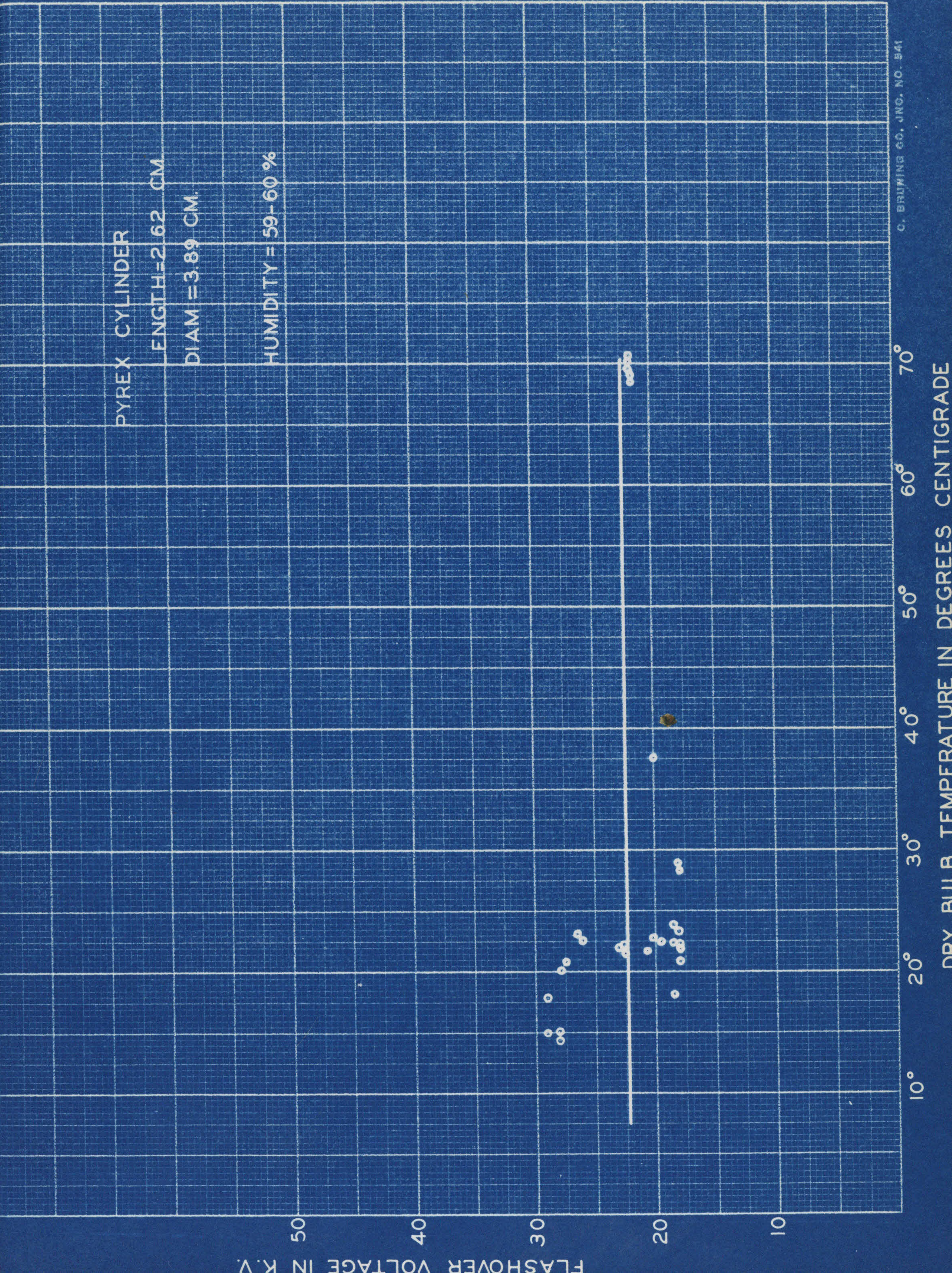

PYREX CYLINDER
LENGTH = 2.62 CM.
DIAM. = 3.89 CM.
HUMIDITY = 55-56 %
FLASHOVER VOLTAGE IN K.V.
50
40
30
20
10
0
10°
20°
30°
40°
50°
60°
70°
80°
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
C. BRUNING CO. INC. NO. 541

CURVE 10

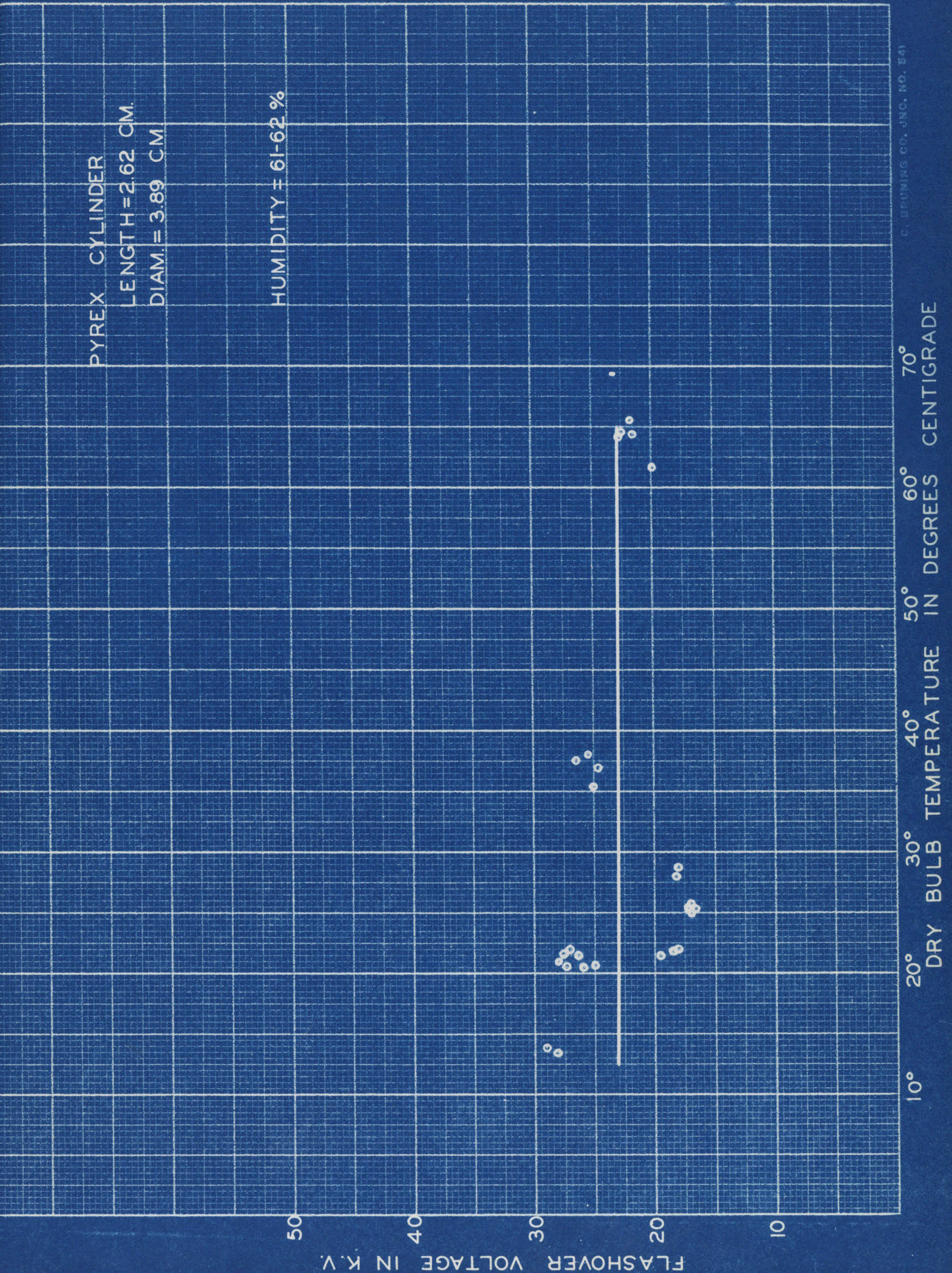

PYREX CYLINDER
LENGTH = 2.62 CM.
DIAM. = 3.89 CM.
HUMIDITY = 67-68%
FLASHOVER VOLTAGE IN K.V.
50
40
30
20
10
10°
20°
30°
40°
50°
60°
70°
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
C. BRUNING CO. INC. NO. 841

CURVE 11

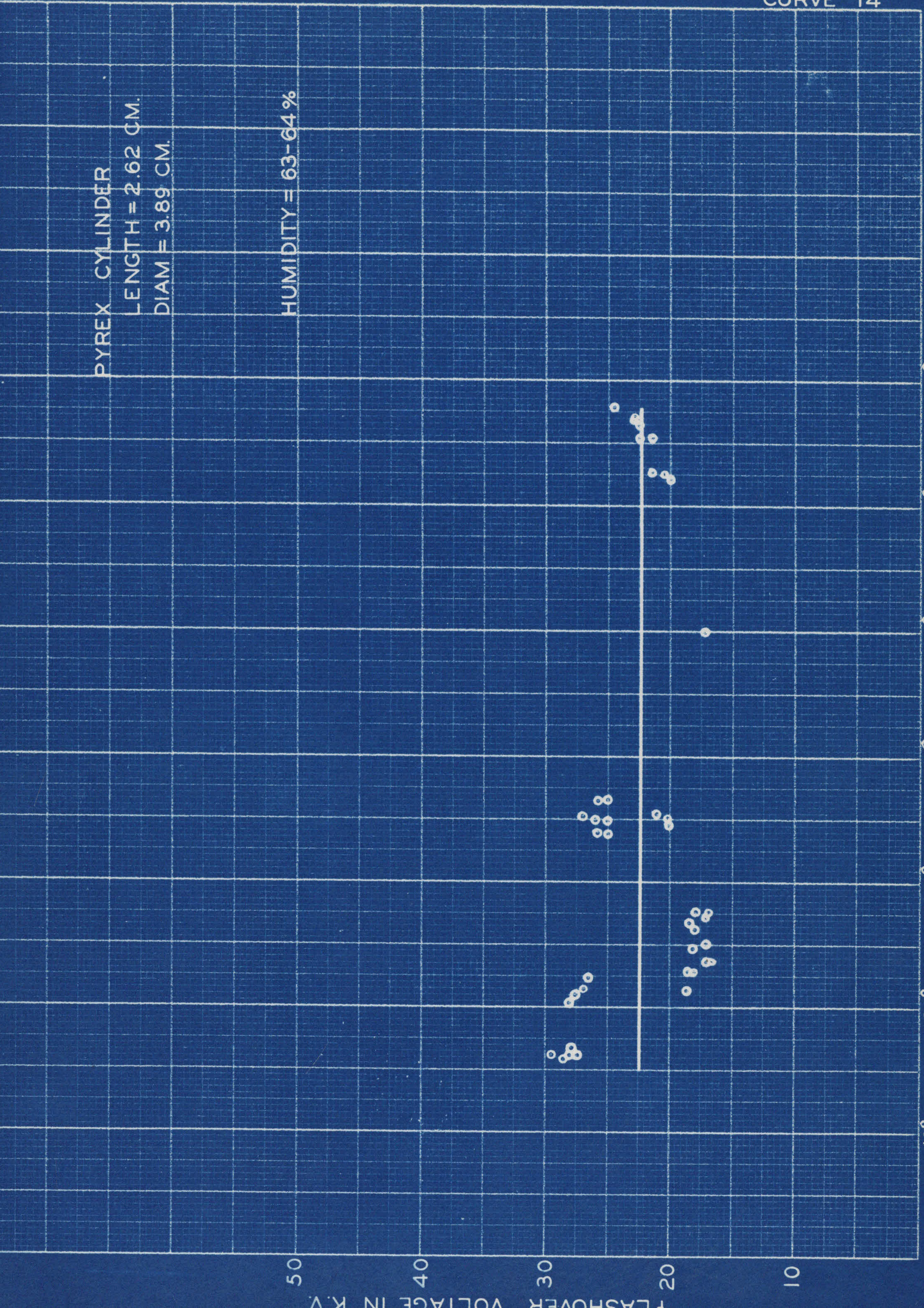

PYREX CYLINDER
LENGTH = 2.62 CM.
DIAM. = 3.89 CM.
HUMIDITY = 57-58%
FLASHOVER VOLTAGE IN K.V.
10
20
30
40
50
0
10°
20°
30°
40°
50°
60°
70°
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE


PYREX CYLINDER
ENGTH=2.62 CM
DIAM.=3.89 CM.
HUMIDITY=59-60 %
10°
20°
30°
40°
50°
60°
70°
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
10
20
30
40
50
FLASHOVER VOLTAGE IN K.V.
C. BRUNING CO. INC. NO. 341

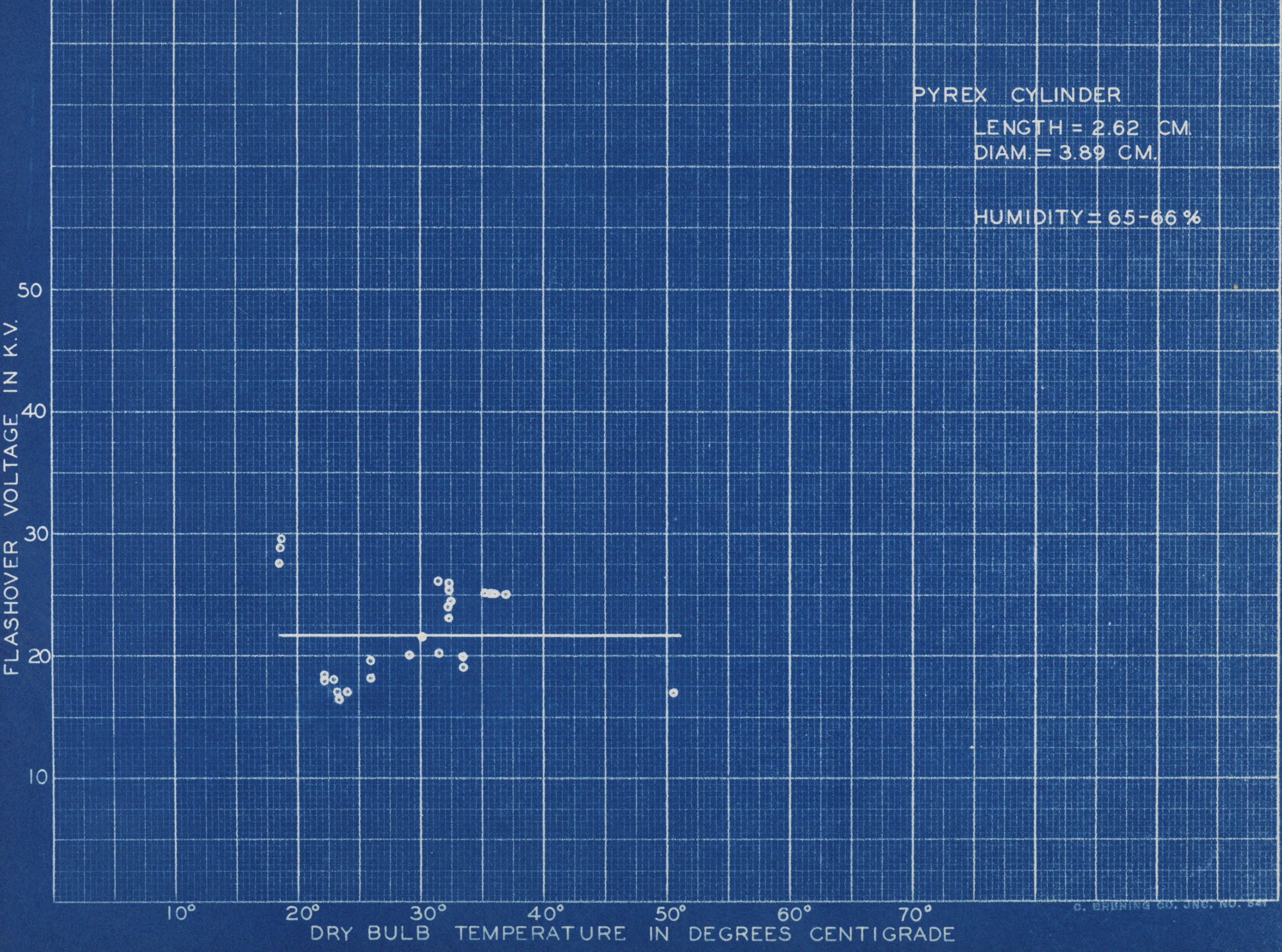
CURVE 13


PYREX CYLINDER
LENGTH=2.62 CM.
DIAM.=3.89 CM
HUMIDITY=61-62 %
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
10°
20°
30°
40°
50°
60°
70°
FLASHOVER VOLTAGE IN K.V.
10
20
30
40
50
C. BRUNING CO. INC. NO. 841

CURVE 14


PYREX CYLINDER
LENGTH = 2.62 CM.
DIAM = 3.89 CM.
HUMIDITY = 63-64 %
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
10°
20°
30°
40°
50°
60°
70°
FLASHOVER VOLTAGE IN K.V.
10
20
30
40
50
C. BRUNING CO. INC. NO. 541

CURVE 15


PYREX CYLINDER
LENGTH = 2.62 CM.
DIAM. = 3.89 CM.
HUMIDITY = 65-66 %
FLASHOVER VOLTAGE IN K.V.
50
40
30
20
10
10°
20°
30°
40°
50°
60°
70°
DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
C. BRUNING CO. INC. NO. 847