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on

Method of Measuring Penetration Time for Deep Drying Insulating Varnishes

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ABSTRACT

The speed of penetration of a number of insulating varnishes was measured by four different methods. Correlations were then made between the penetration times and the viscosities of all the varnishes. Viscosity was found to be a fairly reliable index of penetration time if it is used in the proper equation for each method. The surface tension and wetting ability of these varnishes are apparently of secondary importance in determining the penetration times.

By title, the methods used were:

1. Wick rise
2. Coil dipping
3. Simulated coil dipping
4. Vacuum impregnation

Where a more closely service sumulating comparison of penetration times of varnishes is desired than that obtained from simple viscosity measurements, either method 3 or method 4 is recommended.

INTRODUCTION

(a) Authorization

1. This work was authorized by Bureau of Ships letter JJ52-(5)(355) dated February 23, 1942, to NRL.

(b) Statement of problem

2. The purpose of this work is to develop a method for determining the relative times it takes commercial electrical insulating varnishes to penetrate the windings of an electrical coil. It is also proposed to try to correlate this penetration time with the viscosity, surface tension, and wetting ability of the varnish.

(c) Theoretical considerations

3. The penetration time of a given varnish may logically be expected to depend on viscosity since one way of measuring the viscosity of a liquid is to measure the time it takes for it to be forced through a small opening. The penetration time may also be expected to depend on at least two other factors. One of these is the surface tension of the varnish at the varnish-air interface and another is the related phenomenon concerning the ease with which the varnish wets or spreads on the solid material of the coil.

4. If the penetration times of such dissimilar substances as mercury, water, and a varnish were to be compared, then these interfacial tension effects would probably be more important than the viscosity differences. When comparing the penetration times of relatively similar materials, such as various kinds of electrical insulating varnishes, the viscosity differences may be expected to be the primary variable while interfacial effects will be of secondary importance. One of the purposes in obtaining the following data is to show the extent to which this conclusion is justified.

METHODS

(a) Materials

5. The materials studied in this investigation were commercial insulating varnishes furnished by various varnish companies.

(b) Equipment

6. Since insulating varnishes are applied to a wide variety of equipment in commercial practice it was thought advisable to measure penetration time in a number of different ways and compare the results. The following four methods were used:

Method I - - - - Wick rise
Method II - - - - Coil dipping
Method III - - - - Simulated coil dipping
Method IV - - - - Vacuum impregnation

7. In the wick rise method the end of a strip of standard cloth (#10 cotton duck) was dipped in the varnish and the rate at which the varnish rose in the cloth due to capillary attraction was measured. The atmosphere around the cloth was kept saturated with solvent vapor. See plate 8 for line drawing and plate 11 for a photograph of apparatus.

8. The coil dipping method was based on suspending a standard coil under the surface of the varnish and observing the rate of increase in the apparent weight of the coil as varnish soaked into it. It was necessary in this method to have a number of coils of identical size and winding. This is difficult to obtain in practice and accounts largely for the errors in this method. The coils were all universal wound on an automatic coil winding machine. They had an outside diameter of 2 inches and contained 800 turns of #30 double cotton covered wire. See plates 12 and 13 for photographs of the coils and apparatus. Details of the method are given in the appendix.

9. The simulated coil dipping apparatus is shown on the drawing and photographs on plates 9, 14 and 15. The varnish to be tested was poured into the outer cylinder to a depth of 2 inches above the cloth and copper screen layers. The time it took the varnish to travel horizontally from the edge of the glass discs along cloth and screen layers to the center hole in the discs was noted. The fit of the brass rod through the holes in the center of the glass discs was loose enough to allow air trapped in the cloth by the incoming varnish to escape. The pressure of the discs on the cloth layers was maintained constant by a spring around the brass rod at the top of the apparatus. Details of the calibration of the spring are given in the appendix.

10. The vacuum impregnation apparatus is shown on the drawing and photographs on plates 10, 16, and 17. The procedure when making an experiment with this apparatus was to evacuate it through the stopcock until the pressure inside was well below 1 mm of mercury then immerse the bottom end of the apparatus about 2 inches below the surface of the varnish under test. The stopcock to the vacuum pump was then closed and, after making sure there were no air bubbles clinging to the immersed part of the apparatus, the plate closing the bottom inlet was quickly pushed off and the varnish allowed to rush in. By observing through the transparent top of the apparatus, the penetration time was noted. This was the time it took the leading edge of the varnish to travel horizontally along the single cloth layer from the outer edge of the brass disc to the well in its center. The cloth layer was held under a compression of about 50 lbs. by the flat spring under the brass disc. Details of the calibration of the apparatus are given in the appendix.

11. The viscosities were measured with an Ostwald type viscometer. Both the viscosity and penetration times were measured at 25°C in a constant temperature room.

DATA OBTAINED

(a) Curves or Plots of Data

12. Plates 1 through 3 show plots of amount of penetration versus time for various varnishes using penetration methods I, II, and III. Plates 4 through 7 show plots of penetration time versus viscosity for

various varnishes using all four penetration methods.

13. The fact that the points on plots 4 through 7 all tend to lie on straight lines is interesting. From these plots an equation can be written for each method showing the approximate relation between viscosity and penetration time for various varnishes. The general form of this equation is

$$P = P_o N^s$$

where P_o = a constant that depends on the size of the apparatus and equals P when N is one,
N = viscosity of varnish
S = slope of line for plot of penetration time versus viscosity on log log paper.

The specific equations for the lines on plates 4 through 7 are:

Method I - Wick rise, $P_1 = 3.23\ N^{1.22}$
Method II - Coil dip, $P_2 = 3.85\ N^{0.94}$
Method III - Simulated coil dip, $P_3 = 400\ N^{1.05}$
Method IV - Vacuum impregnation, $P_4 = 7.8\ N^{0.85}$

(b) Date in tabular form

14. In the second and third columns of tables I through IV is given data on the viscosity and observed penetration times of the different varnishes as obtained by the various penetration methods. In the fourth column of each table is given the penetration time as calculated from the specific equation for each apparatus and method. In column five is given the per cent deviation of this calculated value from the observed value for the particular method. The amount of these deviations indicates the extent to which viscosity and the specific equations may be depended upon to give the relative penetrating times of various varnishes.

15. All experiments were made in duplicate or triplicate. The data given on the plots and in the tables are the averaged results.

(c) Probable errors

16. In these experiments one of the results desired was the correlation of the viscosities and the respective penetration times of various varnishes. The errors effecting this correlation were those encountered in the measurement of:

A. Viscosity--It is estimated that the probable error in this measurement was about 2 per cent.
B. Penetration time--To give an idea of the probable accuracy of the various methods, a rough analysis of the main sources of error in each is given in the appendix. An overall estimate of the probable per cent error for each method is as follows:

I Wick rise - 12%
II Coil dipping - 11%
III Simulated coil dipping - 5%
IV Vacuum impregnation - 8%

CONCLUSIONS AND RECOMMENDATIONS

(a) Facts established

17. The penetration time is proportional to a particular power of the viscosity for each of the four methods tried in these experiments. The power to which the viscosity must be raised varies from 1.22 for the wick rise method to 0.85 for the vacuum impregnation method. It is close to one for both the coil dipping methods (0.94 and 1.05).

(b) Opinions

18. Since the viscosity appears to be the important variable in determining penetration times, the surface tension effects in these varnishes are either small or do not differ greatly among the eight randomly chosen varnishes. For practical purposes it appears that the relative penetration times of various varnishes can be taken as proportional to the first power of the viscosity for coil dipping applications and proportional to the 0.85 power of the viscosity for vacuum impregnation applications.

(c) Recommendations

19. It is recommended that viscosity be considered as an index of penetration time in applications where a high degree of accuracy is not essential. In tests where it is necessary that conditions be as nearly service simulating as possible it is recommended that Method III, above, be used for varnishes bought for coil dipping applications while Method IV be used for varnishes bought for vacuum impregnation applications.

SUMMARY

20. The penetration times of a number of insulating varnishes were measured by four independent methods. For each method the penetration could be reasonably well expressed as a function of the viscosity.

21. It was recommended that viscosity be used as a measure of penetration time when a highly service simulating test is not called for. When a more critical test is necessary it was recommended that penetration time be measured by either the simulated coil dipping method or by the vacuum impregnation method, according to the application.

APPENDIX

Details of Methods Employed

(a) Coil dipping Method

1. In the coil dipping method the standard coil was suspended from one of the arms of an ordinary laboratory balance having a sensitivity of 0.03 gm. The coil was weighed in air and then submerged in the varnish under test by raising a filled beaker around it. The weight of the submerged coil was then taken at short intervals of time so that a curve could be obtained showing the rate at which the varnish displaced the air in the windings.

2. The accuracy with which the determination of the time it took for given amounts of varnish to enter the coil was aided by means of a recording milliammeter and an electrical contact on the pointer of the balance. Each time the weight of the coil in the varnish exceeded the amount of the weights placed successively on the opposite pan of the balance the electrical contact was broken and a record of this time made on the moving chart of the recorder. See photograph on plate 13.

(b) Simulated coil dipping Method

3. The cloth used in these experiments for the layers between the glass plates was a soft all cotton flannel with nap on both sides. Its weight was 3.4 oz per sq. yd. and the count was 48 threads per inch for the warf and 42 threads per inch for the filler. The copper screen used between the two cloth layers was square weave with 16 wires (15 mil diameter) per inch.

4. The amount of compression exerted by the coil spring on the cloth and screen layers was adjusted so that a heavy Pennsylvania Mineral oil having a viscosity of 3.65 stokes (25°C) would penetrate from the outer 2" diameter circle to the center 3/8" circle in 115 seconds. In adjusting the compression of spring on a duplicate apparatus of the simulated coil dipping type the calibrating oil might have a viscosity anywhere in the range of 3 to 5 stokes. The corresponding penetration time the oil should give may be read from the broken line through the mineral oil point on plate 6. For example, an oil with a viscosity of 3 stokes should give a penetration time of about 94 seconds in this particular apparatus.

(c) Vacuum impregnation method

5. The type of cloth used for the vacuum impregnation apparatus was the same as that used for the simulated coil dipping test except only one layer of cloth was used. The compression exerted by the flat spring on the cloth layer was adjusted so that, using the vacuum impregnation method, a Pennsylvania oil of viscosity 3.65 stokes would penetrate from the outer 2" diameter circle to the central 3/8" well in 24 seconds. By referring to the dashed line through the mineral oil point on plate 7 the penetration time for a mineral oil having any viscosity in the range of 3 to 5 stokes may be estimated and this value used to set the spring tension of the apparatus.

(d) Analysis of main sources of error

6. Errors which may be expected to have most affected the reproductibility of the various methods are as follows:

I. Wick rise method

A. Sampling errors of cloth strips - 2%
B. Timing - negligible
C. Distance of rise - 5%
D. Method of dipping - small
E. Evaporation - 10%
F. Temperature variations - 1%
G. Overall estimate - 12%

II. Coil dipping method

A. Sampling among coils (this error apparently shows more strongly at low viscosities) - 10%
B. Timing - 2%
C. Weighing, evaporation - negligible
D. Method of dipping and hanging coil - 3%
E. Temperature variations - 1%
F. Overall estimate - 11%

III. Simulated Coil Dipping

A. Timing - 2%
B. Evaporation at advancing edge of varnish - negligible
C. Eccentricity of rings - 3%
D. Assembling of test apparatus - 3%
E. Temperature variations - 1%
F. Overall estimate - 5%

IV. Vacuum Impregnation

A. Timing - (inversely proportional to viscosity) 5% at low viscosity, 0.5% at high.
B. Method of admitting varnish thru valve - rather indeterminate, probably less than 5% on final measurements.
C. Evaporation and recondensation of varnish solvent at advancing edge of varnish - undetermined.
D. Assembling of test apparatus-3%
E. Air ebullition during advance of varnish thru evacuated space - probably less than 5% in final measurements (can be major source of error if a large opening is not provided for admitting the varnish to the vacuum chamber.)
F. Temperature variations - 1%
G. Overall estimate - 8%

TABLE I

Wick Rise Method $P_1 = 3.23\ N^{1.22}$

Varnish*	Viscosity (stokes)	Penetration Time observed (seconds)	calculated (seconds)	Per cent deviation
Chinalak	0.476	127	132	+3.9
PG-1	0.633	200	185	-7.5
M-472	1.38	500	480	-4.0
M-830	1.40	500	580	+16.0
R-741	2.42	1300	950	-26.9
S-110	5.52	1570	2600	+65.5
P-601	13.35	7500	7800	+4.0
#13	16.35	9500	9800	+3.2

*The varnishes in tables I to IV were manufactured by the following companies: Chinalak, PG-1 - John C. Dolph Co., Newark, N.J.; M-472, M-830, R-741, S-110, P-601 - Sterling Varnish Co., Haysville, Penna. #13 - Schenectady Varnish Co. Schenectady, N. Y.

TABLE II

Coil Dipping Method $P_2 = 3.85N^{0.94}$

Varnish	Viscosity (stokes)	Penetration time observed (seconds)	calculated (seconds)	Per cent deviation
Chinalak	0.45	186	183	-1.6
PG-1	0.99	490	383	-21.9
M-472	1.47	540	550	+1.8
M-830	1.48	640	555	-13.3
R-741	2.66	860	960	+11.5
S-110	6.51	2120	2220	+4.7

TABLE III

Simulated Coil Dipping Method $P_3 = 400\ N^{1.05}$

Varnish	Viscosity (stokes)	Penetration time observed (seconds)	Penetration time calculated (seconds)	Per cent deviation
Chinalak	0.476	18.0	18.2	+1.1
PG-1	0.633	25.2	25.0	-0.8
M-472	1.38	55.0	56.0	+1.8
M-830	1.40	60.0	57.0	+8.3
R-741	2.42	88	98.0	+11.3
S-110	5.52	226	224.0	-0.9
P-601	13.35	660	610.0	-7.5
#13	16.35	730	740.0	+1.4
Mineral oil	3.65	115		

TABLE IV

Vacuum Impregnation Method $P_4 = 7.8\ N^{0.85}$

Varnish	Viscosity (stokes)	Penetration time observed (seconds)	Penetration time calculated (seconds)	Per cent deviation
Chinalak	0.45	3.3	4.0	+21.2
PG-1	0.99	8.3	7.8	-6.0
M-472	1.47	11.5	10.8	-6.1
M-830	1.48	10.9	10.9	0
R-741	2.66	18.0	18.0	0
S-110	6.51	34.5	37.8	+9.6
Mineral oil	3.65	24.0		

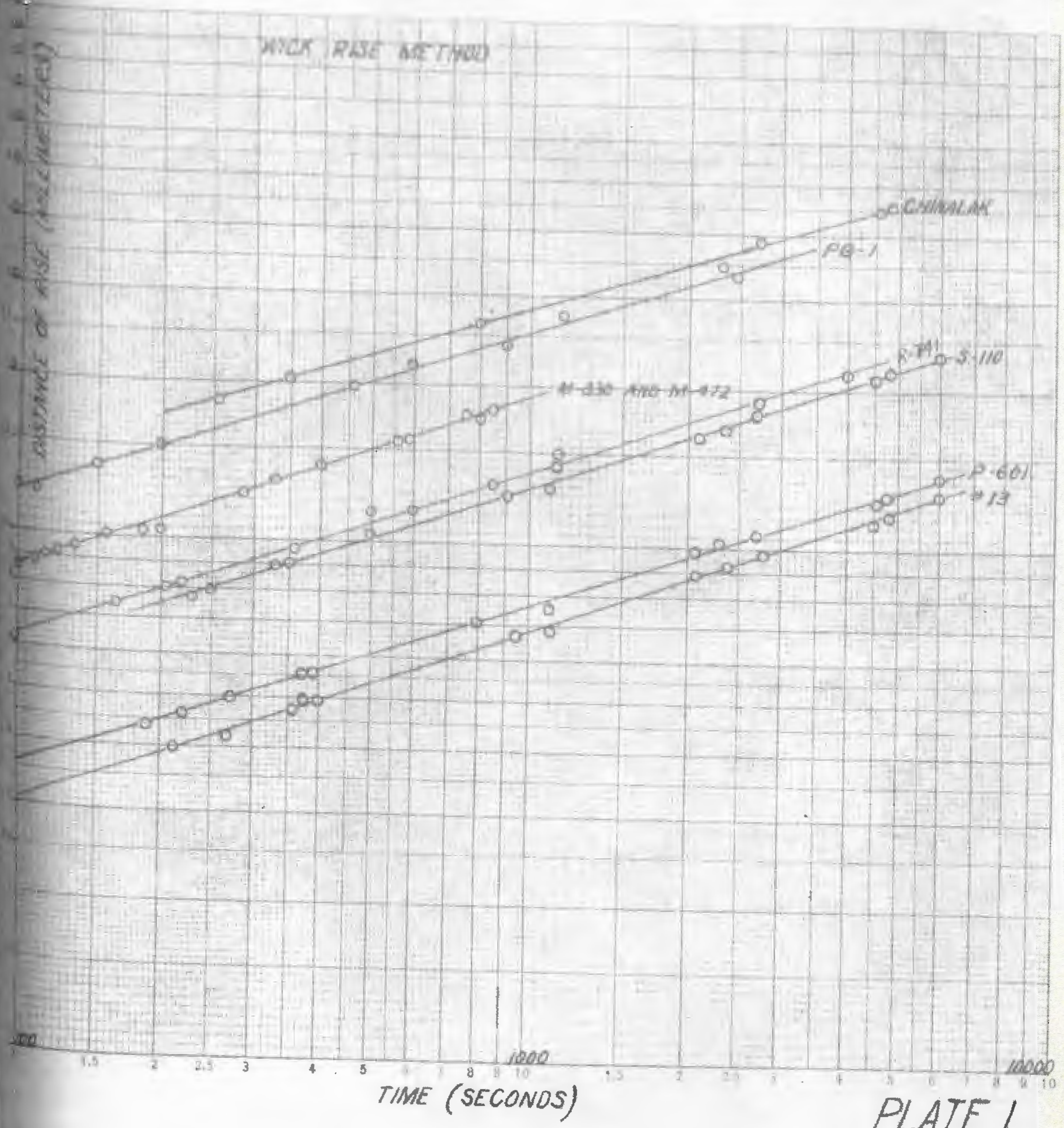
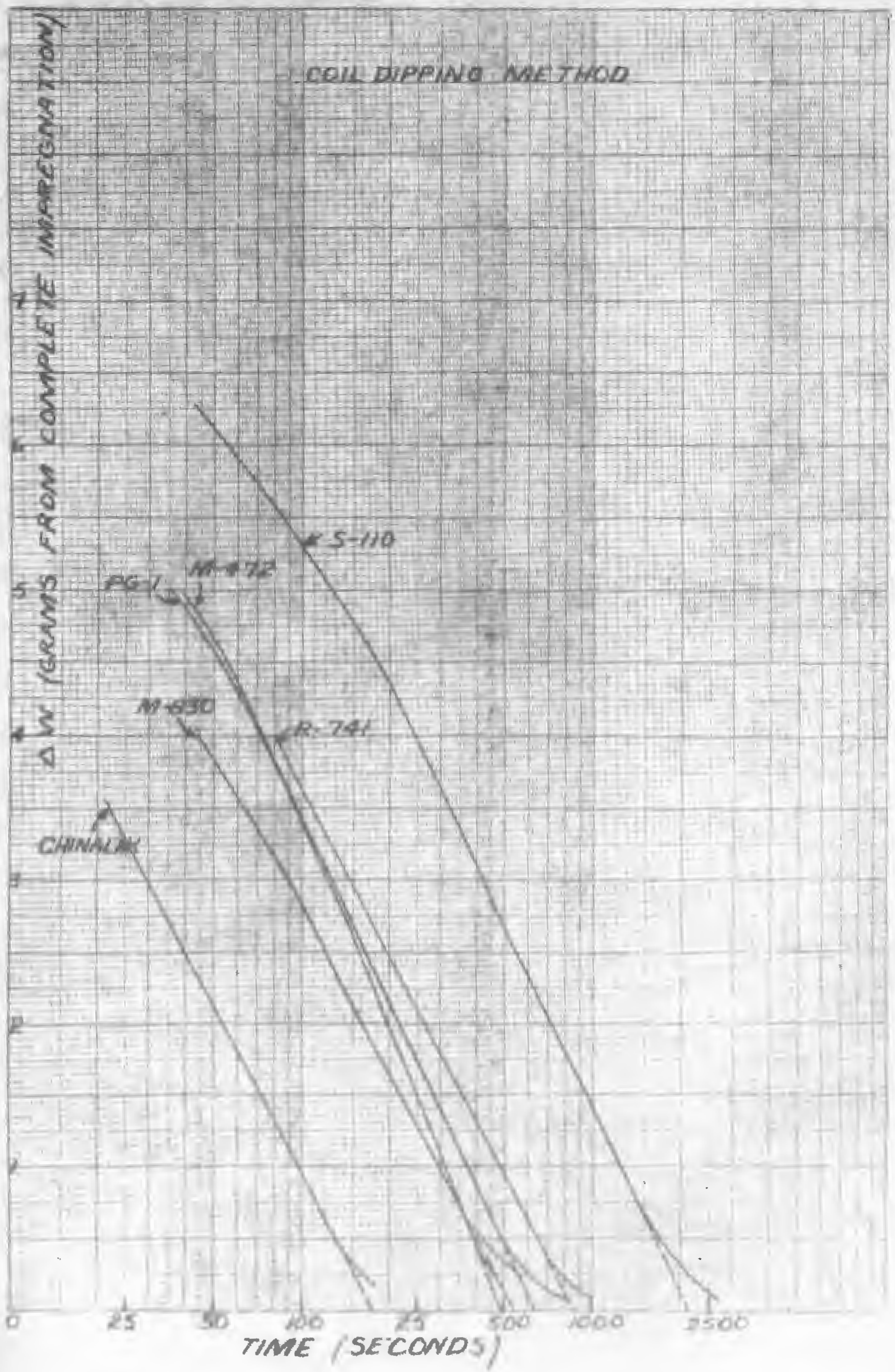

WICK RISE METHOD
DISTANCE OF RISE (MILLIMETERS)
CHINALAK
PG-1
M-330 AND M-472
R-141
S-110
P-601
#13
1000
10000
TIME (SECONDS)

PLATE I



COIL DIPPING METHOD
ΔW (GRAMS FROM COMPLETE IMPREGNATION)
S-110
M-472
PG-1
M-830
R-741
CHINALAK
TIME (SECONDS)

PLATE 2

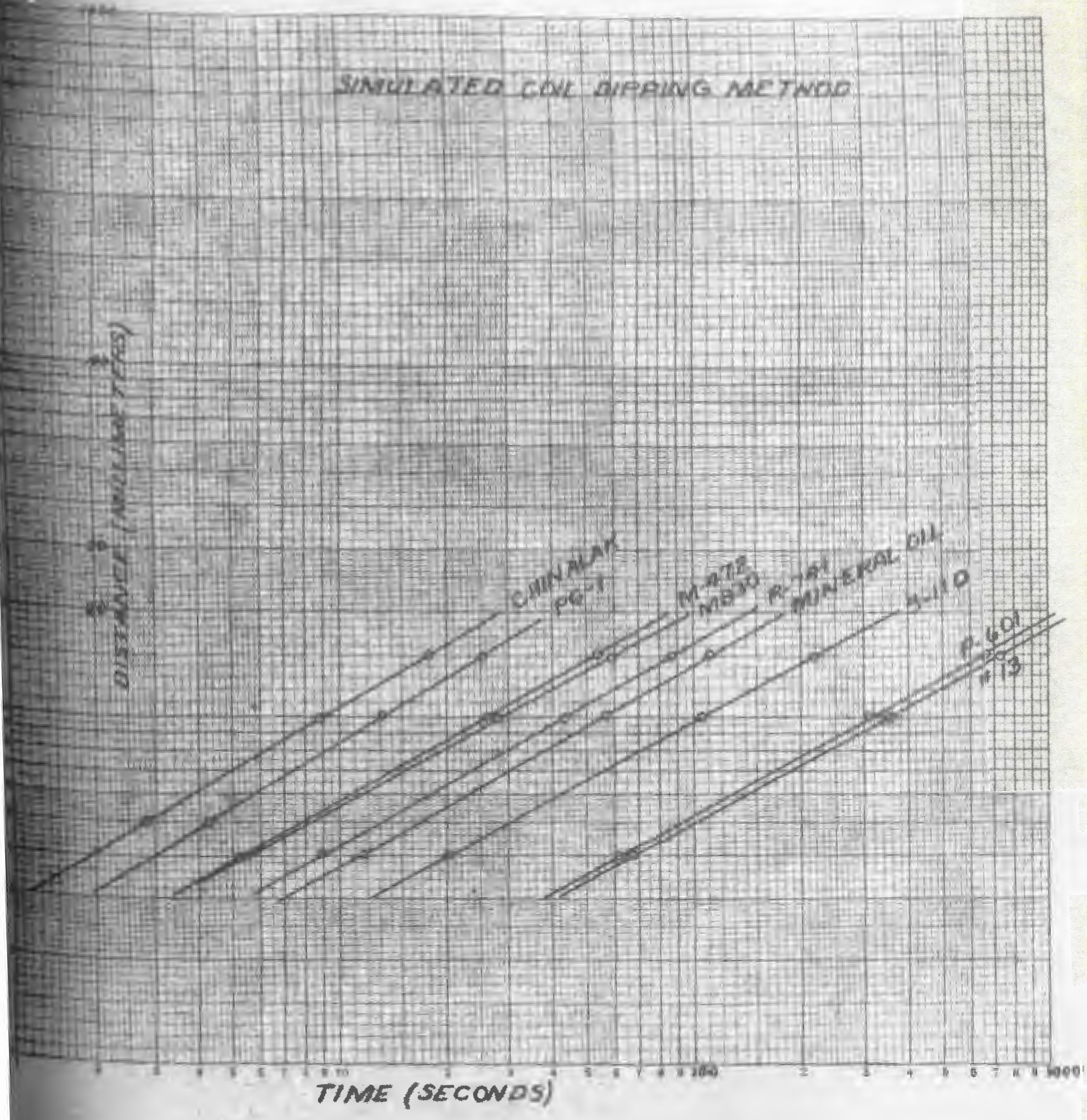
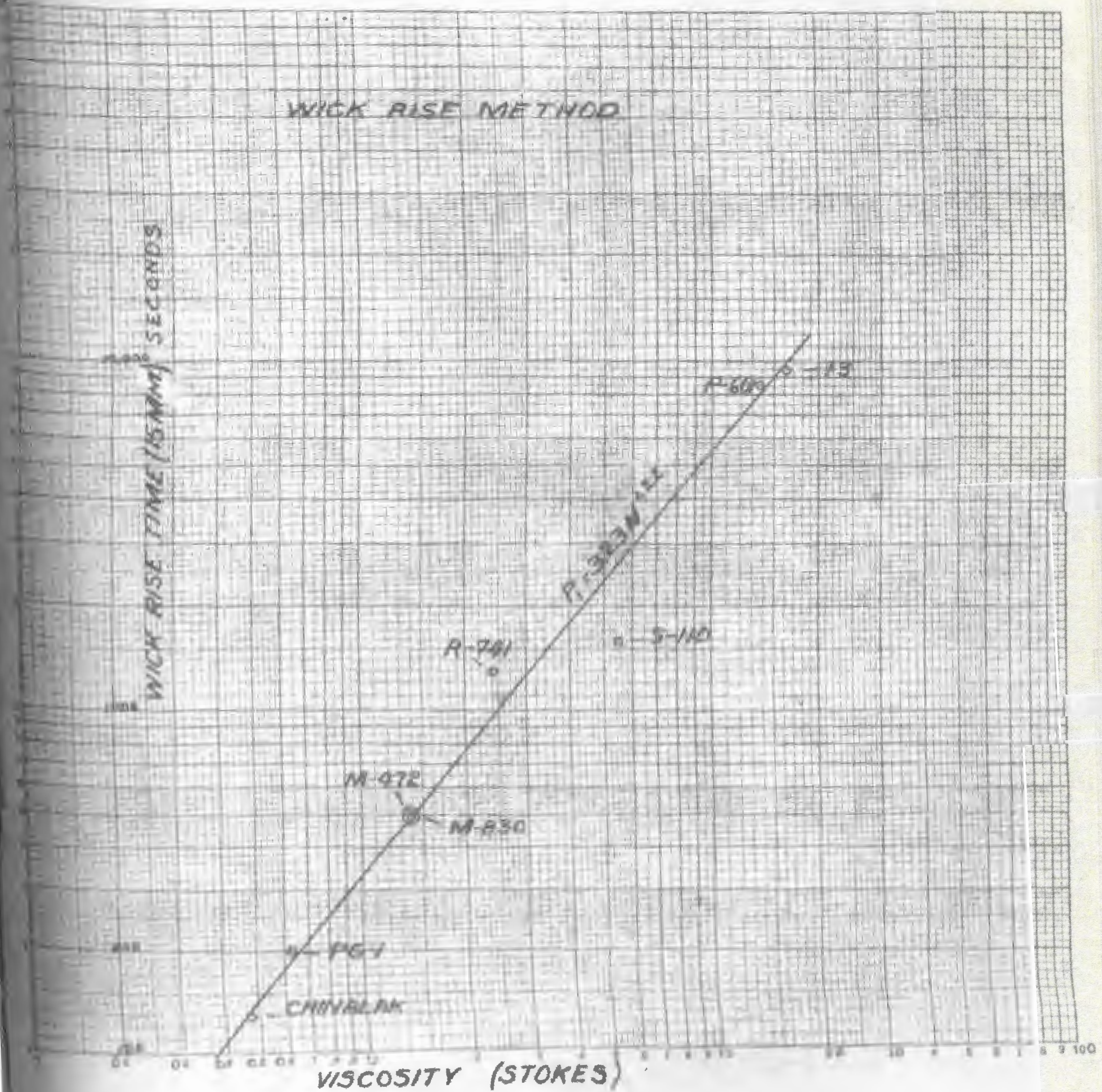
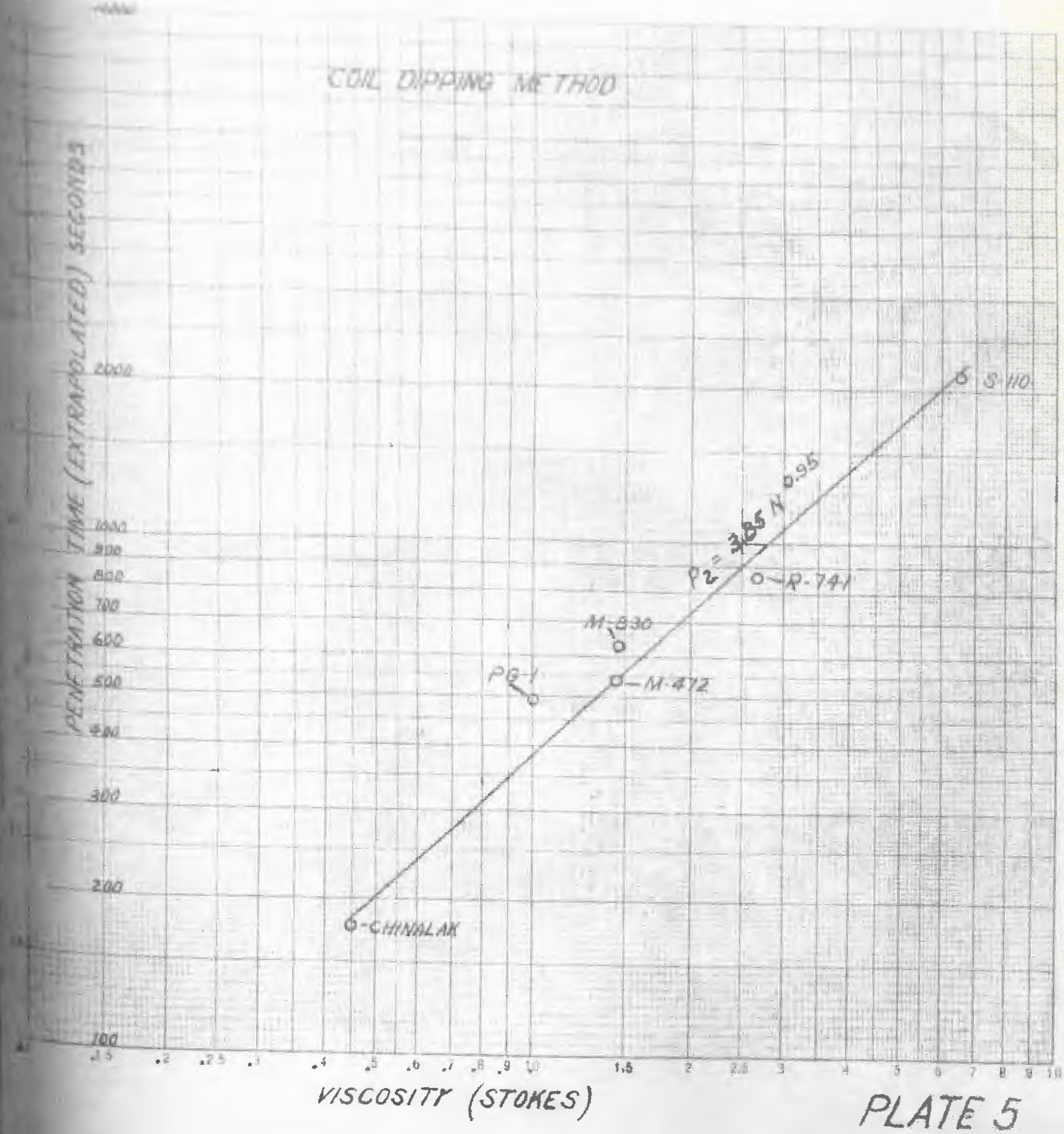

SIMULATED COIL DIPPING METHOD
CHINALAK
PG-1
M-472
MB30
P-784
MINERAL OIL
H-11 D
P-601
#13
TIME (SECONDS)
DISTANCE (MILLIMETERS)

PLATE 3



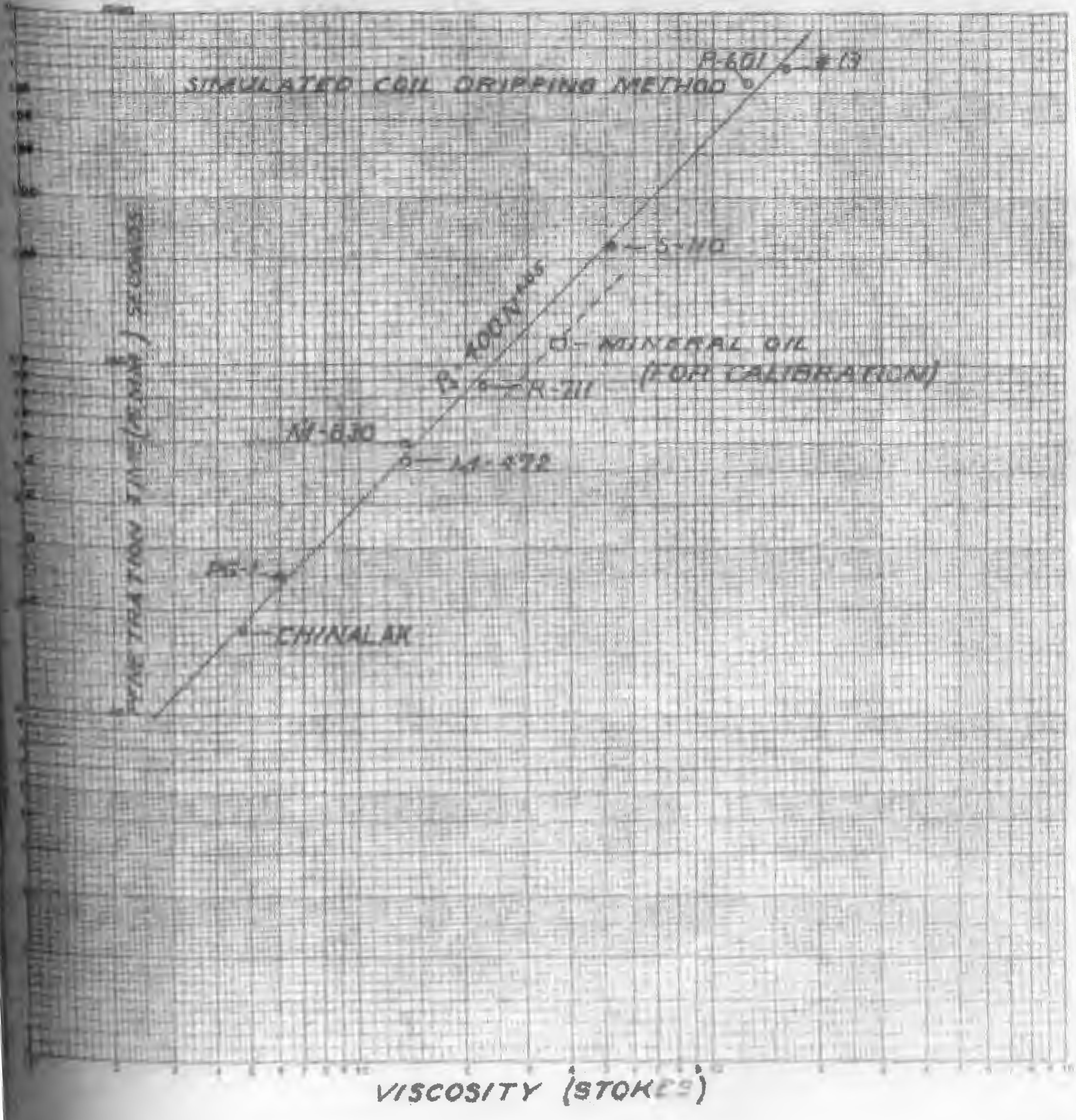
WICK RISE METHOD
WICK RISE TIME (15MM) SECONDS
P = 323W
R-741
S-110
M-472
M-830
PG-1
CHINBLAK
VISCOSITY (STOKES)

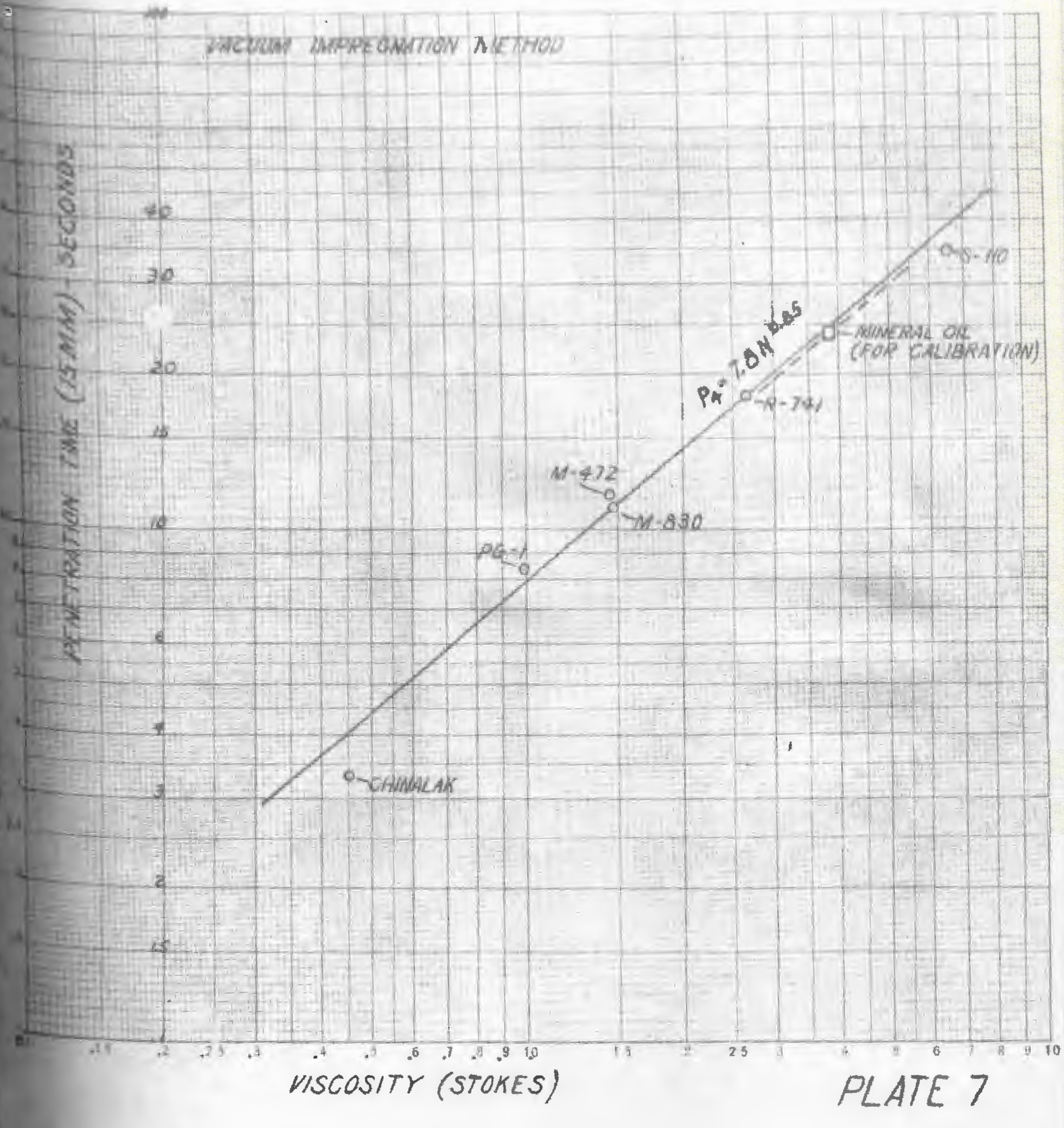
PLATE 4



COIL DIPPING METHOD
PENETRATION TIME (EXTRAPOLATED) SECONDS
VISCOSITY (STOKES)
$P_2 = 385 N^{0.95}$
S-110
R-741
M-830
M-472
PG-1
CHINALAK

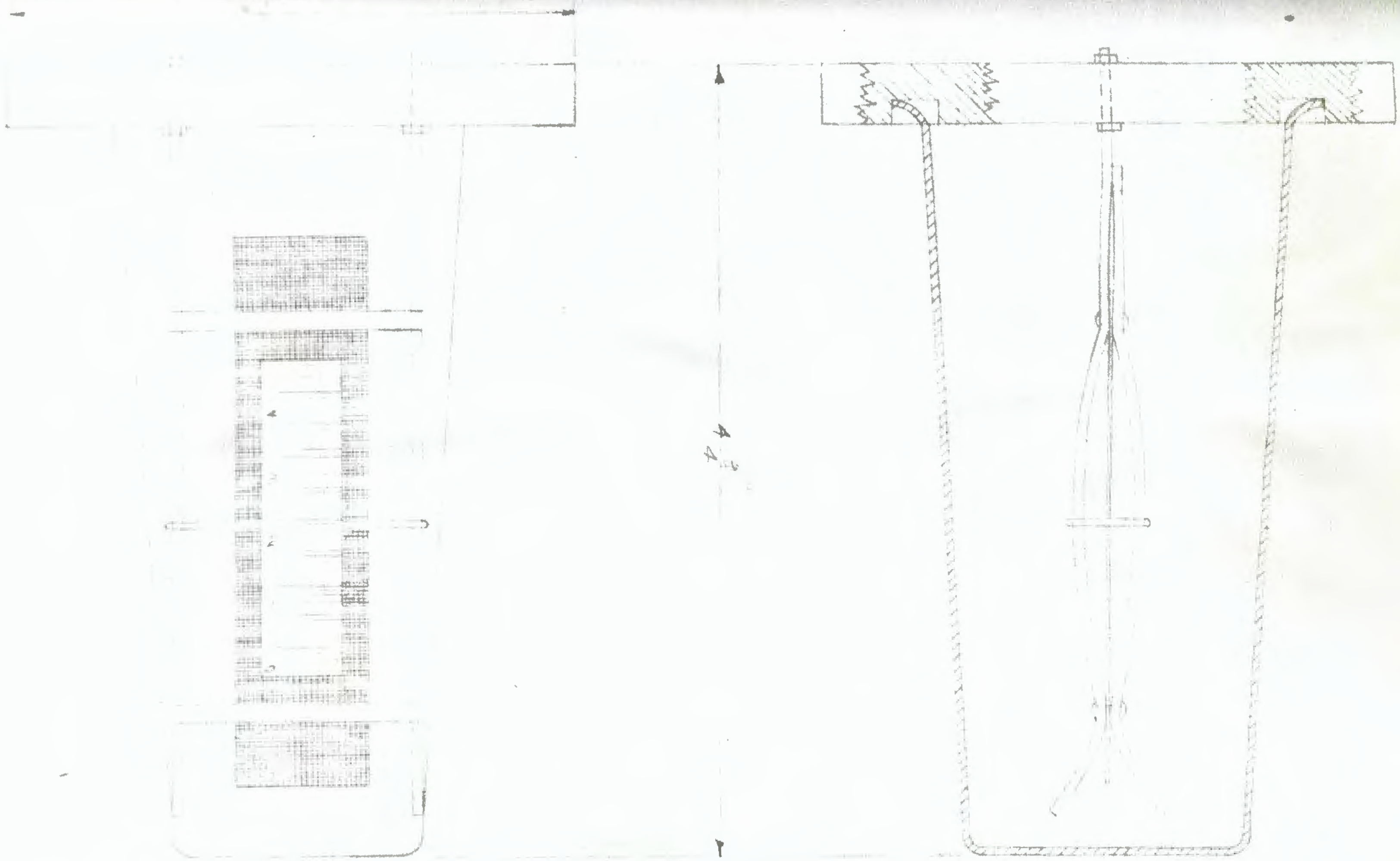
PLATE 5


SIMULATED COIL DRIPPING METHOD
R-601
#13
S-110
MINERAL OIL
(FOR CALIBRATION)
R-211
14-372
CHINALAK
VISCOSITY (STOKES)

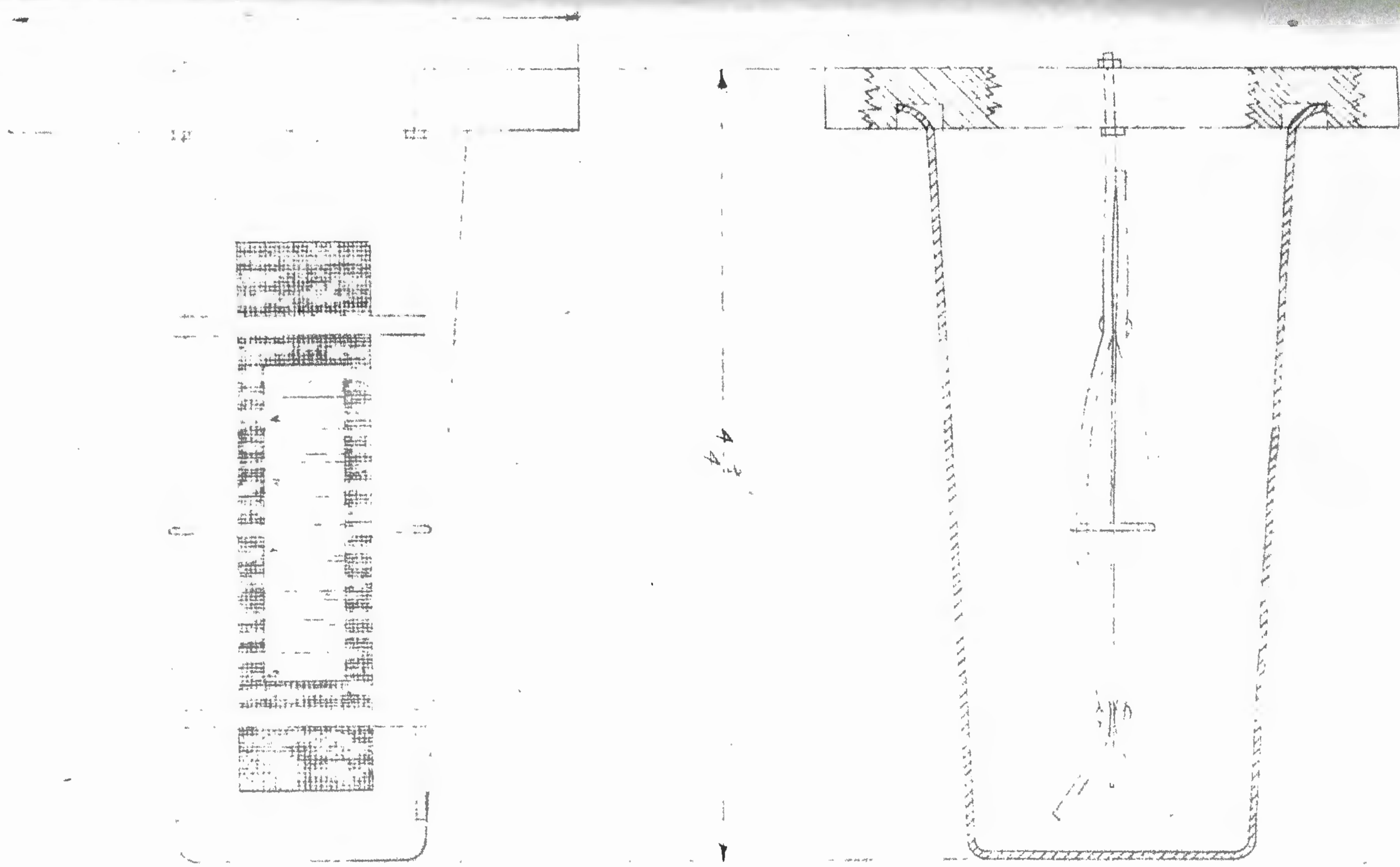


VACUUM IMPREGNATION METHOD
PENETRATION TIME (15 MM) - SECONDS
$P_t = 7.8 N^{0.85}$
S-110
MINERAL OIL (FOR CALIBRATION)
R-741
M-472
M-830
PG-1
CHINALAK
VISCOSITY (STOKES)

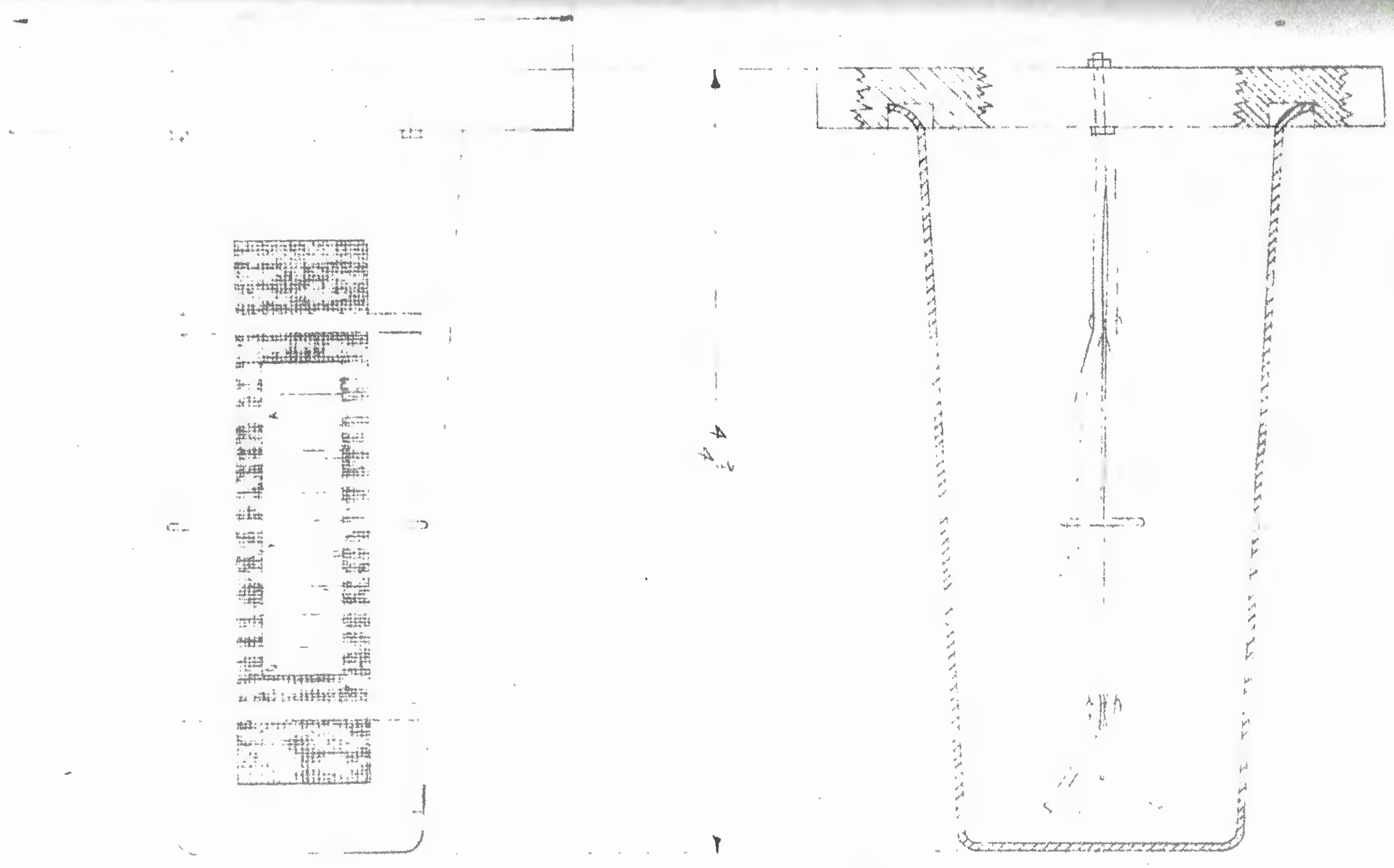
PLATE 7



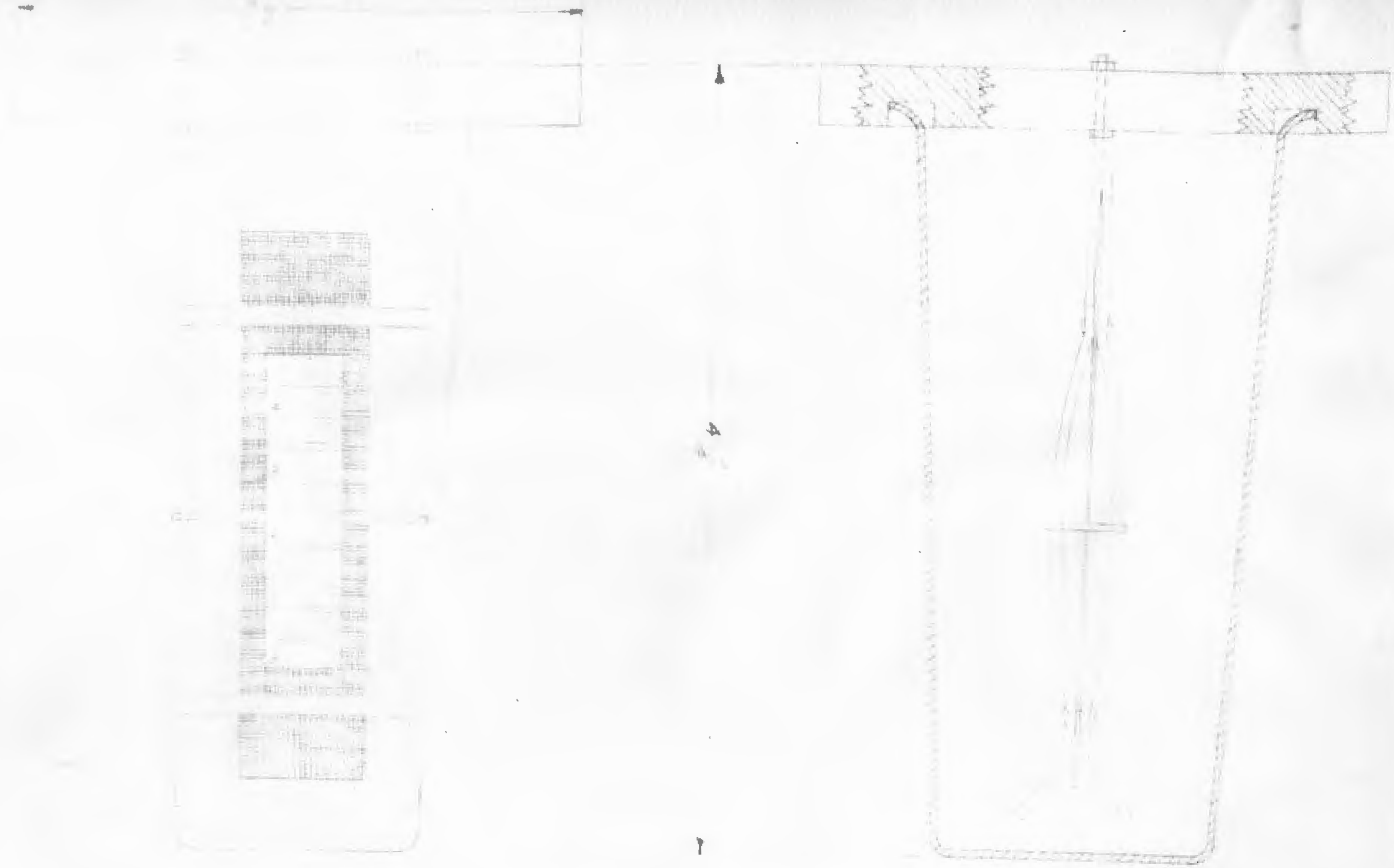
WICK RISE APPARATUS



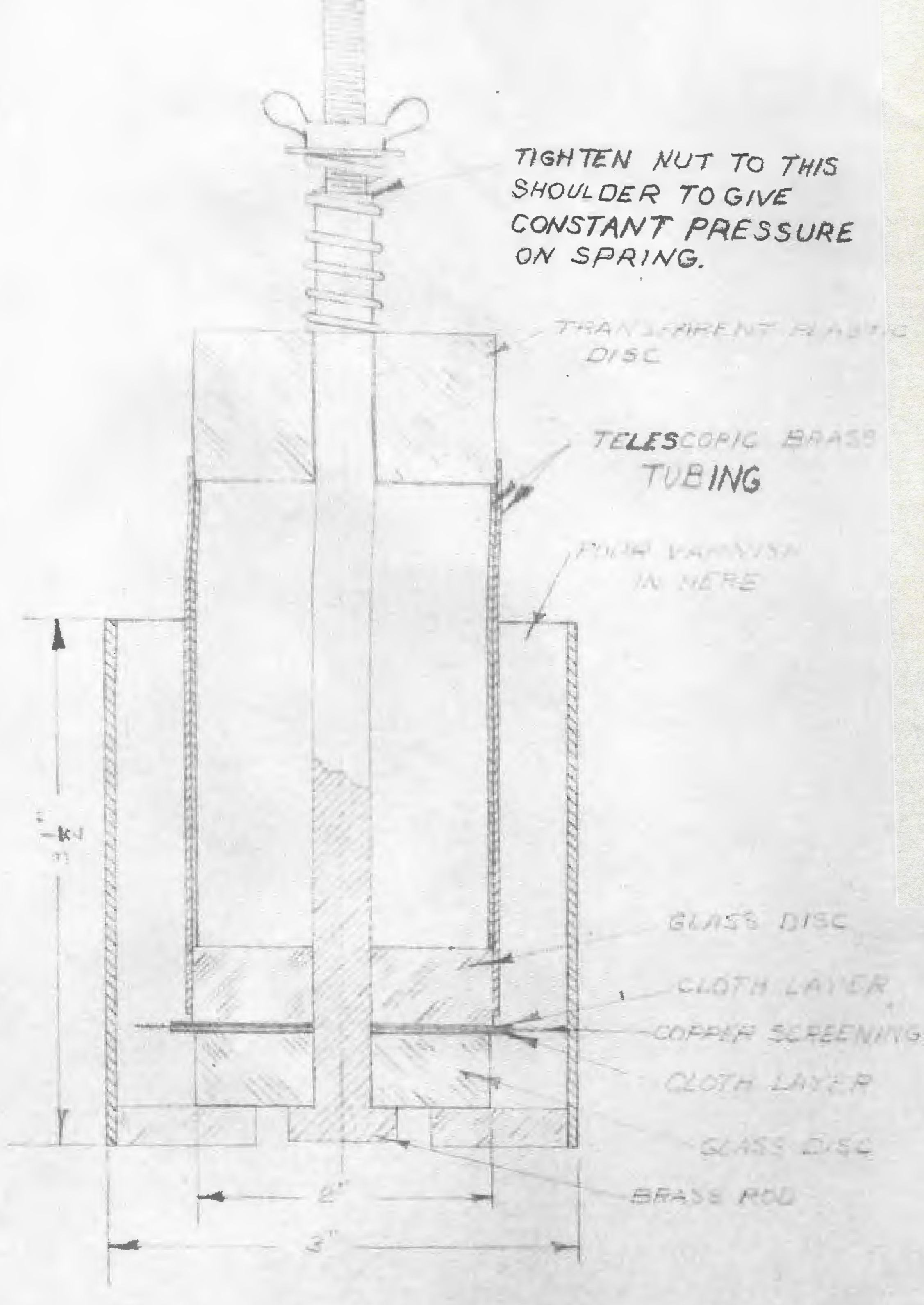
WICK RISE APPARATUS



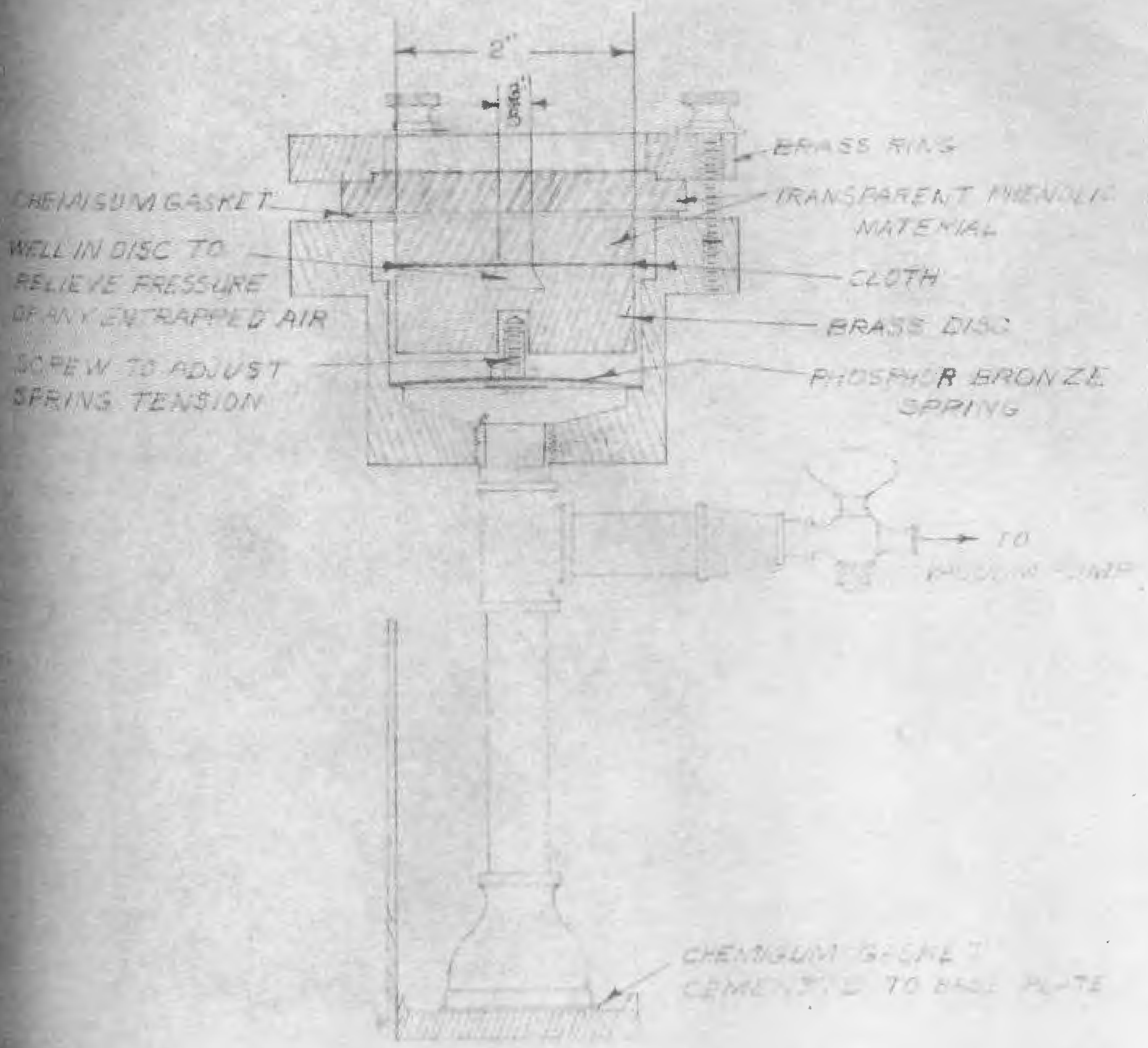
PISE APPARATUS



WICK RISE APPARATUS



SIMULATED COIL
DIPPING APPARATUS



VACUUM IMPREGNATION APPARATUS

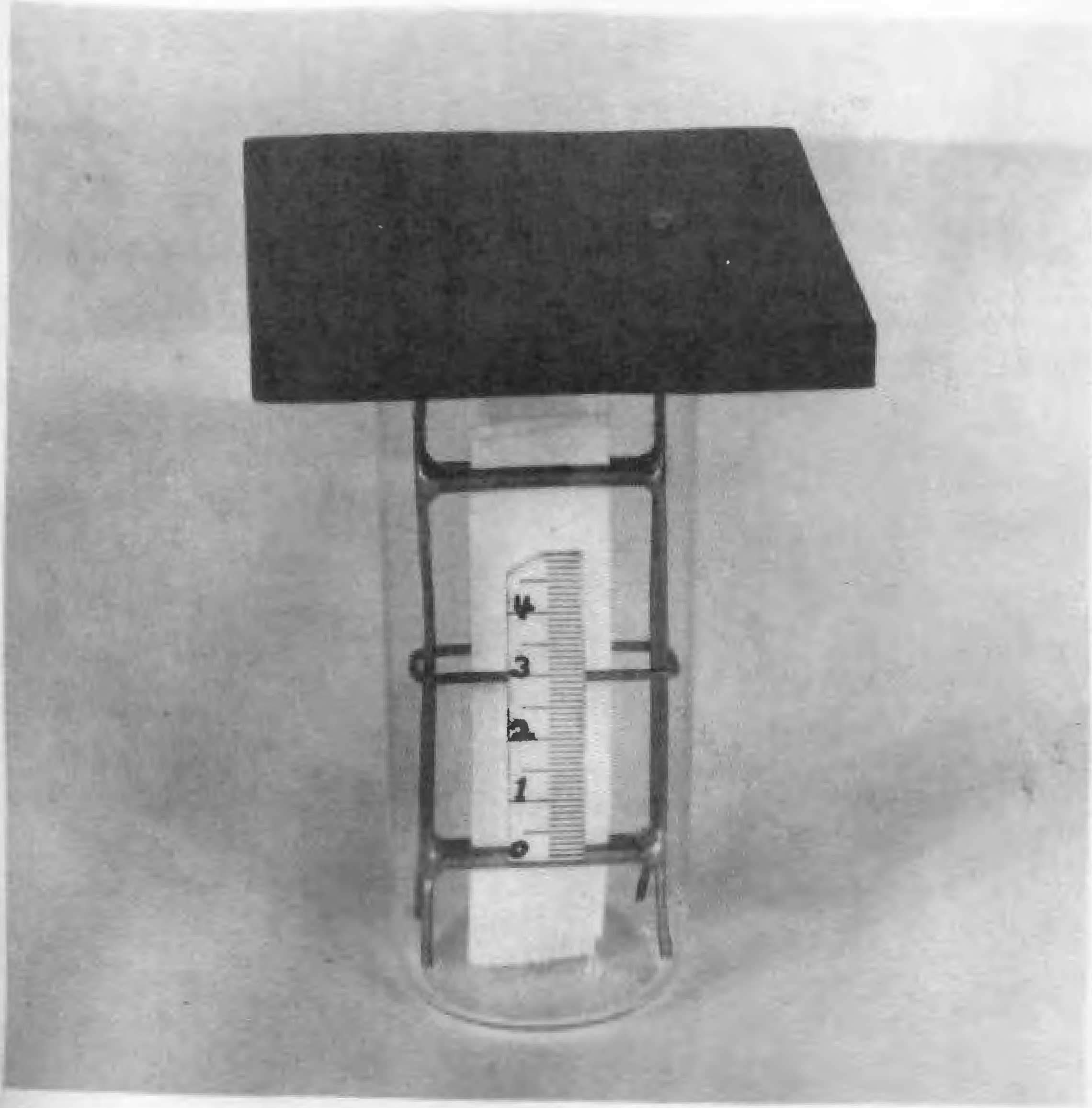


PLATE 11

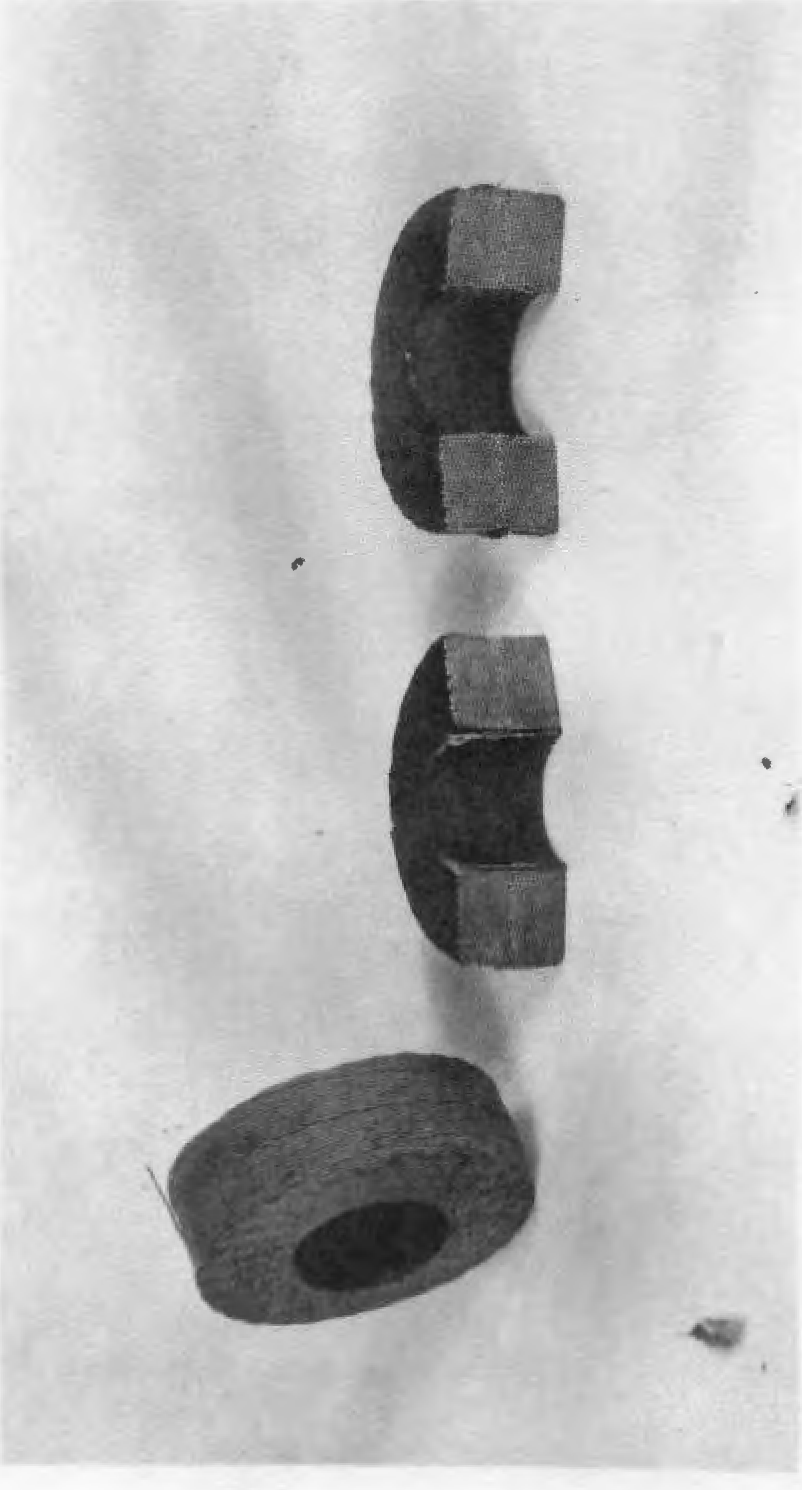


PLATE 12

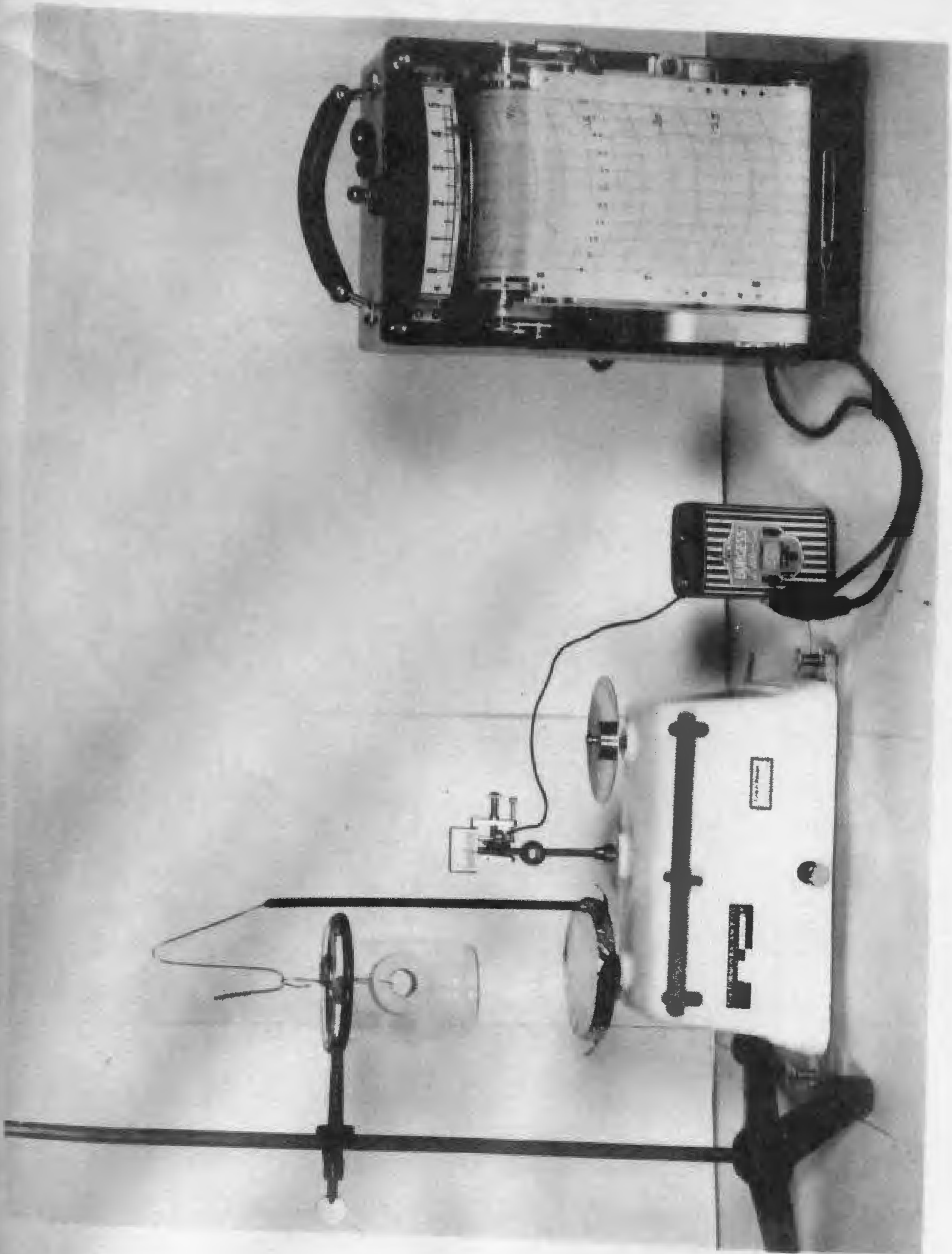


PLATE 13

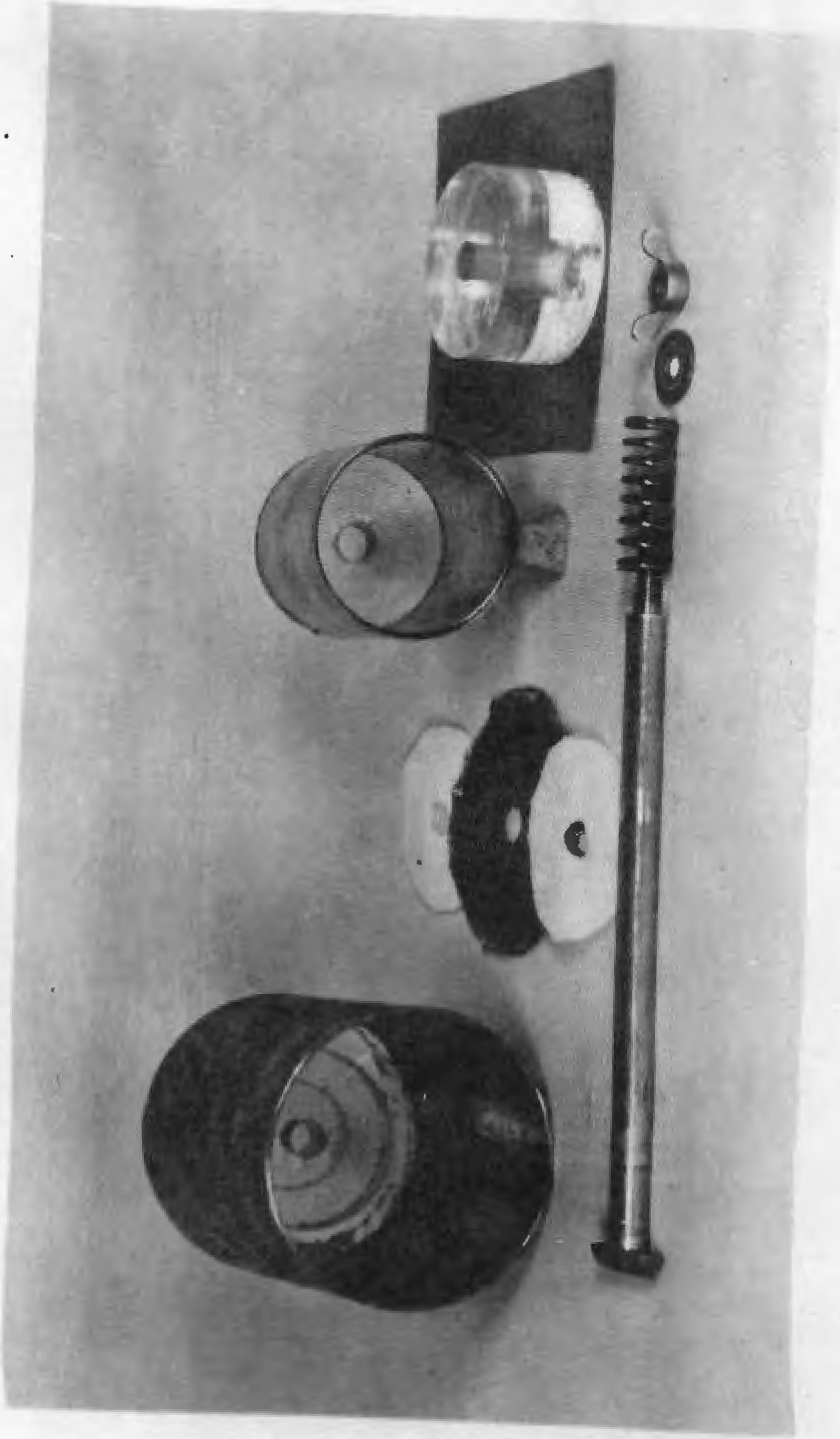


PLATE 14

PLATE 15

PLATE 16

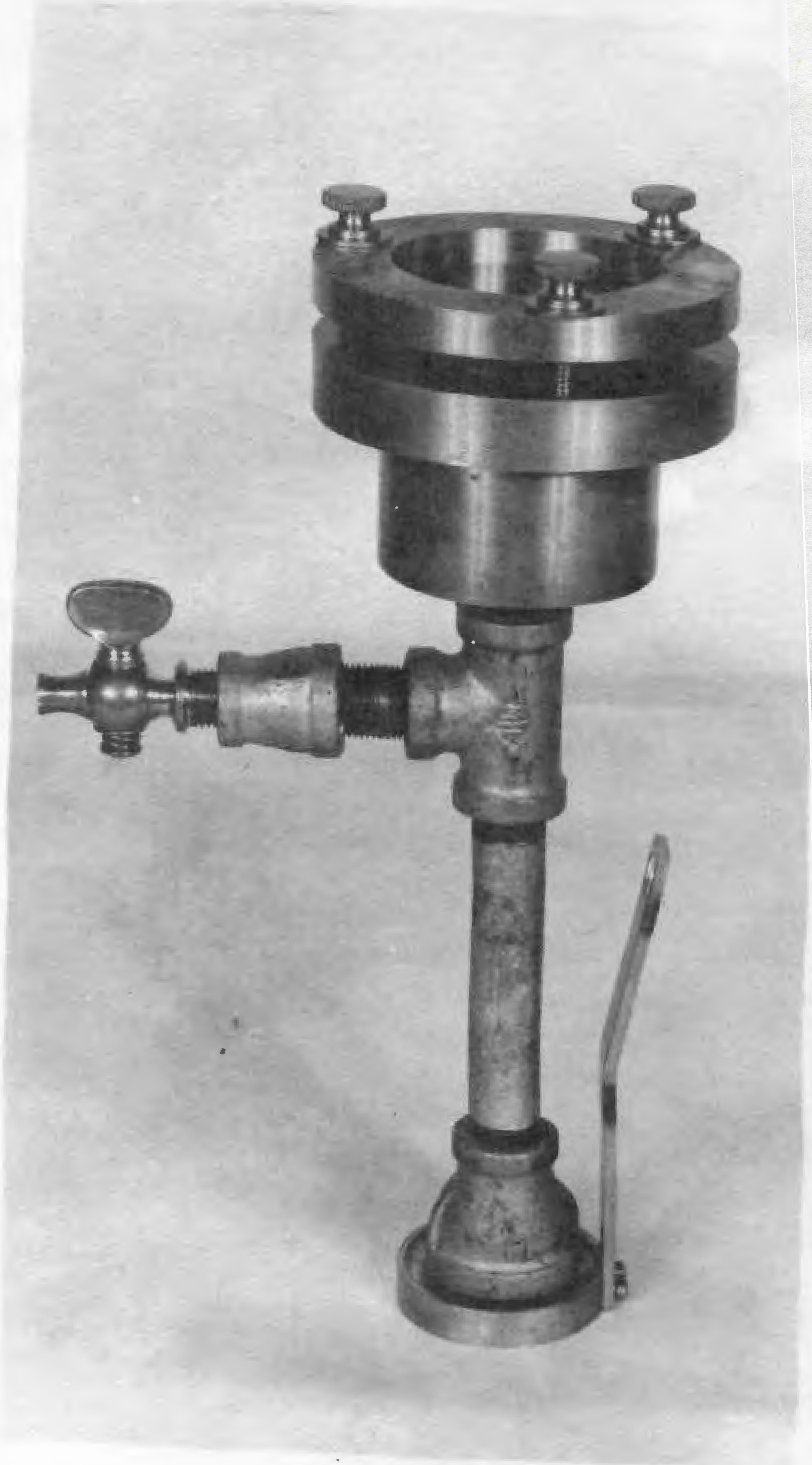


PLATE 17