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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Conversion of Viscosity Determinations Using the Saybolt Viscosimeter with Universal, Furol, and Asphalt Tubes

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Abstract

(1) Saybolt viscosimeter observations taken in seconds Furol can be converted into seconds Universal. Data in this report give the conversion for the range of 10 to 50 seconds Furol.

(2) A new tube, called "Asphalt", is tested and compared with the Furol tube now being used by the Navy. Data in this report show the conversion between from 10 to 50 seconds Asphalt and seconds Furol. From 50 seconds and greater the Asphalt: Furol ratio is approximately 1:10.

(3) The data in this report show that the viscosity equations for Furol and Universal tubes derived by using heavy lubricating oils as reference oils can be used for cracked and straight run residues such as the Navy often purchases for fuel oils.

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INTRODUCTION

(a) Authorization

This problem was authorized by Bureau of Engineering Project Order 86/31 of 2 June 1931.

(b) Statement of Problem

The original problem given in above reference dealt with the characteristics and supply of fuel oil for the Navy. In correlating data given in both the literature and in reports from inspectors, it is often found that some give the the viscosity in seconds Furol and others in seconds Universal for the same temperature range. In this report will be discussed the relationship between the viscosity in terms of seconds Furol or seconds Universal for cracked oils. There will also be discussed the new "Asphalt tube" that is being suggested for use with viscous liquids such as tars and asphalts.

(c) Facts Bearing on the Problem

Equations are given in the literature converting viscosity readings, given in terms of seconds using a certain viscosimeter, to kinematic viscosity. From the kinematic viscosity the desired viscosity in terms of seconds with another viscosimeter can be calculated. The Navy uses the Saybolt viscosimeter with the Universal tube for liquids of low viscosity and the Furol tube for liquids of high viscosity. The ratio between the Universal and Furol is approximately 10:1 in terms of seconds when the time is 40 seconds or greater in seconds Furol. At the present time there is no published literature for the conversion of the viscosity as determined by the Asphalt tube to kinematic viscosity. Therefore, the data in this report as given in conversion from seconds Asphalt to seconds Furol are taken from the experimental chart, Plate II.

(d) Theoretical Considerations

Appendix II of Guy Barr's "A Monograph of Viscometry", published in 1930, gives the equations by which the kinematic viscosity can be calculated from the data obtained with various technical viscosimeters. The equations are:

Redwood No. I		$0.00260T - 1.88/T$	(T 30")
Redwood No.II		$0.0260T - \frac{0.40}{T}$	
Saybolt Universal	(1)	$0.00226T - \frac{1.95}{T}$	(32" T 125")
	(2)	$0.00220T$	(T 200")
Saybolt Furol	(1)	$0.0224T - \frac{1.9}{T}$	(T 40")
	(2)	$0.0216T$	(T 80")
Engler		$E(0.076)^{1-\frac{1}{E3}}$	
		$0.00147T - \frac{3.74}{T}$	
Barbey		$\frac{48.5}{BF}$	

Of the above only those equations for the Saybolt Universal and the Saybolt Furol viscosimeters will be considered in this report. The other equations are given should the reader desire them for comparison.

Using the equations for Saybolt Furol No. I and Saybolt Universal No. 1 and 2, the time in seconds Furol was converted into seconds Universal for viscosities from 10 to 50 seconds Furol. It should be noted that any viscosity readings of less than 40 seconds are open to question due to errors in reading. The values given in this report are those largely less than 40 seconds due to the facts stated in "Statement of Problem". The calculated values are given below and are plotted on Plate I.

Seconds Furol	Seconds Universal Using Equation I	Seconds Universal Using Equation II
10	37.8	
11	49.9	
13	75.5	
15	101.1	95.2
17	125.9	
20	161.3	160.5
25	218.1	220.0
30		276.7
35		331.7
40		385.7
45		439.0
50		491.8

As given under "Facts bearing on the Problem", there are no equations correlating the Saybolt viscosimeter using the "Asphalt" tube with other industrial viscosimeters.

(e) Original Work at this Laboratory

No previous work has been reported from this Laboratory on the correlation of viscosity readings using the Saybolt viscosimeter with Universal, Furol, and Asphalt tubes.

METHODS

(a) The instruments used for this work were the commercial viscosimeters purchased from "The American Instrument Company" of Washington, D.C. The tubes used for the Furol and Universal readings were calibrated by the National Bureau of Standards. The Asphalt tube which has a ratio of approximately 1:10 with the Furol tube was supplied by the American Instrument Company, but was not calibrated by the National Bureau of Standards as no official standard had been passed upon.

The Asphalt tube was first suggested by Mr. H. G. Nevitt, Manager of the Road Oil and Asphalt Department of the White Eagle Oil Corporation of Kansas City, Missouri. The present tube was worked out by him in connection with the American Instrument Company, 774-776 Girard Street, N.W., Washington, D.C. A letter dated December 8, 1934, from the American

Instrument Company gives the following information on the different viscosity tubes as manufactured by them:

Dimensions of Tube

Height of overflow rim above bottom of outlet tube	12.5 cms
Outside diameter of overflow rim at top (maximum)	3.30 "
Diameter of container	2.975 "
Depth of cylindrical part of container (minimum)	8.8 "
Diameter of container between bottom of cylindrical part of container and top of outlet tube (minimum)	0.9 "

Above dimensions apply to barrel for Universal, Furol, and Asphalt Viscosimeters.

"Dimensions of	Universal Outlet	Furol Outlet	Asphalt Outlet
Inside dia. of outlet	0.1765 cms	0.315 cms	0.578 cms
Outside dia. of outlet at lower end	0.30 "	0.43 "	0.660 "
Length of outlet tube	1.225 "	1.225 "	1.225 "

"All our tolerances are closer than specified by the A.S.T.M. "

The oils used were the "A" series described in NRL Reports P-1012, P-1031, and P-1049, and the NRL series described in NRL Report P-25-9 of July 25, 1933. The "A" series were cracked residuums while the NRL series consisted of cracked residuums, straight runs and blends which have a base that is either cracked or straight run. In the legend of Plate I these blends are characterized as to the base.

(b) The experiments were made according to U. S. Government Method 30.41 reported in Bureau of Mines Technical Paper 323B on pages 41-45. The temperature at which some of the experiments were made depended upon the viscosity of the oil. The Asphalt-Furol group was largely run at 100°F or less, except in a few determinations where readings of less than 20 seconds Asphalt were desired. The Furol-Universal readings were largely made at 160 to 200°C

The thermometers used were checked against National Bureau of Standards calibrated thermometers. The cups were calibrated before using. The tubes have already been described.

DATA OBTAINED

(a) The data for the Furol-Universal determinations are plotted in Figure I. The computed curve in "Theoretical Considerations" of this report is plotted as a solid line. The data for the Furol-Asphalt data are plotted in Figure II. The solid line is the curve drawn from the data obtained in this work.

(b) The Furol-Universal values found for the NRL oils and some from the service are given below.

The Furol-Universal values found for the "A" series are given below.

The Furol-Asphalt values found using the "A" series are given below.

Oil No.	Type	Temp. °F	Furol	Univ.
8	Cracked base	200	18.5	148.8
		170	30.5	289.7
9	Cracked base	200	29.7	280.7
		170	64.0	630.9
12	Straight run base	170	14.2	93.5
13	" " "	200	22.4	197.9
		170	40.7	397.0
15	" " "	170	18.3	143.7
16	Cracked base	200	24.2	217.8
		170	43.3	420.9
17	" "	200	19.7	163.0
		170	34.9	333.2
21	Straight run base	200	25.3	229.4
		170	48.5	473.1
22	" " "	200	19.6	162.6
24	Cracked base	200	34.8	335.0
25	" "	200	23.1	204.2
		170	45.8	445.3
26	Straight run base	170	21.7	187.7
27	Cracked base	200	24.3	221.9
		170	57.0	573.7
27A	" "	200	22.3	190.7
30	Straight run base	170	22.7	198.3
32	" " "	200	15.8	113.4
		180	19.4	161.7
		170	22.8	201.0
33	Cracked base	200	21.3	187.6
		170	39.4	380.7
36	Straight run base	180	12.0	65.6
		170	12.9	72.8
37	" " "	200	12.9	74.7
		180	14.7	99.5
38	Cracked base	200	13.1	80.4
		180	15.6	112.4
45	Straight run base	180	19.3	154.4
USS FARRAGUT Fuel Oil	Unknown base	100	132.2	1304.5
		122	57.5	551.4
		185	16.5	116.8
USS LOUISVILLE	" "	160	24.6	202.3
USS NORTHAMPTON	" "	160	31.3	288.5

Oil No.	Temp. °F	Seconds Furol	Seconds Universal
A-1	100	36.0	339.7
A-2	185	19.3	151.7
	160	27.9	253.0
A-3	185	22.8	186.3
	160	34.4	320.7
A-4	160	38.7	364.5
A-5	160	27.3	248.5
A-6	160	28.2	255.6
A-7	160	21.5	182.7
A-8	185	26.0	231.2
	200	20.4	169.0
A-9	160	17.4	131.1
A-10	122	48.7	469.5
A-11	122	28.2	257.2
A-12	185	17.4	130.9
	160	25.8	231.2
A-13	160	41.6	394.7
A-14	160	22.0	185.2
A-15	185	32.7	301.2
	200	23.8	207.4
A-16	122	60.9	591.0
	160	22.7	195.4
A-17	160	28.0	252.7
A-18	185	27.9	250.7
	160	45.6	437.7

No.	Temp.	Asphalt	Furol
A-1(L)	77	10.3	91.3
A-2	100°F	23.0	217.3
	122	9.3	81.2
(L)	77	113.0	1154.9
A-3	77	114.3	1097.6
	100	33.7	318.3
	122	13.8	124.7
(L)	77	114.7	1110.0
A-4	77	149.6	1442.6
(L)	77	151.3	1480.0
A-5	77	68.0	636.4
	85.6	44.4	425.6
(L)	77.0	67.2	640.9
A-6	77	74.7	722.6
	85.6	48.4	472.2
(L)	77.0	71.0	687.5
A-7	77	45.5	448.2
	85.6	31.4	304.9
(L)	77	43.4	429.6
A-9	71.2	31.7	297.9
	72.0	30.6	288.8
	73.0	29.1	272.9
	74.1	27.5	260.1
	75.0	26.4	247.1
	76.1	25.2	234.9
	77	23.3	221.0
(L)	77	24.1	222.1
A-10	77	45.8	446.7
	85.6	28.0	268.1
	84.9	29.7	276.0
(L)	77	39.4	371.3

No.	Temp.	Asphalt	Furol
A-11	77	20.3	190.5
	71.2	25.5	239.3
(L)	77	16.8	154.6
A-12	100	21.1	195.0
(L)	77	72.3	705.4
A-13	77	162.5	1606.3
	100	43.5	413.9
	122	16.6	152.4
(L)	77	171.5	1629.6
A-14	77	39.4	373.5
	85.6	26.6	254.9
(L)	77	39.4	376.5
A-15	100	57.0	547.8
	122	22.5	209.6
(L)	77	179.2	1517.7
A-16	77.0	45.9	437.9
	81.0	40.4	385.3
	81.9	38.5	367.7
	83.0	36.7	349.1
	83.9	35.1	334.2
	84.8	33.3	314.9
	85.6	31.8	304.6
	100.0	15.8	146.1
(L)	77	46.3	439.4
A-17	122	10.0	87.1
(L)	77	109.0	1057.2
A-18	122	16.2	149.5
(L)	77	132.9	1244.0

(L) observations made in June 1934: others in October 1934 by another operator.

(c) The probable error of a determination in this type of work depends upon the accuracy of temperature control with time, accuracy of reading the time, amount of stirring of the sample, especially samples which are very viscous before making the determination, and the uniformity of the sample worked with. This assumes that the thermometers as well as other apparatus have been carefully checked before use. Ordinarily the minimum time for the Furol readings is about 40 seconds, while that for the Universal readings is greater - about 125 seconds. If the time values are greater than the above, the variations among the readings are usually less than 2%.

CONCLUSIONS AND RECOMMENDATIONS

(a) Facts Established

Figure 1 shows that determinations made with either the Furol or Universal viscosimeter can be converted to the other by using the equations given in "Theoretical Considerations" with but small error. The average

deviation for the sixty observations is 3.8 seconds, which for 100 seconds Universal makes an error of 3.8%, for 300 seconds Universal 1.3%, and for 500 seconds 0.8%. The observations show that the time in seconds Universal is usually greater than the calculated values for Furol times of 30 seconds or less, while for Furol seconds between 30 and 50 the observed Universal time is usually less than the calculated time.

Figure II shows that determinations made with the Asphalt tip can be converted to Furol readings. The average deviation was 2.9 seconds from the plotted curve for forty-two readings of Furol time from 85 to 470 seconds. The error at 85 seconds Furol is 3.4%, while at 470 seconds Furol it is 0.6%. Table I gives the conversion of seconds Asphalt to seconds Furol for times from 10 to 50 seconds Asphalt. This is taken from curve drawn in Figure II.

(b) Opinions

It is the opinion of the Laboratory that the Asphalt tube will be of great assistance in getting some idea of the viscosities of heavy fuel oils at temperatures when the flow is very slow where the present apparatus - Saybolt Furol is used. When the flow is such that it takes more than 500 seconds for 60 cc to flow from the tube, the oil comes in drops. What effect this has on the accuracy of the determination is not known. To raise the temperature of the oil to some point where the viscosity is greatly decreased to obtain a reading and then to attempt to predict what the viscosity will be at some lower temperature is questionable when dealing with heavy fuel oils, and especially so when one has to work with emulsions.

The Asphalt tube has been used in determining the viscosity of emulsions at this Laboratory and data will be reported in SSA (Saybolt Seconds Asphalt) in future reports.

Later reports will correlate data using seconds Furol converted to seconds Universal where the Furol readings are low. This work has been delayed in reporting due to lack of information on the conversion of Furol to Universal time when cracked or straight run residues are considered.

(c) Recommendations

It is suggested that the new Asphalt tube be considered by the Navy, when it is finally standardized, in place of the present Furol tube for viscosity measurements of heavy fuels at temperatures where the time of flow for Furol readings become excessively long. To expedite inspection work as well as Laboratory testing the following combination may be suggested:

Heavy fuels	-	30 seconds plus Asphalt tip
Medium "	-	30 to 300 plus Furol tip
Light "	-	30 to 300 plus Universal tip

Thus the time of 30 seconds Asphalt will be equivalent to 284 seconds Furol, or approximately 2800 seconds Universal.

SUMMARY

This report gives the results of a study of viscosity determinations using viscous bunker fuels to show that readings in seconds Furol can be converted to seconds Universal using the equation given for heavy lubricating oils. This report also shows that the new Asphalt tube will be very useful when studying viscous fuels at low temperatures such as the pumping temperature. Using Figure II or Table I in this report, determinations in seconds Asphalt can be converted to seconds Furol. A reading of 500 seconds Furol corresponds approximately to a reading of 50 seconds Asphalt.

Table 1

Conversion of Seconds Asphalt to Seconds Furol

	0.0	0.2	0.4	0.6	0.8
10	87.5	89.5	91.4	93.4	95.3
11	97.3	99.2	101.2	103.1	105.1
12	107.2	109.3	111.3	113.5	115
13	117.9	119.9	120.9	122.8	124.9
14	126.3	128.3	130.3	132.2	134.1
15	136	138	140	142	144
16	146	148	150	152	154
17	156	158	160	162	164
18	166	168	170	172	174
19	176	177.8	179.8	181.8	183.8
20	185.5	187.5	189	191	193
21	195.5	197.3	199.2	201.3	203.2
22	205.3	207.5	209.5	211.5	213.5
23	215	217	219	221	223
24	225.2	227	229	231	233
25	235	237	239	241	243
26	244.5	246.5	248.5	250.5	252.5
27	254.5	256	258	260	262
28	264.3	266.2	268.1	270.1	272
29	274.1	276.1	278.1	280.1	282
30	284.1	286	288	290	292
31	294	296	298	300	302
32	304	306	308	310	312
33	314	316	318	319.9	321.9
34	323.8	325.8	327.8	329.7	331.7
35	333.7	335.8	337.7	339.6	341.6
36	343.7	345.6	347.6	349.6	351.7
37	353.6	355.6	357.5	359.3	361
38	363	365.2	367.2	369.1	371
39	373	375	377	379	380.9
40	382.9	384.7	386.5	388.3	390.2
41	392.3	394.3	396.3	398.3	400.3
42	402.7	404.5	406.4	408.3	410.2
43	412.2	414.2	416.1	418.1	420.1
44	422.1	424	426	428	430
45	432	434	436	438	440
46	442	444	446	448	450
47	452	454	456	458	460
48	462	464	466	468	470
49	472	474	476	478	480
50	482				

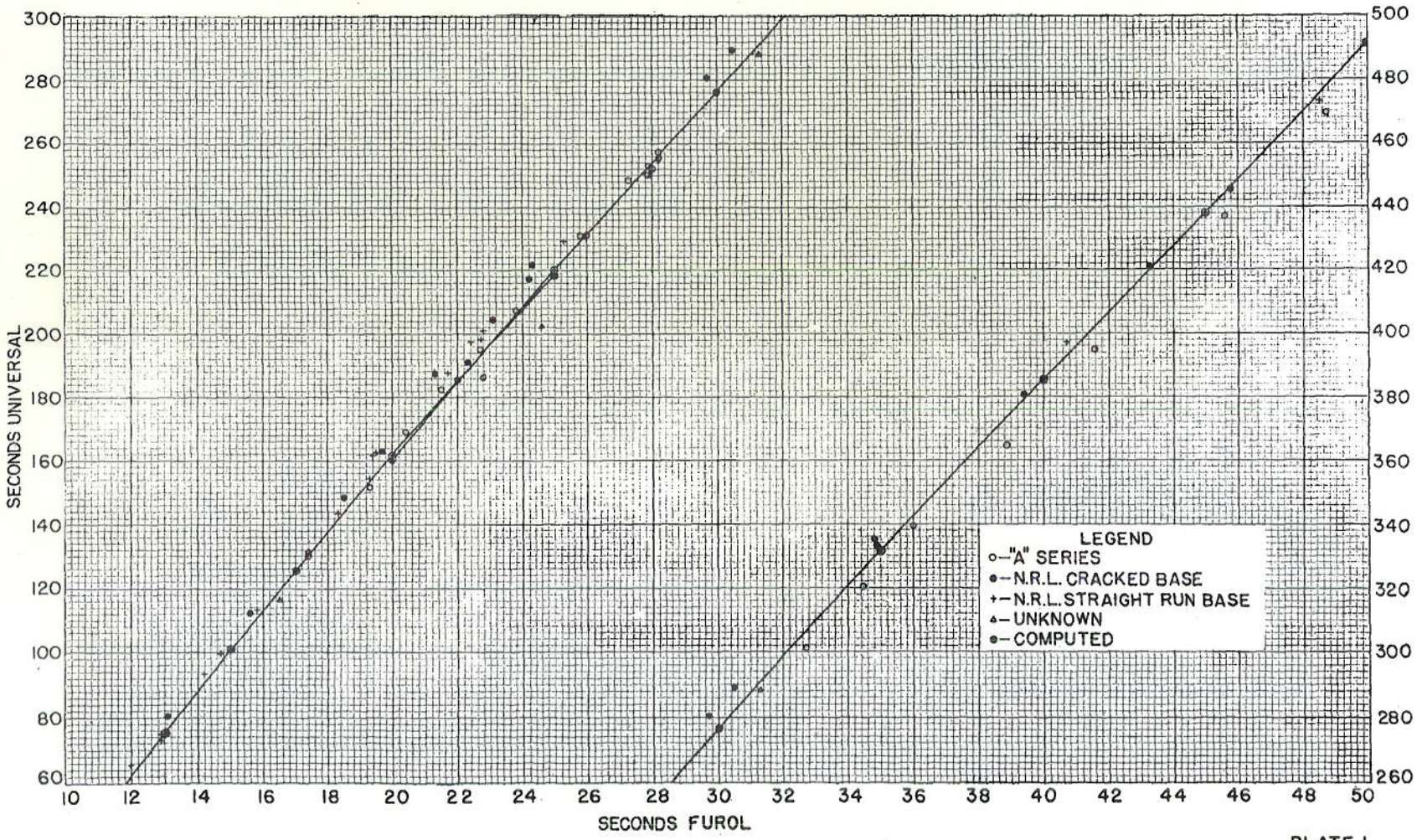
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PLATE I

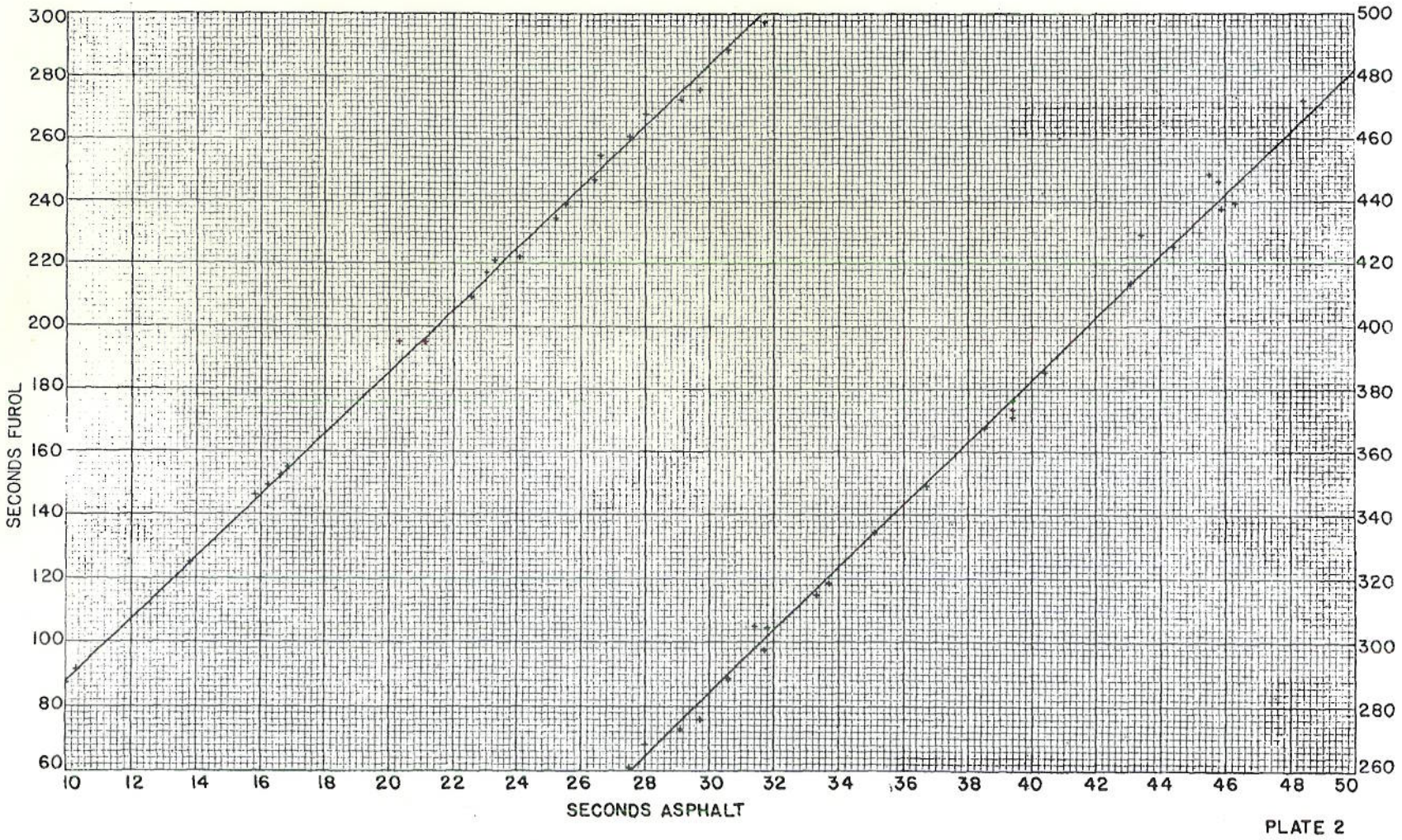
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PLATE 2