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SAYBOLT VISCOSITY OF BLENDS

BY

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Bureau of Standards

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I. INTRODUCTION

Various formulas and diagrams have been published for determining the viscosity of liquid mixtures, but they are mostly expressed in Engler degrees and are not convenient for the user of the Saybolt Universal viscosimeter.[1] Dunstan and Thole[2] quote the Arrhenius formula as modified by Kendall[3]:

$$\log \mu = a \log \mu_1 + b \log \mu_2, \qquad (1)$$

where a and b are the molecular percentage concentrations of the two components in the mixture. They give a table which shows that this formula applies with an error of less than 0.1 per cent to mixtures of carbon tetrachloride and benzene, and conclude:

> These facts militate against the view which recently has been persistently set forth, that fluidity and not viscosity is the essential additive property, and they show that neither fluidity nor viscosity is the true additive property but the logarithms of these quantities (since obviously $\frac{1}{\mu}$ may be substituted for μ without affecting the result).

Since lubricating oils are not definite chemical compounds, and the values of a and b in equation (1) are unknown, it is necessary

[1] D. Holde, The examination of hydrocarbon oils, translated by E. Mueller, p. 110, 1915; Engler-Höfer, Das Erdöl, **1**, p. 60, 1913; F. Schulz, Chem. Rev., **16**, p. 297, 1909; H. C. Sherman, T. T. Gray, and H. A. Hammerschlag, Jour. Ind. & Eng. Chem., **1**, p. 13, 1909; and T. T. Gray, 8th Int. Cong. Appl. Chem., **10**, pp. 153-158, 1913.

[2] A. E. Dunstan and F. B. Thole, the viscosity of liquids, p. 42, 1914.

[3] Meddelanden f. K. Vetensk. Nobelinstitut, **2**, p. 23, 1913.

to abandon the probably most accurate form of this equation and revert to the form as originally proposed by Arrhenius[4]:

$$\log \mu = v_1 \log \mu_1 + v_2 \log \mu_2, \qquad (2)$$

where v_1 and v_2 are the percentage volume concentrations, and μ_1 and μ_2 are the viscosities of the two components in the mixture, expressed in cgs units or poises. For a 50 per cent mixture, this equation may be written:

$$\mu = \sqrt{\mu_1 \mu_2}, \qquad (3)$$

which is convenient for slide-rule calculations.

II. PRELIMINARY INVESTIGATION OF THE VISCOSITY OF MIXTURES

Table 1 was calculated from experimental data obtained in previous work,[5] using mixtures of kerosene and spindle oil at 30° C (86° F).

TABLE 1.—Viscosities of Mixtures of Kerosene and Spindle Oil at 30° C

Per cent spindle oil content	Time Engler	Density g/cc	Viscosity in poises[a]	Viscosities calculated on the assumption that the additive property is—		
				Viscosity	Fluidity	Log viscosity
0	55.1	0.80	0.0117	....	....	....
25	59.8	.81	.0206	0.0232	0.0149	0.0202
50	66.7	.83	.0348	.0412	.0308	.0357
75	81.3	.84	.0618	.0730	.0530	.0622
100	111.8	.85	.1113	....	....	....

[a] See Winslow H. Herschel, B. S. Tech. Paper No. 125, p. 13, 1919. The first value is calculated by equation (15) and the others by equation (14).

From Table 1, and from other evidence which will be given later, it is believed that equation (2) is the best available as a first approximation for finding the viscosity of mixtures of petroleum oils, or of other liquids which are chemically inert with respect to each other and do not have a definite chemical composition. The errors are, however, very large in some cases, which is to be expected, especially since Dunstan and Thole state that the equation holds fairly well for mixtures of liquids when one component is present to the extent of 90 per cent or more, but it is not valid throughout the whole range of mixtures.

[4] S. Arrhenius, Zeit. Physikal. Chem., 1, p. 285, 1887.

[5] These data were used in preparing Fig. 7, p. 37, of B. S. Tech. Paper No. 100, but have not been published otherwise.

III. BLENDING TABLE

When the Saybolt Universal viscosimeter is used, the viscosity μ in poises may be calculated from the Saybolt viscosity, or time of flow in seconds, t, by the equation

$$\text{kinematic viscosity} = \frac{\mu}{\gamma} = 0.00220\ t - \frac{1.80}{t}, \qquad (4)$$

where γ is the density of the oil in grams per cubic centimeter.[6] For very high viscosities equation (4) may be reduced to

$$\text{kinematic viscosity} = 0.00220\ t, \qquad (5)$$

which may be used when the error does not exceed an allowable amount as shown by Table 2.

TABLE 2.—Error Due to Neglect of Kinetic Energy Correction

Saybolt viscosity	Kinematic viscosity by—		Error in equation 5
	Equation 4	Equation 5	
			Per cent
32	0.0141	0.0704	400.0
50	.0740	.1100	48.7
75	.1410	.1650	17.0
100	.2020	.2200	8.9
200	.4310	.4400	2.1
300	.654	.660	.9
400	.875	.880	.6
500	1.096	1.100	.4
1000	2.193	2.200	.1

Table 2 shows that the error due to the use of equation (5) will be within the experimental error if the Saybolt viscosity exceeds, say, 300 seconds.

It is common practice for oil refiners or jobbers to carry a relatively small number of oils of different viscosities in stock, and to obtain oils of intermediate viscosities by mixing. Such mixed oils are known as blends.[7]

To avoid at least part of the waste of time and labor involved in cut and try methods, it is desirable that a simple table or diagram, as accurate as possible, should be available to solve the problem of obtaining a blend of definite viscosity from two oils of

[6] Winslow H. Herschel, B. S. Tech. Paper No. 112, p. 19, 1919.

[7] It appears from L. Archbutt and R. M. Deeley (Lubrication and lubricants, p. 256; 1912) that in England a mixture of petroleum oil with an animal or vegetable oil is known as a blend. In the United States, however, such a mixture would be called a compounded oil. Since the components of a compounded oil are less apt to be chemically inert with respect to each other than are the components of a blend, there would be a probability of greater error in calculating the viscosity of a compounded than of a blended oil. According to Espy "A certain amount of fatty oil will have a greater effect in raising or lowering the viscosity of a mixture with mineral oil than the same amount of mineral." (W. E. Espy, Petroleum, 8, p. 27; 1919.)

known viscosity. Since there is no definite relation between the viscosity and the density of oils (except when they are all from the same crude), it is necessary to assume for the sake of simplicity that γ is the same for the two components of a blend. Then values of the kinematic viscosity obtained from equation (4) may be used in equation (3) in place of μ without affecting its validity, and the resulting values of the kinematic viscosity of the blend may be converted into corresponding values of the Saybolt viscosity by means of the equation:

$$t = 227.3\frac{\mu}{\gamma}\left(1 + \sqrt{1 + \frac{0.01584}{\left(\frac{\mu}{\gamma}\right)^2}}\right); \tag{6}$$

or for high viscosities

$$t = 445\frac{\mu}{\gamma}. \tag{7}$$

Table 3 shows the Saybolt viscosities of blends containing 25, 50, and 75 per cent of either of two oils. It was calculated from equations (3) and (4), the need of equation (6) being avoided by using a diagram with Saybolt viscosities plotted against kinematic viscosities.[8] Each line of the table shows values of Saybolt viscosity for blends with a given viscosity of the lighter oil, the headings of the columns showing the viscosity of the heavier oil. Each rectangle formed by the intersection of a line and a column contains three values, which are the viscosities of blends of the two oils in question. Beginning at the top of a rectangle, these values are for blends containing 25, 50, and 75 per cent, respectively, of the heavier oil.

When equations (5) and (7) may be used, it is simple to make corrections for differences in density. If it is assumed that Table 3 applies to unit density, and γ is the actual density of a component, the table should be entered with the corrected Saybolt viscosity, which is equal to $t\gamma$. Correcting the viscosities of both components in this manner, and finding from the table (or a similar table for higher viscosities), the uncorrected viscosity of the blend, T, it is necessary first to find the density of the blend ρ by taking the weighted arithmetical mean of the densities of the components. Then the desired viscosity of the blend is equal to $\frac{T}{\rho}$.

[8] Data for this diagram may be found in Table 9, p. 21, of B. S. Tech. Paper No. 112, previously referred to.

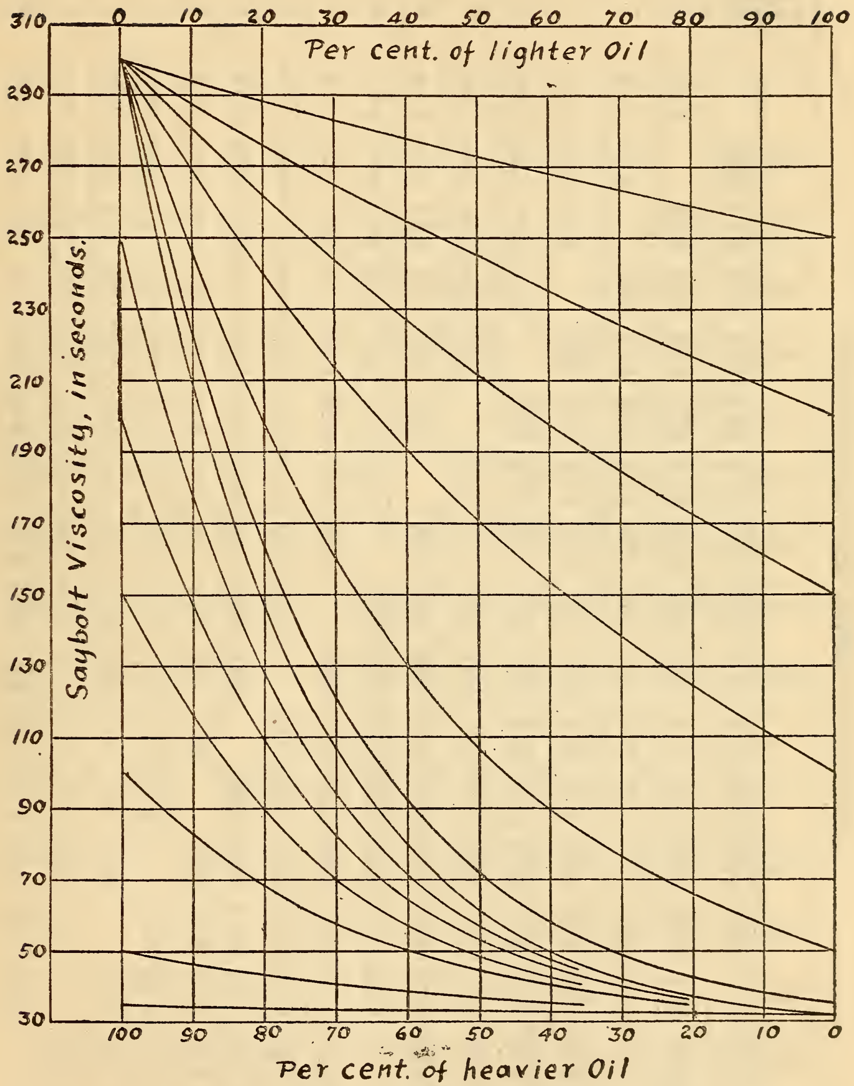

Fig. 1.—*Calculated variations in viscosity of blends with the viscosity and per cent of oils*

TABLE 3.—Saybolt Viscosities of Blends

[Both constituents being at the

VISCOSITIES OF LIGHTER OIL OVER 160 VISCOSITY

Viscosity of heavier oil		35	40	45	50	60	70	80	90	100	110	120	130	140	150	160
		33	33	34	34	35	35	35	36	36	36	36	37	37	37	37
		33	35	36	37	39	40	41	43	44	45	46	47	47	48	49
		34	37	40	42	46	50	54	58	62	65	68	72	75	78	81
300	322		36	37	37	38	39	39	40	40	40	41	41	41	42	42
	347		37	39	40	42	44	46	48	49	51	52	54	55	56	57
	372		38	42	44	49	54	58	63	67	71	75	79	83	87	91
290	314	293		41	42	42	44	45	45	46	47	47	48	48	48	49
	341	295		42	44	47	49	52	55	57	59	60	62	63	65	67
	369	297		43	47	52	58	63	68	73	78	82	87	91	95	100
280	305	285	282		46	48	49	50	52	52	53	54	55	56	57	57
	334	290	285		47	52	55	58	61	63	65	67	69	71	73	75
	366	294	287		49	56	61	67	73	78	83	88	93	98	102	107
270	297	277	274	272		52	54	56	57	58	59	60	61	62	63	64
	328	283	279	275		55	59	62	65	68	71	73	76	78	80	82
	362	290	284	277		57	64	70	76	82	87	92	98	103	108	113
260	289	272	269	266	263		62	63	65	66	68	69	70	71	72	73
	322	279	274	270	265		64	68	72	76	79	81	84	87	90	93
	359	289	282	275	267		67	74	80	87	93	99	105	110	115	120
250	280	261	259	257	255	252		72	74	75	77	78	80	81	82	83
	316	273	269	264	260	255		74	79	83	86	89	93	96	99	102
	355	285	278	271	264	257		77	84	91	98	102	109	115	121	127
240	272	253	251	249	247	244	242		82	84	86	87	89	91	92	94
	309	268	263	259	254	250	245		85	89	93	96	101	104	108	111
	352	283	276	269	262	255	247		87	95	101	106	115	120	126	133
230	264	245	243	241	239	237	235	233		93	95	96	98	100	101	103
	302	263	259	254	250	245	240	235		95	100	103	107	111	115	119
	348	280	273	266	259	252	245	238		97	105	111	118	124	132	139
220	255	237	236	234	232	229	227	225	222		103	105	107	109	110	112
	296	257	252	248	244	239	235	230	225		104	109	114	118	122	126
	344	276	270	262	256	249	242	235	227		108	115	122	129	135	142
210	246	229	227	225	224	221	219	217	215	212		112	114	116	118	120
	289	251	247	243	239	234	229	225	220	215		114	119	124	128	132
	340	274	267	260	253	246	239	232	225	217		117	124	131	138	145
200	237	221	219	218	216	214	211	209	207	205	202		121	124	126	129
	282	245	241	237	233	228	224	219	215	210	205		124	129	134	138
	335	270	263	257	250	243	236	229	222	215	207		128	135	142	149
190	228	213	211	209	208	206	204	201	199	197	195	192		132	134	136
	274	238	234	230	226	222	218	213	208	204	199	195		135	139	143
	331	266	260	253	246	240	233	226	219	212	205	197		138	145	152
180	219	204	202	200	199	197	195	193	191	189	187	185	182		142	145
	267	231	228	224	220	216	212	208	203	199	194	190	185		144	149
	326	263	257	250	244	237	230	223	216	208	201	194	187		147	154
170	210	195	194	192	190	189	187	185	183	181	179	177	175	172		152
	259	225	222	218	214	210	206	202	198	193	189	184	180	175		155
	321	260	254	247	241	234	227	220	213	206	199	192	185	177		157
160	200	187	186	184	183	181	179	177	175	174	172	170	167	165	163	
	252	218	215	211	208	204	200	196	192	188	183	179	174	170	165	
	316	256	250	244	237	231	224	217	210	204	197	190	183	175	168	
	400	300	290	280	270	260	250	240	230	220	210	200	190	180	170	

VISCOSITIES OF HEAVIER OIL, FOR LIGHTER OILS OVER 160 VISCOSITY

NOTE.—The three values in each group are vicosities of blends of the three percentage compositions given above.

Containing 25, 50, and 75 Per Cent of Heavier Oil

same temperature as the blend.]

170	180	190	200	210	220	230	240	250	260	270	280	290	300	400	
37	37	38	38	38	38	38	38	38	39	39	39	39	39	40	
50	51	52	53	53	54	55	56	57	57	58	59	60	61	65	32
84	88	91	93	96	99	103	106	109	112	114	117	120	123	150	
42	43	43	43	43	43	43	43	44	44	44	44	44	45	46	
58	59	60	61	62	63	64	65	66	67	68	69	70	71	79	35
94	98	101	105	108	111	115	118	122	125	128	131	135	138	170	
50	50	50	51	51	51	51	52	52	52	53	53	53	54	55	
69	70	72	73	74	75	77	78	79	80	81	83	84	85	96	40
105	109	113	117	121	125	129	133	137	140	144	148	152	155	191	
58	58	59	59	60	60	60	61	61	62	62	63	63	64	66	
77	79	81	83	85	86	88	90	91	93	94	96	97	99	112	45
112	118	122	126	130	135	139	143	148	152	156	160	165	169	208	
64	65	65	66	66	67	67	68	68	69	69	70	70	71	74	
85	87	89	91	93	95	97	99	100	102	104	105	107	108	124	50
118	124	128	132	137	142	147	151	155	160	164	168	173	177	220	
74	75	75	76	77	77	78	79	80	80	81	81	82	82	87	
96	98	100	102	104	106	108	110	113	115	117	119	121	123	141	60
126	131	136	142	147	152	157	162	166	171	176	181	186	191	235	
84	85	86	88	89	90	91	92	92	93	94	94	95	96	102	
105	108	111	113	116	119	121	124	126	129	131	133	135	138	157	70
133	139	144	150	155	160	165	170	176	182	187	192	198	202	249	
95	97	98	99	100	101	102	102	103	104	105	106	106	107	115	
114	118	121	124	126	129	132	135	138	140	143	145	148	150	171	80
139	144	150	156	162	168	173	179	185	190	196	201	206	212	260	
105	106	108	109	110	111	112	113	114	115	116	117	118	119	128	
122	126	129	132	135	139	141	144	147	149	152	155	157	160	184	90
145	150	156	162	168	174	180	186	192	197	202	208	213	219	271	
114	115	117	118	120	121	122	123	125	126	127	128	129	131	139	
130	133	137	140	143	146	150	153	156	159	162	165	168	171	196	100
148	155	161	168	174	180	186	192	198	204	209	215	220	226	279	
122	124	125	127	129	130	131	133	134	135	137	138	139	140	149	
136	140	143	147	150	153	157	160	164	167	170	173	177	180	206	110
151	158	165	171	178	184	190	196	202	208	214	220	226	232	287	
131	133	135	136	138	140	141	142	144	145	146	147	148	149	160	
142	146	150	153	157	160	164	168	171	175	178	182	185	188	215	120
156	162	169	176	182	188	195	201	207	213	219	225	231	237	293	
138	140	142	144	145	147	148	150	151	153	154	156	157	158	170	
147	152	156	160	164	168	172	176	179	183	186	190	193	196	225	130
159	165	172	179	185	192	199	205	211	218	224	230	236	242	300	
147	149	150	152	154	155	157	158	160	161	163	164	166	167	180	
154	158	162	167	171	175	179	182	186	190	194	197	200	204	234	140
161	168	175	182	189	195	202	209	215	222	228	234	241	247	306	
155	157	159	161	163	165	167	168	170	172	173	175	176	178	190	
159	164	169	173	178	182	186	190	193	197	200	204	207	211	244	150
165	172	179	186	193	200	207	213	220	226	232	239	245	252	311	
163	165	167	170	172	174	175	177	179	181	183	184	186	187	200	
165	170	174	179	183	188	192	196	200	204	208	211	215	218	252	160
168	175	183	190	197	204	210	217	224	231	237	244	250	256	316	
170	180	190	200	210	220	230	240	250	260	270	280	290	300	400	

VISCOSITIES OF LIGHTER OIL LESS THAN 160 VISCOSITY

VISCOSITIES OF HEAVIER OIL, FOR LIGHTER OILS LESS THAN 160 VISCOSITY

It seems probable that an extension of Table 3 to higher viscosities might prove serviceable in estimating the viscosity of oils too viscous to be run in the Saybolt viscosimeter. The viscosity of the lighter component and of the blend could be determined by viscosimeter, and then the viscosity of the more viscous component found from the table.

IV. GRAPHICAL METHODS OF INTERPOLATION

On account of the large number of variables involved, it is difficult to represent Table 3 graphically. Any pair of oils may be selected, as in Fig. 1, but to give all the information in the table in this manner would necessitate a large number of diagrams with

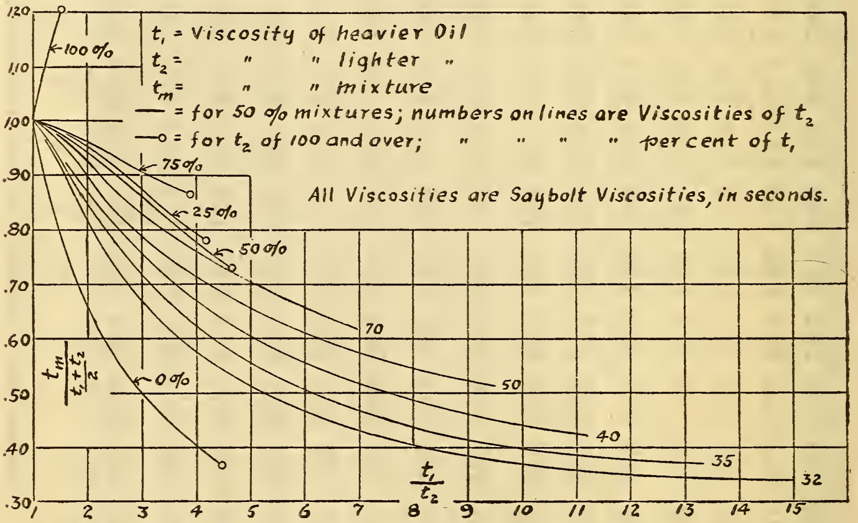

FIG. 2.—*Relation between calculated viscosities of blends, when the additive property is assumed to be the Saybolt viscosity and when it is assumed to be the logarithm of the viscosity in poises*

no ready means of interpolating between them. It will be noted that the greater the difference in the viscosity of the component oils, the greater the curvature of the lines, which would be straight if Saybolt viscosities were additive. In reality two errors are involved in the assumption that Saybolt viscosities are additive, since they are not proportional to viscosities in poises, and even the latter are not additive.

Lockhart [9] says that when there is a considerable difference in viscosity of the component oils the viscosity of a blend may be as much as 30 per cent below the viscosity calculated from the vis-

[9] L. B. Lockhart, American lubricants, p. 18; 1918.

cosity of the two oils and the proportions taken; that is, calculated on the erroneous assumption above referred to. As will be seen, the error may be much greater than 30 per cent.

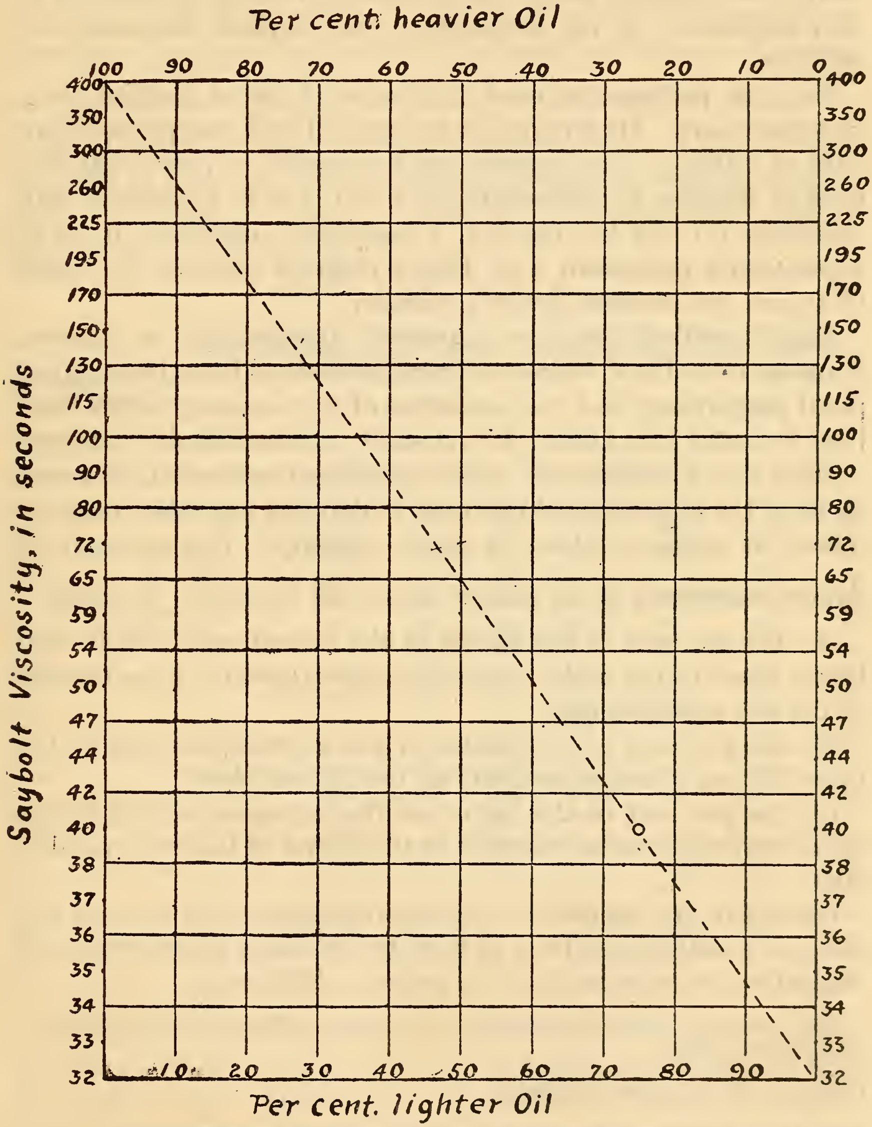

FIG. 3.—*Diagram for interpolating the viscosity of a blend, calculated on the assumption that the additive property is the logarithm of the viscosity in poises*

In order to reduce the number of variables, and be able to present more information on one diagram, Fig. 2 was calculated from the data of Table 3. While it gives no data for the lighter oils, except for 50 per cent blends, it might serve to estimate viscosities of blends containing not less than 25 per cent of either oil, when both oils had a viscosity of at least 100 seconds. The figure shows that in the extreme case of mixing oils of 32 and 300 seconds viscosity, the resulting blend has a viscosity of only 37 per cent of that calculated on the assumption that Saybolt viscosities are additive.

Fig. 3 is perhaps the most satisfactory form of diagram for a blending chart. Its form is due to Espy,[10] but it was plotted from data of Table 3. No attempt has been made to prove that this form of diagram is mathematically exact, and in agreement with equations (2) and (4), but Fig. 3 was found graphically to be in approximate agreement with Espy's diagram between the limits of 55 and 300 seconds, Saybolt viscosity.

Espy's method may be expressed algebraically as follows: Suppose two oils of widely differing viscosities have been mixed in all proportions, and the viscosities of the resulting blends have been recorded in a table. It is desired to determine in what proportion two available oils, with viscosities intermediate between those of the experimental oils used in deriving the table, must be mixed to obtain a blend of given viscosity. The per cent of lighter component in the desired blend will be $100\frac{B-A}{C-A}$, where

A = the per cent of the lighter of the experimental oils in the blend, given in the table, having the same viscosity as the heavier of the two available oils.

B = the per cent of the lighter of the experimental oils in the blend having the same viscosity as the desired blend.

C = the per cent of the lighter of the experimental oils in the blend having the same viscosity as the lighter of the two available oils.

Obviously any method is only approximate which neglects the effect of density upon time of flow, but within a limited range of viscosities the error may not be serious. Espy says:

> The viscosity of a blend, calculated by the above method, will check within a limit of three points;

that is, within three seconds.

V. COMPARISON WITH ESPY'S RESULTS

In order to check Espy's results more accurately, a series of tests was made with two oils of approximately the same viscosities as used by him. The specific gravities of these oils were 0.850 for the light and 0.878 for the heavy, while Espy's values were

[10] W. E. Espy, Petroleum, 8, p. 27; 1919.

0.872 and 0.903, respectively.[11] If μ is the viscosity as calculated from equation (4), and μ' is the viscosity of a blend, in poises, as estimated from the viscosities of the two components, then $\frac{\mu}{\mu'}$ is a correction factor by which viscosities of a blend, estimated by equation (2), must be multiplied to obtain the values as given by test. $\frac{t}{t'}$ is a corresponding correction factor for Saybolt viscosities.

Table 4 shows correction factors calculated from results of tests. In order to avoid the error in the assumption of constant density, no use was made of Table 3, but the table was calculated directly from equations (2), (4), and (5).

TABLE 4.—Check of Espy's Results

Percentage of lighter oil in blend	W. E. Espy tests at 100° F (37.3° C)				Bureau of Standards tests at 68° F (20° C)			
	t	μ	$\frac{t}{t'}$	$\frac{\mu}{\mu'}$	t	μ	$\frac{t}{t'}$	$\frac{\mu}{\mu'}$
100	55	0.0754	....	....	56.2	0.0775	....	....
95	57	.0804	0.977	0.964	60.1	.0866	1.005	1.012
90	60	.0876	.967	.948	63.1	.0936	.994	.991
85	64	.0968	.965	.944	66.0	.1002	.974	.961
80	68	.1060	.955	.934	70.1	.1094	.971	.951
75	72	.1153	.937	.918	74.8	.1193	.954	.940
70	76	.1240	.916	.893	80.2	.1315	.951	.937
65	81	.1351	.902	.878	85.2	.1424	.933	.919
60	87	.1483	.892	.870	90.4	.1534	.913	.897
55	95	.1653	.895	.876	98.2	.1698	.911	.898
50	103	.1823	.889	.872	107.8	.1895	.920	.909
45	112	.2014	.886	.869	114.6	.2037	.897	.884
40	122	.2220	.880	.866	124.5	.2239	.891	.881
35	135	.2486	.886	.876	141.5	.2580	.924	.921
30	149	.2776	.890	.882	154.5	.2840	.922	.917
25	167	.3139	.907	.901	169.2	.3138	.921	.917
20	185	.3502	.914	.908	187.0	.3490	.926	.923
15	205	.3909	.918	.916	203.1	.3813	.916	.915
10	229	.4390	.932	.927	240.4	.4540	.989	.985
5	254	.4895	.936	.935	267.3	.507	.996	.995
0	300	.580	....	....	295.2	.562	....	....

It will be noticed that there is considerable difference between the correction factors for viscosities in poises and in time of flow for a given test. These values approach each other as the viscosity increases or the kinetic energy correction decreases, and they would be equal for very high viscosities for which equations (5) and (7) are valid. Table 4 also shows that there is a systematic error in Table 3 other than that due to the disregard of variations in density in calculations involving equations (4) and (6). Assum-

[11] Private communication.

ing these equations to be correct, there must be a systematic error in equation (2) which requires further investigation.

VI. TESTS WITH GASOLINE

The Saybolt Universal viscosimeter should not be used for gasolines or other liquids having a viscosity of less than 32 seconds, but if this is done, equations (4) and (6) must be replaced by

$$\frac{\mu}{\gamma}=0.00130\,t-\frac{0.93}{t} \qquad (8)$$

and

$$t=385\frac{\mu}{\gamma}\left(1+\sqrt{1+\frac{0.00484}{\left(\frac{\mu}{\gamma}\right)^2}}\right) \qquad (9)$$

Under these conditions the flow is turbulent, and the time of discharge is influenced only slightly by a considerable change in μ, the viscosity in poises, as shown by Table 5. In calculating this table no use was made of equation (8), viscosities in poises being obtained by the Ubbelohde viscosimeter,[12] but equation (9) was used to obtain values of t marked with an asterisk (*).

TABLE 5.—Tests of 50 Per Cent Blends of Oils from Various Crudes with Gasoline and Other Diluents, at 20° C (68° F)

Oils	Specific gravity $\frac{15.6°}{15.6°}$C	t	μ	$\frac{t}{t'}$	$\frac{\mu}{\mu'}$	Percentage error in μ if additive property is—	
						log μ	1/μ
1. Pennsylvania	0.864	259.7	0.485				
2. Mid continent	.901	668.6	1.315				
3. Texas	.932	673.9	1.361				
4. California	.942	390.4	.788				
5. Mineral seal	.832	54.0	.0708				
6. Kerosene	.782	33.9	.0172				
7. Commercial gasoline	.743	* 30.0	.0059				
8. Aviation gasoline	.700	* 28.8	.0036				
50 per cent blends:							
1+5		95.4	.1613	0.888	0.871	14.9	61.7
1+6		53.3	.0694	.849	.761	31.4	76.1
1+7		38.8	.0313	.816	.584	71.6	81.2
1+8		36.0	.0229	.840	.546	83.4	84.4
2+5		130.8	.2360	.790	.774	30.6	71.6
2+6		59.6	.0859	.667	.572	74.9	80.3
2+7		41.2	.0386	.665	.437	129.0	† 84.8
2+8		39.4	.0328	.727	.475	110.7	† 89.1
3+5		117.9	.2131	.708	.687	45.7	68.4
3+6		56.1	.0788	.626	.516	94.0	† 78.6
3+7		39.8	.0353	.641	.393	154.7	† 83.4
3+8		35.4	.0219	.648	.312	221.0	† 83.6
4+5		104.6	.1861	.839	.788	26.9	65.1
4+6		53.1	.0716	.734	.616	62.4	76.6
4+7		38.2	.0308	.726	.450	122.0	† 80.9
4+8		34.7	.0200	.736	.374	167.5	† 82.0

[12] Winslow H. Herschel, B. S. Tech. Paper No. 125; 1919.

A table similar to Table 3, but extended to still lower viscosities might perhaps be used to gain a rough idea of the viscosity of a gasoline. The viscosity of a blend and of the component heavy oil could be determined by instrument, and the viscosity of the component gasoline could then be taken from the table. But this and all other uses, in open viscosimeters, of blends containing gasoline is subject to large errors on account of the evaporation of the gasoline from the blend.

The tests of Tables 4 and 5 show that the assumption that the additive property is log μ does not give as low a viscosity of blend as found by test, and, as shown in Table 1, the only other common assumption which would enable a lower viscosity to be predicted is that fluidities are additive. This indicated that this latter assumption might give better results in extreme cases. As shown in the last column of Table 5, this is the case in tests marked with a dagger (†), but the errors are so great with either assumption that there is not much choice between them.

Table 5 shows that the error in calculating the viscosity of a 50 per cent blend varies greatly, but it does not show clearly how much of this variation is due to the source of the oils and how much to the difference in range of viscosity between the two components of a blend. According to Espy the variation due to differences in crudes is negligible, although, as will be seen, this conclusion is probably due to the limited range of his experiments.

VII. TESTS WITH OILS FROM DIFFERENT CRUDES, BUT OF APPROXIMATELY THE SAME VISCOSITY AT THE TEMPERATURE OF TEST

Two heavy oils, N and P, one of naphthene and the other of paraffin crude, of approximately the same viscosity at 55° C (131° F), were selected and blended with two lighter oils, M and Q, of the same crudes. It was desired to use heavier oils than in the tests with gasoline, and this necessitated an increase in temperature. With a time of flow much over 500 seconds, it is very difficult to get check results, but, on the other hand, if the time is decreased by an increase of temperature, there is an increase in the error due to the change of volume of the oil after it leaves the outlet tube. The temperature of 55° C was adopted as a compromise between these considerations.

By making the four possible 50 per cent blends of oils of different viscosities it was found that the maximum correction factor was obtained for a blend of N and Q and a minimum factor for a blend of P and M. It is noteworthy that these last two blends are both of unlike crudes. The assumption seemed reasonable that the maximum and minimum correction factors for blends of any proportion would follow the same law, and the tests of Table 6 appear to confirm this.

Table 6 shows that the correction factor is lower when the heavy oil is of naphthene than of paraffin base. In order to see whether this rule was still valid when kerosenes of the two crudes were used as diluents, the final series of tests were run with the results as shown in Table 7. The Saybolt viscosities marked with an asterisk (and also that of the kerosene in Table 5) were calculated from the viscosity as determined by the Ubbelohde viscosimeter. The letters in Table 7 have the same significance as regards the source of the oils as in Table 6, but the viscosities of the oils are different in the two tables.

TABLE 6.—Tests of Blends of Unlike Crudes at 55° C (131° F)

Oils	Percentage of lighter oil in blend	Specific gravity $\frac{15.6°}{15.6°}$C	t	μ	$\frac{t}{t'}$	$\frac{\mu}{\mu'}$
N+Q	100	0.885	111.5	0.1965	....	....
	90	....	122.7	.2202	0.945	0.940
	80	....	134.0	.2441	.883	.874
	70	....	152.1	.2817	.853	.845
	60	....	181.1	.3410	.863	.857
	50	....	209.7	.3990	.846	.842
	30	....	290.2	.565	.839	.837
	20	....	343.6	.674	.847	.837
	10	....	424.0	.838	.873	.877
	0	.934	577.4	1.147	....	....
P—M	100	.925	111.7	.2060	....	....
	90	....	126.6	.2363	.977	.975
	85	....	136.3	.2557	.972	.971
	80	....	144.2	.2710	.952	.949
	70	....	170.2	.3220	.958	.957
	60	....	203.8	.3861	.977	.974
	50	....	238.5	.4520	.971	.968
	40	....	278.9	.530	.960	.962
	35	....	299.7	.568	.950	.951
	30	....	323.2	.612	.943	.945
	20	....	377.1	.710	.930	.931
	10	....	445.6	.836	.936	.936
	5	....	481.1	.901	.925	.923
	0	.878	567.7	1.060	....	....
N+M	50	....	219.5	.4282	.885	.882
P+Q	50	....	236.2	.4376	.962	.959

TABLE 7.—Tests of Blends Containing Kerosenes of Different Crudes at 20° C (68° F)

Oils	Percentage of lighter oil in blend	Specific gravity $\frac{15.6°}{15.6°}$C	t	μ	$\frac{t}{t'}$	$\frac{\mu}{\mu'}$
N+Q	100	0.806	*33.7	0.0166	....	....
	90	....	35.2	.0213	0.965	0.847
	80	....	37.6	.0286	.918	.750
	70	....	41.1	.0389	.848	.673
	60	....	46.5	.0537	.767	.613
	50	....	55.6	.0768	.683	.578
	40	....	70.3	.1115	.623	.554
	30	....	98.7	.1730	.604	.566
	20	....	149.2	.2803	.621	.606
	15	....	189.0	.3520	.644	.636
	10	....	273.3	.534	.764	.761
	5	....	384.8	.758	.880	.877
	0	.911	534.8	1.064	....	....
P+M	100	.808	*33.8	.0171	....	....
	90	....	35.8	.0231	.976	.904
	80	....	39.0	.0325	.950	.848
	70	....	43.1	.0438	.891	.765
	60	....	48.6	.0582	.805	.678
	50	....	58.1	.0815	.728	.634
	40	....	75.8	.1215	.687	.632
	30	....	107.6	.1886	.679	.654
	20	....	168.4	.3116	.731	.722
	15	....	206.8	.3872	.738	.733
	10	....	267.5	.506	.789	.783
	5	....	346.2	.662	.839	.836
	0	.882	503.6	.969	....	....
N+M	50	....	57.4	.0812	.704	.602
P+Q	50	....	56.5	.0776	.716	.612

It is seen that the naphthene base oil in Table 7 is cut to a greater extent than the paraffin base oil, but the difference is not so great as in Table 6. In both tables the blends containing component oils of the same crudes show values of the correction factors which are intermediate between the extreme values for blends of unlike crudes.

VIII. GRAPHICAL REPRESENTATION OF RESULTS OF TESTS

Fig. 4 shows the results of tests except those of Table No. 5, Series 2, which were omitted to avoid confusion. It will be noted that the time ratio, or correction factor, is not a minimum for the 50 per cent blends, as might be expected. The points for these blends are located on vertical dotted lines, there being one blend in Espy's tests and in Series 1, and four blends in Series 3 and 4.

Assuming that the points should lie on smooth curves, Fig. 4 may be used as an indication of the reliability of the tests. Espy's tests and those of Series 1, for example, show greater irregularities in Fig. 4 than when plotted in the form of Fig. 1. While the figure is convenient for interpolation between tests in a series of blends of two given components, it is not convenient for interpolation between one series and another.

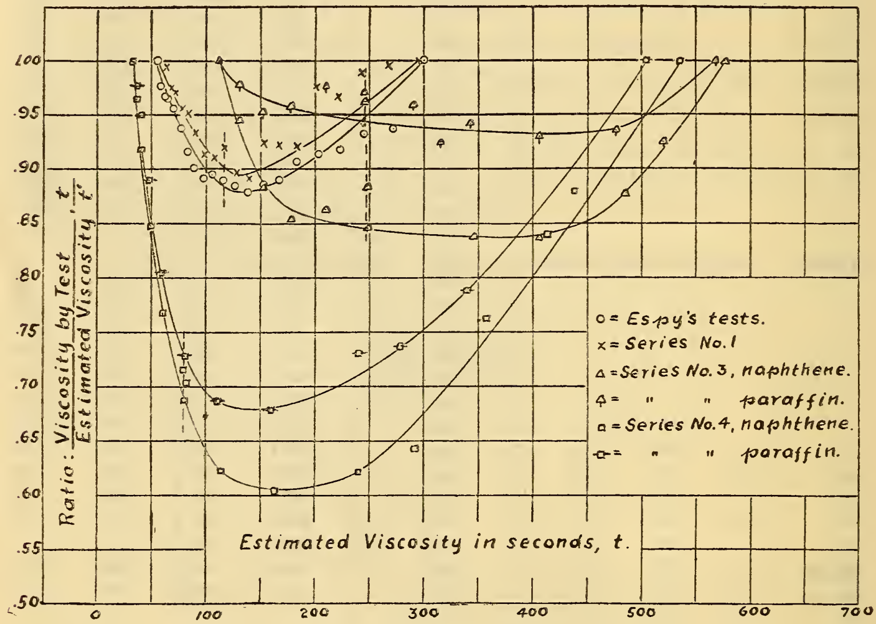

FIG. 4.—*The relation between the viscosity as determined by test, and as estimated by the logarithmic rule*

By the use of Fig. 3 the viscosity of a blend could be obtained on the assumption that it depended upon only three independent variables, the Saybolt viscosities of the two component oils and their proportions. But experiment has shown that the viscosity of a blend also depends upon the source of the crude, and it is possible that the range of boiling point should also be taken into account.

In order to reduce the number of variables and facilitate graphical representation it was decided to concentrate attention upon 50 per cent blends. If the correction factor for this blend is known the factors for other proportions may be estimated by sketching in curves similar in shape to those of Fig. 4. The variable due to source may be eliminated by using separate diagrams for naphthene and paraffin crudes, as the difference between them is not so great as to make the error in interpolating between them of serious amount. Density may be eliminated by using poises instead of Saybolt viscosities. Then the only remaining variables are the viscosities of the two component oils, for which the correction factor for a 50 per cent blend is desired.

A blend of any proportions may be considered as a 50 per cent blend of two other blends. Thus a blend containing 20 per cent of the lighter oil may be considered as a 50 per cent blend of two others, one containing 10 and the other 30 per cent of the lighter of the original components. In this case it would be necessary to reestimate the viscosity of the 20 per cent blend by equation (3) from the experimentally determined viscosities of the 10 and 30 per cent blends. The tests of Series 2, 3, and 4 were used in this manner to estimate viscosities of 50 per cent blends, and the results are shown in Fig. 5.

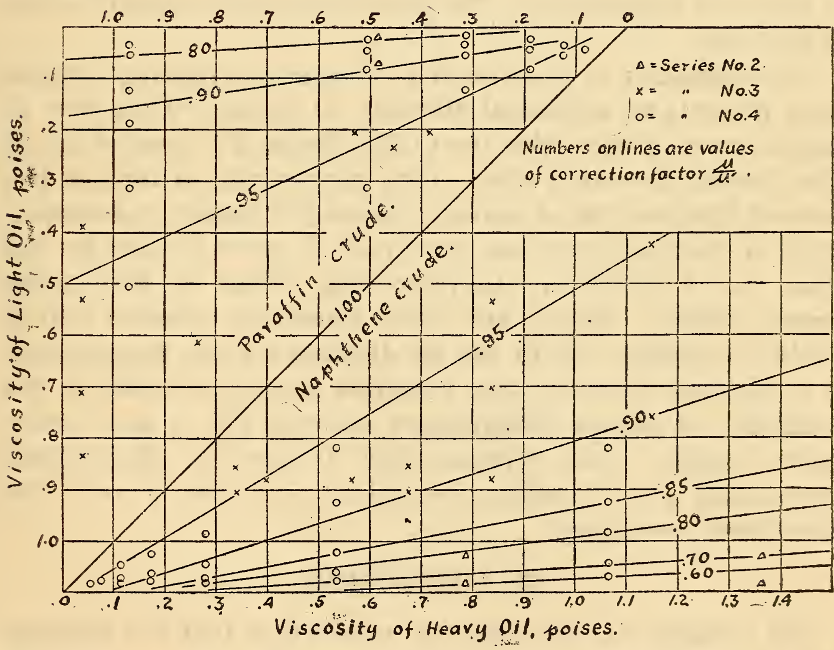

FIG. 5.—*Diagram for estimating the correction factor for viscosities calculated by the logarithmic rule*

The figure is divided into two sections by the diagonal line marked 1.00, the upper portion being for the blends P + M and the lower for the blends N + Q. In plotting the diagram each point was marked with the corresponding value of $\frac{\mu}{\mu'}$ (not shown) and the lines drawn to conform as well as possible with these values, as in making a contour map. As might be expected from Fig. 4, the points for the upper portion of the diagram were more discordant than those for the lower. No use was made of Series 1, because the tests were less concordant and the range of viscosities was not large.

From the tests of Series 2 and 4 the errors in the logarithmic rule for estimating the viscosity of blends might at first sight appear so large as to render the rule of little value. But in actual blending operations such light diluents are not used and the errors would be much smaller. Excluding steam-engine cylinder oils or "cylinder stock," the range in viscosity is from about 750 down to 80 seconds at 100° F (37.8° C), or say 1.5 to 0.12 poise. In the extreme case, therefore, the correction factor, from Fig. 5, would be 0.75 for naphthene and 0.80 for paraffin crudes, corresponding to an error in viscosity of 33 and 25 per cent, respectively. The errors in Saybolt viscosity would be still less.

The estimation of the viscosity of blends containing cylinder stock presents an additional difficulty on account of the error in measurement of viscosities due to the change of volume of the oil after leaving the outlet tube. Espy gives results of tests on two series of blends of oils of 300 and 55 seconds' viscosity, the temperature of test being in one case 100° F (37.8° C) and in the other 210° F (98.9° C). Corresponding values in these series agreed within 1 second, and Espy apparently assumes that it would be entirely safe to use his diagram for any temperature. It is believed, however, that attention should be called to the possibility of serious disagreement between Fig. 5 and experimental results, when cylinder stock is used at temperatures approaching 100° C, unless precautions are taken to avoid the error above mentioned.

IX. CONCLUSION

The evidence of the tests here recorded is that the viscosity of a blend can best be estimated from the rule that the logarithms of the viscosities, in poises, are additive. The determination of viscosities in poises, from Saybolt viscosities, has been discussed in previous papers. The larger the difference between the viscosities of the constituent oils the greater will be the error in the logarithmic rule, the true viscosity being less than the estimated value. For equal differences of viscosity, the error increases as the viscosity of the lighter component decreases. The true viscosity will be greater than calculated on the assumption that fluidities are additive.

Since it was found that the error in the logarithmic rule depended upon the source of the component oils, it seemed preferable to use an uncorrected table or diagram, calculated by this rule, and give data concerning variations in the correction factor, so that each user of the diagram could select the appropriate correction factor according to the crudes to be used. Diagrams are given for finding the correction factor for 50 per cent blends of oils of any crude or any viscosity, and for then estimating the correction factor for blends of other proportions. It is believed that by this means the error in estimating the viscosity of a blend will be comparable with the error in determining the viscosity of the component oils.

WASHINGTON, January 24, 1920.