VISCOSITY DATA OF ORGANIC LIQUIDS

by J. W. M. BOELHOUWER, G. W. NEDERBRAGT and
G. VERBERG

Koninklijke/Shell-Laboratorium, Amsterdam
(N.V. De Bataafsche Petroleum Maatschappij, The Hague)

Summary

Viscosities have been measured of thirty-seven organic liquids, with molecular weights ranging from 120 to 807, and the viscosity-temperature curves obtained are compared with those of *n*-paraffins. The influence of ring structures and polar groups on viscosity is discussed.

§ 1. *Introduction.* Viscosity data of pure organic liquids with molecules of medium size are increasingly recorded in the literature. Evans[1]), in 1938, collected the data of a number of hydrocarbons, including 74 with 20 or more C-atoms. Since then Klos, Neyman-Pilat and Pilat[2]) have reported on hydrocarbons containing 22 C-atoms and consisting of short chains and aromatic or naphthenic ring structures. Cosby and Sutherland and later Schiessler and coworkers[3]) published viscosity data of a large variety of cyclic and non-cyclic hydrocarbons, having for the greater part between 20 and 40 C-atoms.

Viscosities are also known, through the work of Bingham and Stephens[4]), of Joglekar and Watson[5]) and of Bried et al.[6]), of many esters with a number of atoms comparable to that of the above mentioned hydrocarbons. A few alcohols and acids with a carbon chain of some length have also been investigated by Bingham et al.[4]) [7]).

When two medium-sized hydrocarbons or esters have the same viscosity at one temperature, they may have quite different viscosities at another temperature. For example, large differences in slope of the viscosity-temperature curve do exist between long flexible molecules that can move in parts and more compact, more rigid molecules that can only move as a whole. As these differences made it desirable to extend viscosity measurements over a wide temperature range, two of the authors of the present article measured the viscosities of four *n*.-paraffins and three branched-chain paraffins for temperatures up to 300°C [8]). The work has since been extended still further. The present article deals with a group of nine oxygen-containing compounds without ring structure, a group of nineteen hydrocarbons with ring structure, a group of six oxygen compounds with ring structure while the remaining three compounds contain S or I.

Details on the preparation of the organic compounds investigated are given at the end of the article together with the boiling points at 4 millibars.

§ 2. *Measuring methods.* The measuring methods were the same as those described in the previous article on this subject [8]). The kinematic viscosities of most of the compounds were determined with the aid of an Ostwald viscometer (constant of viscometer multiplied by time of flow of liquid from higher to lower bulb). Multiplication of these viscosities by densities gave the dynamic viscosities.

In the case of the other compounds the time was measured which it took a short wedge-shaped needle to descend in a capillary filled with the liquid. The dynamic viscosity is here equal to a viscometer constant multiplied by the difference in density between needle and liquid, the value thus obtained being multiplied by the time of descent. The viscometer constant was determined by calibration with water, taking 0.8937 cP for the viscosity of water at 25°C.

The densities used in these calculations were determined by means of a small pycnometer with a long calibrated stem, suspended in the same vapour bath as the viscometer.

§ 3. *Experimental results.* The kinematic viscosities of the thirty-seven liquids are collected in table I, the densities in table II and the dynamic viscosities in table III. The measurements in most cases were made at temperatures ranging from room temperature up to 280 or 300°C, thus reaching the limit above which cracking of the compounds is to be feared. The high melting point made it impossible in a number of cases to determine viscosities at the lower temperatures, while in other cases high volatility of the compound was the reason for omitting the measurements at the highest temperatures.

TABLE I

Kinematic viscosities in cs at various temperatures

	Visc. type	20°C	50°C	80°C	130°C	180°C	240°C	300°C
1,10-decane diol	f.n. 1)			17.05	3.78	1.435	0.689	
cetyl alcohol	0. 2)		11.88 4)	5.61	1.927	0.988	0.590	0.400
stearic acid	O.			9.41	3.66	1.858	1.004	0.633
ethylpalmitate	f.n.	6.89 3)		2.35	1.280	0.825	0.550	0.387
methylstearate	f.n.		4.63	2.69	1.434	0.912	0.607	0.428
ethylstearate	f.n.		4.88	2.83	1.501	0.958	0.633	0.441
palmitone.	f.n.			5.52 5)	3.05	1.794	1.120	0.774
palmitol	f.n.			8.42 5)	3.76	2.00	1.198	0.808
tripalmitin	f.n.			14.23	5.52	2.97	1.731	1.147
1, 3, 5,-trimethylbenzene	O.	0.843	0.630	0.502	0.437 6)			
1, 3, 5,-trimethylcyclohexane.	O.	0.887	0.621	0.488	0.413 6)			
phenanthrene	O.				1.241	0.767	0.505	0.367
perhydrophenanthrene .	O.	8.45	3.99	2.33	1.238	0.793	0.525	
1,2-diphenylpropane . .	O.	6.96	2.96	1.710	0.916	0.600	0.406	
1,6-diphenylhexane . .	f.n.	9.82	4.22	2.40	1.257	0.811	0.544	0.433 7)
1,6-dicyclohexylhexane .	f.n.	19.14	7.28	3.76	1.782	1.069	0.681	0.525 7)
1,6-di-p-tolylhexane . .	f.n.		4.68 4)	2.86	1.427	0.897	0.592	0.424
1,2-di (2,4,6,-trimethylphenyl) ethane . . .	O.				2.82	1.325	0.755	0.487
1,2-di (2,4,6,-trimethylcyclohexyl) ethane . .	O.			4.53	1.834	1.030	0.619	0.418
1,10-diphenyldecane . .	f.n.	16.45	6.56	3.50	1.741	1.081	0.707	0,501
1,10-dicyclohexyldecane.	O.		12.09	5.78	2.54	1.464	0.900	0.617
octadecylbenzene. . . .	f.n.		6.80	3.73	1.880	1.172	0.760	0.602 7)
octadecylcyclohexane. .	O.		9.52	4.91	2.32	1.386	0.876	0.607
1,6-di-α-naphthylhexane	f.n.			16.51 5)	5.38	2.30	1.218	0.772
1,1-diphenylhexadecane .	f.n.	38.5 3)		6.27	2.61	1.471	0.905	0.624
4-hexadecylbiphenyl . .	O.			6.74	2.91	1.661	1.029	0.709
4-hexadecylbicyclohexyl	O.		19.14 4)	9.62	3.78	2.048	1.206	0.809
p-dicetylbenzene	f.n.			11.09	4.61	2.56	1.548	1.045
phenylnonylether . . .	O.	4.89 3)		1.623	0.902	0.609	0.415	
ββ' diphenoxy diethyl ether	O.			3.80	1.564	0.919	0.586	0.476 7)
palmitophenone	O.			3.97	1.900	1.162	0.746	0.513
α-naphthylcetyl ether .	O.		15.92	6.70	2.709	1.523	0.938	0.642
β-naphthylcetyl ether .	O.			7.10	2.833	1.585	0.974	0.692
hydroquinone bisdodecyl ether	O.			6.34 5)	3.31	1.874	1.165	0.794
phenylnonyl thioether	O.	4.854 3)		1.757	1.014	0.678	0.471	
phenylcetyl thioether . .	O.		6.73	3.69	1.859	1.166	0.762	
1,6-diiodohexane. . . .	O.	3.531 3)	2.004	1.231	0.698	0.475		

1) f.n. = falling needle.

2) O. = Ostwald.

3) at 25°C.

4) at 55°C.

5) at 90°C.

6) at 100°C.

7) at 280°C.

TABLE II

Densities in g/cm³ at various temperatures							
	20°C	50°C	80°C	130°C	180°C	240°C	300°C
1,10-decane diol			0.883	0.850	0.812	0.762	
cetyl alcohol		0.808 †)	0.790	0.755	0.718	0.671	
stearic acid				0.799	0.765	0.722	0.674
ethylpalmitate	0.857 *)		0.816	0.779	0.741	0.693	0.644
methylstearate		0.843	0.821	0.785	0.748	0.702	
ethylstearate		0.838	0.816	0.780	0.743	0.697	
palmitone			0.796 °)	0.770	0.738	0.698	0.657
palmitol			0.797 °)	0.771	0.737	0.698	0.656
tripalmitin			0.866	0.833	0.799	0.760	0.717
1,3,5,-trimethylbenzene. . .	0.862		0.813				
1, 3, 5-trimethylcyclohexane	0.774	0.750	0.726	0.710 §)			
phenanthrene				1.044	1.009	0.965	0.919
perhydrophenanthrene . . .	0.943	0.923	0.903	0.870	0.837	0.794	
1, 2-diphenylpropane . . .	0.977		0.931	0.893	0.855	0.806	
1,6-diphenylhexane	0.952	0.931	0.910	0.875	0.840		0.762 ′)
1,6-dicyclohexylhexane . .	0.868	0.847	0.828	0.795	0.763	0.721	0.691 ′)
1,6-di-p-tolylhexane		0.915 †)	0.898	0.864	0.829	0.787	0.740
1,2-di(2, 4, 6, trimethylphenyl) ethane				0.902	0.868	0.825	0.777
1,2-di (2, 4, 6-trimethylcyclohexyl) ethane			0.837	0.804	0.771	0.728	
1,10-diphenyldecane	0.930	0.909	0.889	0.856	0.822	0.782	
1,10-dicyclohexyldecane . .		0.845			0.763		
octadecylbenzene		0.839	0.819	0.786	0.752	0.712	
octadecylcyclohexane		0.804	0.785	0.753	0.721	0.682	
1,6-di-α-naphthylhexane . .			1.026	0.995	0.963	0.924	0.884
1,1-diphenylhexadecane . .	0.907 *)		0.871	0.838	0.804	0.764	0.721
4-hexadecylbiphenyl			0.876	0.843	0.810	0.770	0.728
4-hexadecylbicyclohexyl . .		0.846 †)	0.820	0.799	0.768	0.731	0.691
p-dicetylbenzene			0.815	0.783	0.752		0.675
phenylnonyl ether	0.892 *)		0.851			0.727	
ββ′ diphenoxy diethyl ether			1.058	1.015	0.973	0.920	
palmitophenone			0.858	0.824	0.790	0.748	0.699
α-naphthylcetyl ether . . .		0.916	0.896		0.829	0.788	
β-naphthylcetyl ether . . .			0.886	0.853	0.820	0.779	0.736
hydroquinone bisdodecyl ether.			0.842 °)	0.816	0.782	0.741	0.700
phenylnonyl thioether . . .	0.924 *)		0.884				
phenylcetyl thioether . . .		0.889	0.869	0.834	0.801	0.758	
1,6-diiodohexane	2.033 *)	1.995	1.950	1.875	1.799		

*) at 25°C.
†) at 55°C.
°) at 90°C.
§) at 100°C.
′) at 280°C.

TABLE III

Dynamic viscosity in cp at various temperatures							
	20°C	50°C	80°C	130°C	180°C	240°C	300°C
1,10-decane diol			15.05	3.21	1.165	0.525	
cetyl alcohol		9.59 †)	4.43	1.454	0.709	0.396	0.248
stearic acid			7.84	2.93	1.421	0.724	0.426
ethylpalmitate	5.90 *)		1.918	0.996	0.611	0.381	0.249
methylstearate		3.90	2.21	1.126	0.682	0.426	0.280
ethylstearate		4.09	2.31	1.171	0.712	0.442	0.287
palmitone			4.39 °)	2.35	1.323	0.782	0.508
palmitol			6.71 °)	2.90	1.476	0.836	0.530
tripalmitin			12.32	4.60	2.37	1.316	0.823
1,3,5,-trimethylbenzene	0.727	0.528	0.408	0.348 §)			
1,3,5,-trimethylcyclohexane	0.687	0.466	0.354	0.293 §)			
phenanthrene				1.295	0.774	0.487	0.337
perhydrophenanthrene	7.97	3.68	2.10	1.077	0.663	0.417	
1,2-diphenylpropane	6.80	2.82	1.592	0.818	0.513	0.327	
1,6-diphenylhexane	9.35	3.93	2.18	1.100	0.681	0.432	0.330 ′)
1,6-dicyclohexylhexane	16.62	6.17	3.11	1.417	0.815	0.491	0.363 ′)
1,6-di-p-tolylhexane		4.29 †)	2.57	1.232	0.743	0.466	0.314
1,2-di (2, 4, 6,-trimethylphenyl) ethane				2.54	1.150	0.623	0.378
1,2-di (2, 4, 6,- trimethylcyclohexyl) ethane			3.79	1.475	0.794	0.451	0.285
1,10-diphenyldecane	15.30	5.97	3.11	1.490	0.888	0.553	0.371
1,10-dicyclohexyldecane		10.22	4.78	2.02	1.117	0.653	0.426
octadecylbenzene		5.71	3.06	1.477	0.882	0.541	0.412 ′)
octadecylcyclohexane		7.65	3.85	1.747	1.000	0.598	0.390
1,6-di-α-naphthylhexane			16.83 °)	5.35	2.218	1.126	0.683
1,1-diphenylhexadecane	34.9 *)		5.46	2.18	1.183	0.691	0.450
4-hexadecylbiphenyl			5.90	2.45	1.345	0.793	0.516
4-hexadecylbicyclohexyl		16.19 †)	7.88	3.02	1.574	0.881	0.559
p-dicetylbenzene			9.03	3.61	1.923	1.104	0.706
phenylnonyl ether	4.36 *)		1.381	0.734	0.472	0.302	
ββ′-diphenoxy diethyl ether			4.02	1.588	0.894	0.539	0.421 ′)
palmitophenone			3.41	1.565	0.918	0.558	0.359
α-naphthylcetyl ether		14.58	6.00	2.336	1.262	0.739	0.480
β-naphthylcetyl ether			6.29	2.417	1.300	0.759	0.510
hydroquinone bisdodecyl ether			5.34 °)	2.701	1.466	0.864	0.555
phenylnonyl thioether	4.49 *)		1.553				
phenylcetyl thioether		5.98	3.21	1.551	0.933	0.578	
1,6-diiodohexane	7.18 *)	4.00	2.40	1.309	0.854		

*) at 25°C.
†) at 55°C.
°) at 90°C.
§) at 100°C.
′) at 280°C.

§ 4. *Discussion.* In the first article the viscosities of branched-chain paraffinic hydrocarbons were compared with those of straight-chain paraffinic hydrocarbons. It was found that an isoparaffinic hydrocarbon with the branching near the centre of the molecule has

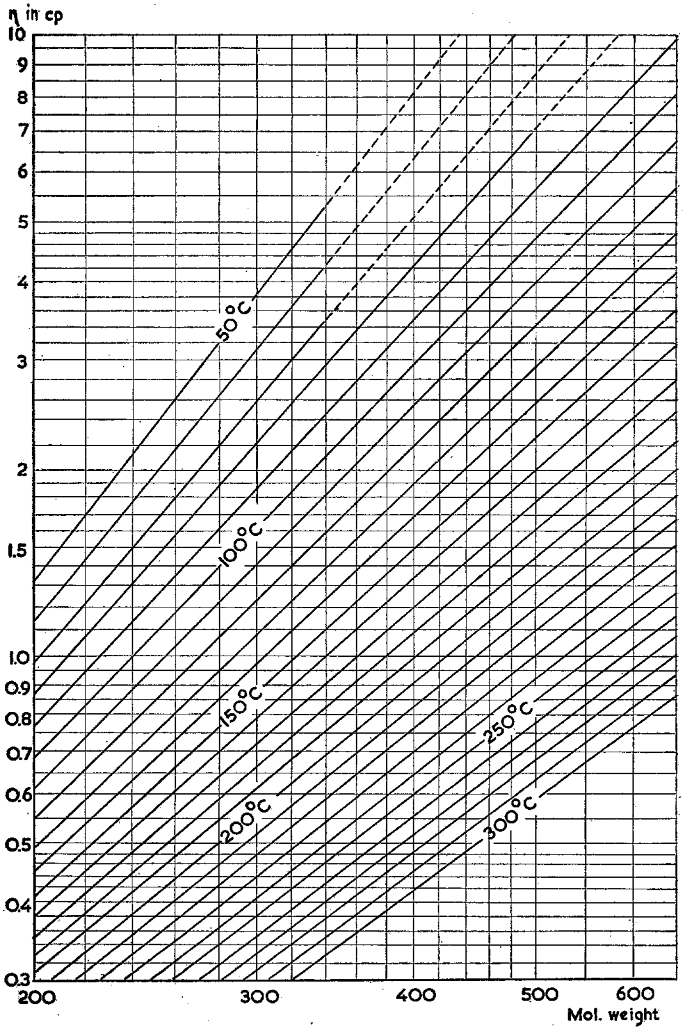


Fig. 1.

a lower viscosity than its normal isomer in the same ratio as the sum of the squared distances of the C atoms to the centre of gravity of the molecule in the case of the isoparaffin is lower than in the case of the normal paraffinic hydrocarbon. The sum of the squared distances was calculated in the manner described by H. A. Kramers 9).

We continue the practice of comparing the viscosities of newly

TABLE IV

	M	Molecular weight of the paraffin equiviscous at.					
		50°C	80°C	130°C	180°C	240°C	300°C
1,10-decane diol	174.3			526	415	350	
cetyl-alcohol.	242.4		409	348	311	293	
stearic acid	284.5		527	500	466	430	404
ethylpalmitate	284.5		284	284	285	286	
methylstearate.	298.5	301	301	303	304	306	
ethylstearate	312.5	307	307	309	312	313	
palmitone.	450.8		444 *)	445	447	451	454
palmitol	452.8		540 *)	497	477	470	467
tripalmitin	807.3		638 *)	629	628	627	627
1,3,5,-trimethylbenzene	120.1	(133)	(139)				
1,3,5-trimethylcyclohexane	126.1	(126)	(127)				
phenanthrene	178.1			326	327	334	346
perhydrophenanthrene	192.2	294	294	296	299	303	
1,2-diphenylpropane	196.1	265	260	256	258	261	
1,6-diphenylhexane	238,4	302	299	299	304	309	
1,6-dicyclohexylhexane	250.5	360	350	342	337	335	
1,6-di-p-tolylhexane	266.4		322	318	320	325	330
1,2,-di(2, 4, 6-trimethylphenyl) ethane	266.4			464	413	392	373
1,2-di(2, 4, 6-trimethylcyclohexyl) ethane	278.3		381	349	332	318	309
1,10-diphenyldecane	294.5	355	350	350	355	362	368
1,10-dicyclohexyldecane.	306.3		423	411	405	403	403
octadecylbenzene	330.3	350	347	349	353	357	361 †)
octadecylcyclohexane	336.4		384	381	380	380	380
1,6-di-α-naphthylhexane	338.5			680	604	568	553
1,1-diphenylhexadecane	378.3		448	428	420	417	418
4-hexadecylbiphenyl	378.3		465	455	452	455	459
4-hexadecylbicyclohexyl	390.4		528	508	495	487	484
p-dicetylbenzene.	526.9		558	556	556	561	566
phenylnonyl ether	220.2		245	243	246	248	
ββ'-diphenoxy-diethyl ether	258.1		392	362	356	357	366 †)
palmitophenone	316.5		365	360	361	362	361
α-naphthylcetyl ether.	368.3		468	444	435	436	437
β-naphthylcetyl ether	368.3		477	451	443	443	455
hydroquinone bisdodecyl ether	446.4		485 *)	478	475	480	482
phenylnonyl thioether	236.3		257				
phenylcetyl thioether.	334.4	355	355	358	364	372	
1,6-diiodohexane.	337.9	304	312	328	347		

*) at 90°C.
†) at 280°C.

investigated substances with those of the *n*.-paraffinic hydrocarbons, although we plan to do it along different lines. To this end fig. 1 has been prepared where the logarithms of the dynamic viscosities of the normal paraffinic hydrocarbons [8]) have been plotted versus the logarithms of the molecular weights. Points of equal temperature have been connected by lines that are nearly straight in this medium molecular weight range. A graph of this kind permits reading of the molecular weight of the paraffin that is equiviscous at a given temperature with the compound under investigation.

Table IV is derived from table III by replacing each viscosity value by the molecular weight of the equiviscous paraffin. A column is added containing the molecular weights of the substances investigated.

The figures for the first group, the nine acyclic compounds with one or more oxygen atoms, clearly demonstrate the great effect of an alcohol or acid group and the very small influence of an ester group or a ketone group on viscosity.

The esters ethyl palmitate and ethyl stearate are as viscous as the paraffins of the same molecular weight. Methyl stearate is slightly more viscous than the paraffin of the same molecular weight. It appears that the polar group, being nearer to one end of the chain of the molecule, is less shielded by the other parts of the molecule and has now a small influence on viscosity. Parallel to this there is an influence on volatility, for the boiling point at 4 millibars of methyl stearate (178.7°C) is rather high if compared with the boiling point 164.5°C of ethyl palmitate with one CH_2 group less and the boiling point 184.7°C of ethyl stearate with one CH_2 group more.

The correspondence in viscosity between straight chain esters and hydrocarbons of equal molecular weight holds at all temperatures; such differences as remain seem to indicate a slightly flatter viscosity-temperature curve in the case of the esters.

Tripalmitin, a compound with three ester groups, has a relatively low viscosity. It is clear that this is due to the branching of the molecule. The sum of the squared distances of the CH_2 groups and the O atoms from the centre of gravity of the molecule is lower than in the case of an unbranched chain. This causes the viscosity of tripalmitin to be lower at any temperature, although the ratio between the viscosities at low and high temperature is left unchanged. This means that, plotted in a graph, the resulting curve will come to lie among curves of straight chain esters and hydrocarbons of lower molecular weight which are less steep. It is thus quite clear why in table IV triplamitin has a somewhat steeper viscosity-temperature curve than the normal paraffins.

Stearic acid with the same overall formula as ethyl palmitate has a much higher viscosity. The viscosity just above the melting point is equal to that of a paraffin of nearly twice the molecular weight. This illustrates the well-known phenomenon of association to double molecules. In fig. 2 the ratio of the molecular weights of equiviscous paraffin and the investigated substance is plotted versus temperature. The line for stearic acid, beginning near the melting point with a value not far from 2, slopes down to 1.4 at 300°C. Even at 300°C many double molecules are present. In fig. 3 the viscosity-temperature curve of stearic acid and the curves of some other acids [7] [10]

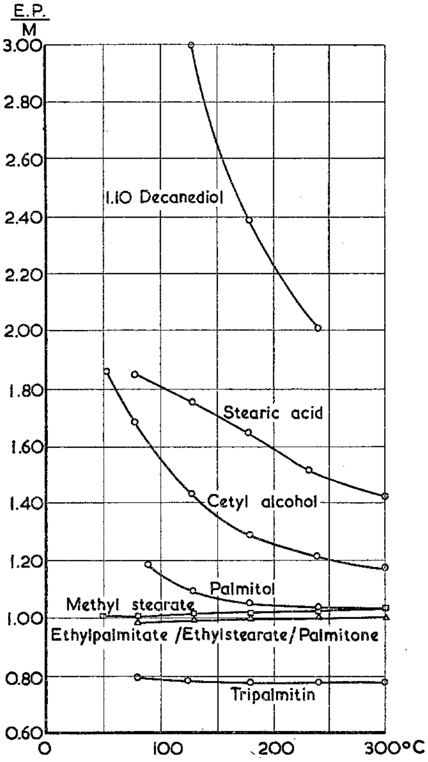


Fig. 2.

have been drawn in a graph together with the curves of the normal paraffins $C_7 H_{16}$ to $C_{43}H_{88}$. The values for the smaller paraffins have been taken from Evans' table, the values for *n.*-hexadecane and higher compounds were found by interpolation between the values of the four normal paraffins investigated earlier.

Cetyl alcohol and 1.10 decane-diol also have high viscosities. The

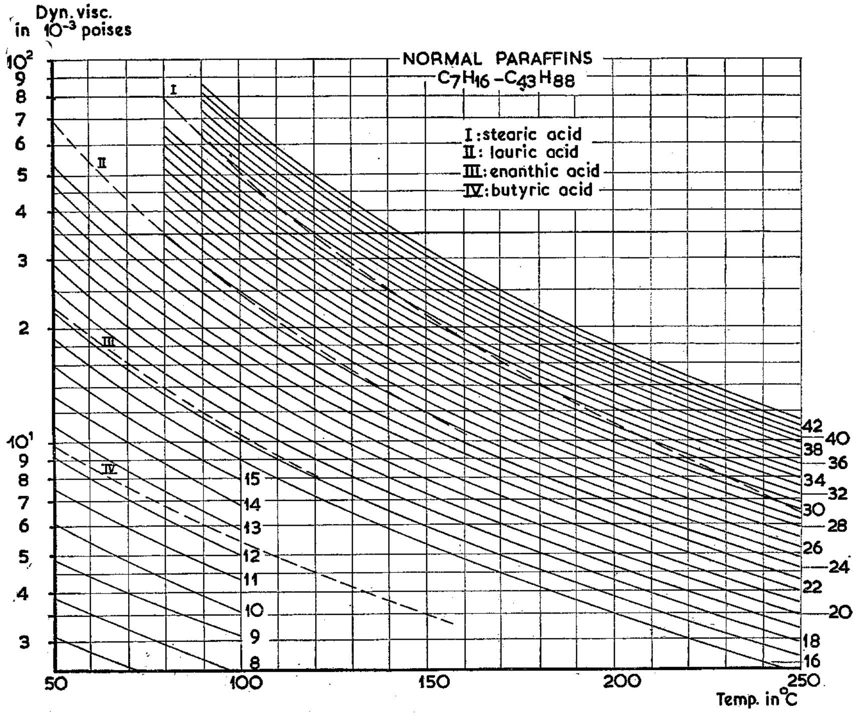


Fig. 3.

influence of temperature on the association is greater than in the case of the acid, as may be seen in fig. 2. The viscosity of palmitol is not much higher than that of a paraffin of the same molecular weight Association will be less than in the case of the normal alcohols. Moreover, when association occurs, the influence on viscosity is less, as the result of association in the case of palmitol is a branched structure and not a chain of greater length. Fig. 4 illustrates how the viscosity-temperature curves of those and other alcohols 11) 12) 13) intersect the curves of the normal paraffins.

The cyclic hydrocarbons in table IV include twelve aromatic and seven naphthenic hydrocarbons. The viscosity-temperature curves of *p*.-dicetylbenzene, octadecylbenzene and some other alkylbenzenes [1]) have been drawn in fig. 5, while the curves in fig. 6 represent hydrocarbons with two or more aromatic rings. Several of the aromatic hydrocarbons have viscosity-temperature curves that are slightly flatter than those of the normal paraffins at high temperatures and steeper at low temperatures. It is thus obvious that it is impossible to make a division along viscosity and temperature axes of a graph in such a way that the curves of these aromatic hydrocarbons as well as those of the normal paraffins become straight lines.

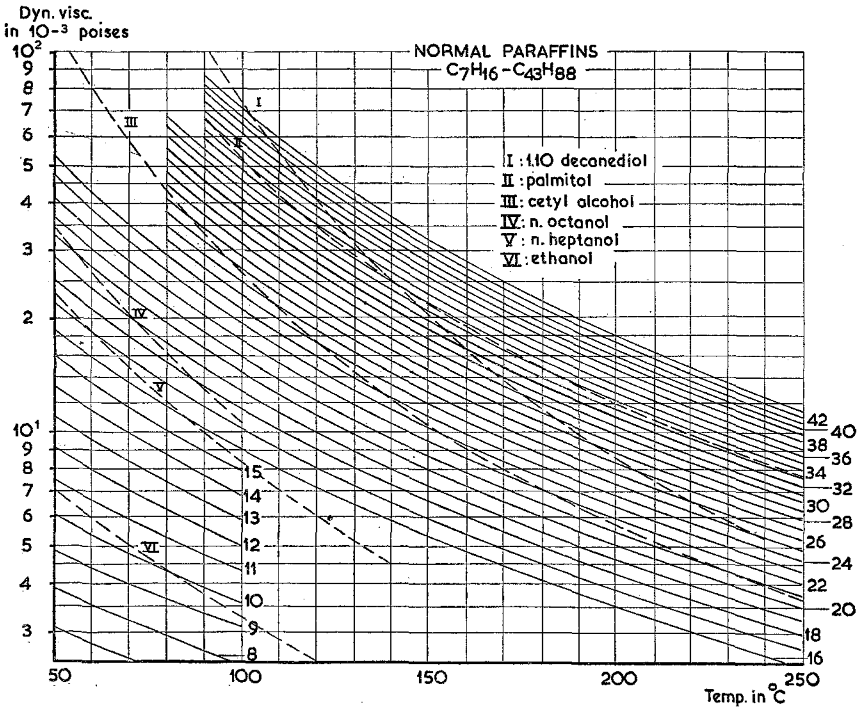


Fig. 4.

The aromatics octadecylbenzene, 1,6-di-phenylhexane, 1,10-diphenyldecane and 4-hexadecylbiphenyl are less viscous than the corresponding hydrogenated forms. This is in agreement with nearly all the data on pure aromatic and pure naphthenic hydrocarbons. In the case of mineral oil fractions a viscosity increase on hydrogenation has been observed in a number of cases, although hydrogenation more often results in lower viscosity. Aromatics showing viscosity decrease when hydrogenated are therefore of special interest. Our tables show three examples: trimethyl-benzene, 1,2-di (2,4,6-trimethylphenyl) ethane and phenanthrene. Results obtained by Schiessler et al. show an identical picture in the case of compounds containing anthracene or phenanthrene rings.

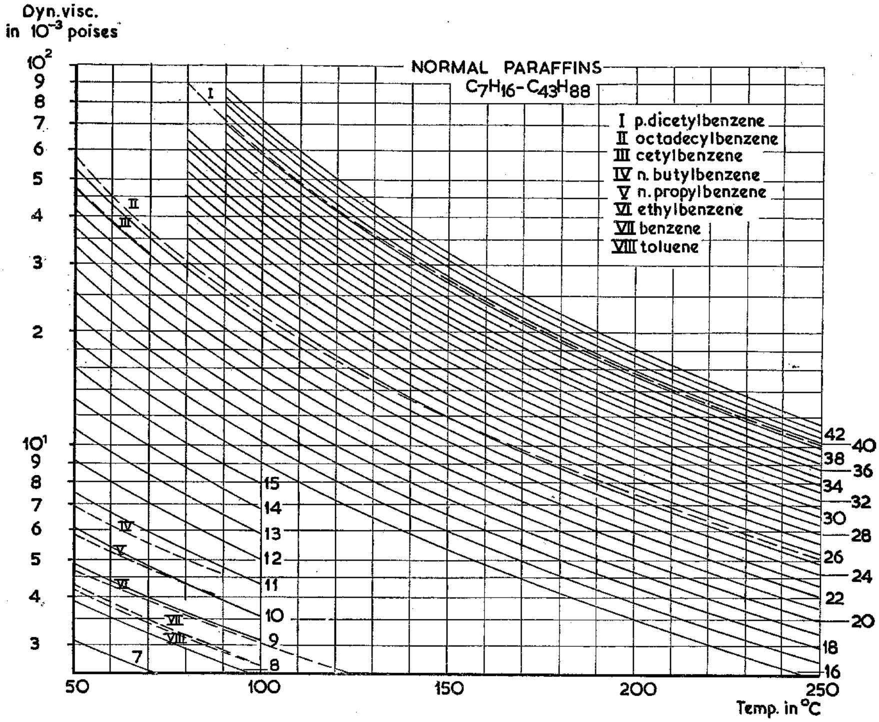


Fig. 5.

Hydrocarbons consisting of phenyl, biphenyl or naphthyl with a chain of some length have a rather flat viscosity-temperature curve, as is evident from this and preceding work. The lower part of table IV shows that the curve remains flat when ether oxygen is introduced. When instead of oxygen the heavier sulphur is introduced, the curve may even become flatter. The viscosity of phenylhexadecylthioether is less temperature-dependent than that of octadecylbenzene with nearly the same molecular weight.

The introduction of iodine in a straight chain also may result in a flat viscosity-temperature curve, as in the case of 1,6-diiodohexane. This only holds for the dynamic viscosity, the kinematic viscosity being susceptible to greater changes with temperature than in the case of the *n.*-paraffins of about the same kinematic viscosity.

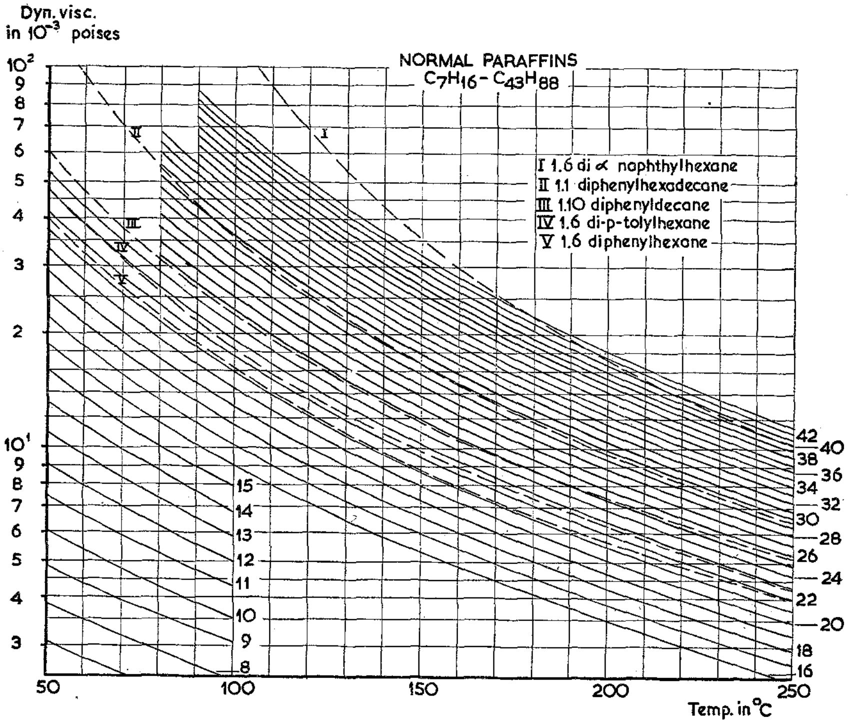


Fig. 6.

§ 5. *Preparation of the organic compounds investigated.*

1.10-Decane diol $CH_2OH(CH_2)_8CH_2OH$. Sebacic diethyl ester was hydrogenated at 250°C in the presence of Adkins catalyst and purified by vacuum distillation. Melting point: 70.1–71.2°C. Boiling point at 4 millibars: 152.9°C.

Cetyl alcohol $CH_3(CH_2)_{14}CH_2OH$. Ethyl palmitate was hydrogenated in the presence of Adkins catalyst at 250°C. The alcohol was purified by converting into the acetate, which was rectified and afterwards saponified. The alcohol was crystallized from ethanol. Melting point: 49.5–49.7°C.

Stearic acid $CH_3(CH_2)_{16}COOH$. The stearate fraction, obtained on rectifying a mixture of methyl palmitate and stearate, was saponified. The potassium salt was crystallized from 50% ethanol. Stearic acid was liberated from the potassium salt with hydrochloric acid. Crystallized from methyl ethyl ketone. Melting point: 69.2–69.4°C. Boiling point at 4 millibars: 203.4°C.

Ethyl palmitate $CH_3(CH_2)_{14}COOC_2H_5$. Prepared by esterifying pure palmitic acid with ethyl alcohol in the presence of concentrated sulphuric acid. Purified by crystallization from ethanol. Boiling point at 4 millibars: 164.5°C.

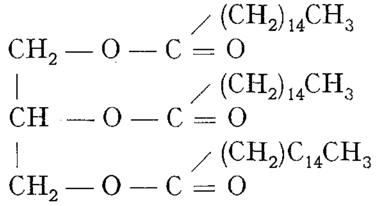
Methyl stearate $CH_3(CH_2)_{16}COOCH_3$. Pure stearic acid was esterified with methyl alcohol in the presence of concentrated sulphuric acid. Purified by crystallization from methanol. Melting point: 38.7–39.1°C. Boiling point at 4 millibars: 178.7°C.

Ethyl stearate $CH_3(CH_2)_{16}COOC_2H_5$. Prepared by esterifying pure stearic acid with ethyl alcohol in the presence of concentrated sulphuric acid. Purified by crystallization from ethanol. Melting point: 33.7°C. Boiling point at 4 millibars: 184.7°C.

Palmitone $CH_3(CH_2)_{14}CO(CH_2)_{14}CH_3$. This ketone was prepared by heating pure palmitic acid with iron turnings at 300°C (according to Grün. Z. angew. Chem. **39** (1936) 421). Purified by crystallization from methyl ethyl ketone. Melting point: 83.1–83.4°C. Boiling point at 4 millibars: 273.3°C.

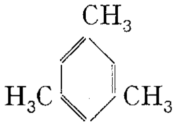
Palmitol $CH_3(CH_2)_{14}CHOH.(CH_2)_{14}CH_3$. This secondary alcohol was prepared by hydrogenating palmitone at 100°C in the presence of nickel on kieselguhr. Purified by crystallization from methyl ethyl ketone and from ethanol. Melting point: 86.5–86.8°C. Boiling point at 4 millibars: 277.8°C.

Tripalmitin



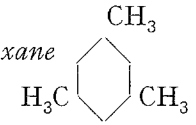
Prepared from anhydrous glycerol and palmityl chloride in the presence of pyridine. Purified by crystallyzing five times from absolute ethanol and twice from toluene. Melting point: 66.1–66.4°C.

1.3.5-Trimethylbenzene



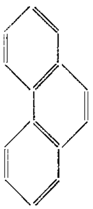
Commercial mesitylene was rectified. Boiling point: 164.4–164.6°C Boiling point at 4 millibars: about 27.9°C.

1.3.5-Trimethylcyclohexane



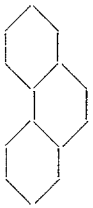
Prepared by hydrogenating pure 1.3.5-trimethylbenzene at 210°C in the presence of nickel on kieselguhr. Purified by rectification. It consists of a mixture of cis and trans isomers. Boiling point: 136–140°C. $n_D^{20} = 1.4280–1.4289$.

Phenanthrene



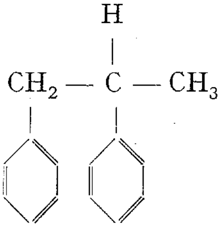
Commercial phenanthrene was purified with chromic acid in glacial acetic acid as described by Bachmann, J. Am. Chem. Soc. **57** (1935) 557. Melting point: 99.6–99.9°C. Boiling point at 4 millibars: 149.1°C.

Perhydrophenanthrene



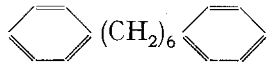
Prepared by hydrogenation of pure phenanthrene at 225°C in the presence of nickel on kieselguhr. Purified by vacuum distillation. $n_D^{20} = 1.5033$. Boiling point at 4 millibars: 107.7°C.

1.2-Diphenylpropane



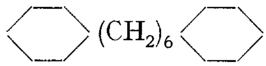
Phenylbenzylketone was converted with methylmagnesiumiodide into methylphenylbenzylcarbinol. This tertiary alcohol was dehydrated by refluxing with glacial acetic acid, containing a small quantity of sulphuric acid. 1.2-diphenylpropene-1 thus obtained was converted into 1.2-diphenylpropane by reduction with sodium in boiling isoamyl alcohol. It was crystallized from acetone at —80°C. Solidification point: +0.1°C, $n_D^{20} = 1.5591$. Boiling point at 4 millibars: 114.7°C.

1.6-Diphenylhexane



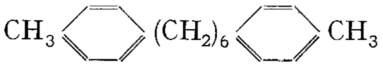
Prepared by reaction of a mixture of 1.6-dibromohexane and bromobenzene with sodium. Purified by vacuum rectification. $n_D^{20} = 1.5406$. Boiling point at 4 millibars: 164.3°C.

1.6-Dicyclohexylhexane



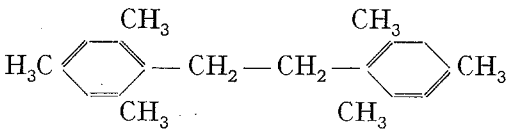
Prepared by hydrogenating 1.6-diphenylhexane in the presence of nickel on kieselguhr at 100°C. Purified by rectification. $n_D^{20} = 1.4754$. Solidification point: 6.9°C. Boiling point at 4 millibars: 158.3°C.

1.6-Di-p-tolylhexane



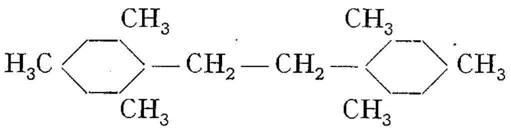
Prepared by allowing a mixture of parabromotoluene and 1.6-dibromohexane to react with sodium. Purified by vacuum distillation and crystallization from pentane. Melting point: 53.8–54.1°C.

1.2-di-(2, 4, 6-trimethylphenyl) ethane



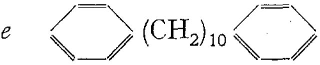
1.3.5-trimethylbenzene was allowed to react with 1.2-dibromoethane in the presence of aluminiumchloride. Purified by distillation and crystallization from ethanol. Melting point: 117.5–117.7°C. Boiling point at 4 millibars: 178.1°C.

1.2-di-(2, 4, 6-trimethylcyclohexyl) ethane



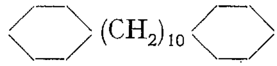
Prepared by hydrogenating 1,2-di(2, 4, 6-trimethylphenyl) ethane at 225°C in the presence of nickel on kieselguhr. Purified by vacuum distillation. It consists of a mixture of cis and transisomers. Boiling point at 4 millibars: 149.9°C.

1.10-diphenyldecane



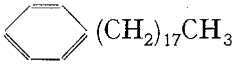
Prepared by allowing a mixture of bromobenzene and 1.10-dibromodecane to react with sodium. Purified by vacuum distillation, followed by crystallization from acetone at —30°C. Solidification point 17.9°C. Boiling point at 4 millibars: 206.2°C.

1.10-dicyclohexyldecane



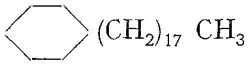
Prepared by hydrogenating 1.10-diphenyldecane in the presence of nickel on kieselguhr at 100°C. Crystallized from benzene-ethanol mixture. Melting point: 33.7–34.0°C. Boiling point at 4 millibars: 202.6°C.

Octadecylbenzene



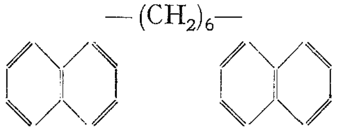
Prepared at the Amsterdam University, see Wibaut, Overhoff and Jonker, Rec. **62** (1943) 31.

Octadecyl cyclohexane



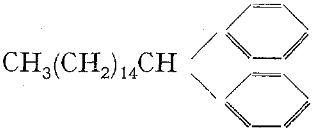
Prepared by reducing stearophenone with aluminium isopropylate to 1-phenyl-octadecanol-1, dehydrating this alcohol with potassium hydrosulphate to 1-phenyl-octadecene-1 and hydrogenating the latter at 150°C in the presence of nickel on kieselguhr. Crystallized from methyl ethylketone. Melting point: 41.5–41.7°C. $n_D^{70} =$ $= 1.4419$.

1.6-Di-α-naphthylhexane



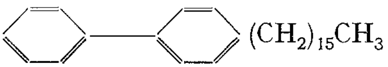
Prepared by reacting a mixture of α-bromonaphthalene and 1.6-dibromohexane with sodium. Isolated from the reaction mixture by vacuum distillation, followed by crystallization from ethanol. Melting point: 86.2–86.6°C.

1.1-diphenylhexadecane



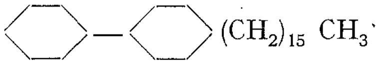
Prepared at the Amsterdam University, see Wibaut, Overhoff and Jonker, Rec. **62** (1943) 31.

4-hexadecylbiphenyl



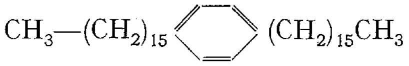
A mixture of biphenyl and palmityl chloride was converted with the aid of aluminium chloride into 4-biphenylpentadecylketone. This ketone was reduced to the secondary alcohol with aluminium isopropylate. The secondary alcohol was dehydrated to 4-biphenylhexadecene-1 by heating with potassium hydrosulphate. Biphenyl hexadecene-1 was converted into 4-hexadecylbiphenyl by hydrogenation at 150°C in the presence of Adkins catalyst. It was crystallized from a mixture of benzene and light petroleum. Melting point: 72.1–72.4°C.

4-hexadecylbicyclohexyl



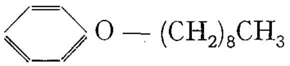
Prepared by hydrogenating 4-hexadecylbiphenyl at 150°C in the presence of nickel on kieselguhr. It was crystallized from methylethylketone. Melting range: 38.4–41.4°C (A mixture of cis and trans isomers). Boiling point at 4 millibars: 255.4°C.

p-dicetylbenzene



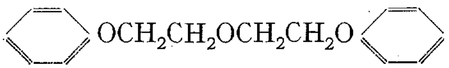
Prepared at the Amsterdam University, see Wibaut, Overhoff and Jonker, Rec. **62** (1943) 31.

Phenylnonylether



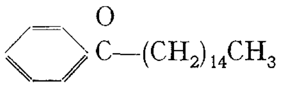
Prepared by reacting *n*-nonylbromide with sodium phenolate in alcoholic solution. Crystallized from ethanol at 0°C. Solidification point: 12.9°C.

ββ'-diphenoxy-diethyl ether



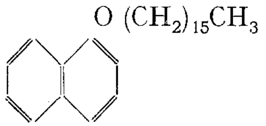
Prepared by reaction of ββ'-dichlorodiethyl ether with sodium phenolate in isoamyl alcohol. Crystallized from ethanol. Melting point: 65,8–66.2°C. Boiling point at 4 millibars: 188.5°C.

Palmitophenone



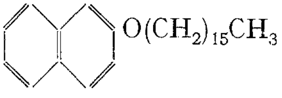
Prepared by allowing palmityl chloride and benzene to react in the presence of aluminium chloride. Crystallized from ethanol. Melting point: 58.8–59.2°C.

α-naphthyl cetyl ether



Prepared by allowing cetyl bromide to react with sodium α-naphtholate in alcoholic solution. Crystallized from ethanol. Melting point: 43.9–44.1°C. Boiling point at 4 millibars: 255.1°C.

β-naphthyl cetyl ether

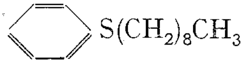


Prepared by reacting cetyl bromide with sodium β-naphtholate in alcoholic solution. Crystallized from ethanol. Melting point: 60.5–60.8°C. Boiling point at 4 millibars: 257.9°C.

Hydroquinone bis-dodecyl ether

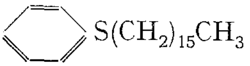
Prepared by reacting dodecylbromide with the disodium compound of hydroquinone in alcoholic solution. It was crystallized from ethanol. Melting point: 74.3–74.6°C. Boiling point at 4 millibars: 279.9°C.

Phenyl nonyl thioether



Prepared by reacting *n*-nonylbromide with sodium thiophenolate in alcoholic solution. Crystallized from ethanol at 0°C. Melting point: 21.4–21.9°C.

Phenyl cetyl thioether



Prepared by reacting cetylbromide with sodium thiophenolate in alcoholic solution. Crystallized from a mixture of acetone and ethanol. Melting point: 49.0–49.4°C.

1.6-diiodohexane $I(C_2H)_6I$. Prepared by letting hexane diol-1.6 react with iodine and red phosphorus. Purified by vacuum distillation. Solidification point: 9.45°C. Boiling point at 4 millibars: 120.2°C.

Acknowledgement. The authors wish to express their gratitude to the management of the N.V. De Bataafsche Petroleum

Maatschappij for their permission to publish the results of this work.

Our thanks are due to Miss L. Toneman and Mr. P. de Klerk for their assistance in measuring and preparing the compounds.

Received, 9th February 1950

REFERENCES

1) Evans, E. B., J. Inst. Petr. Techn. **24** (1938) 38, 321, 537.
2) Klos, S., E. Neyman-Pilat and S. Pilat, J. appl. Chem. (U.S.S.R.) **13** (1940) 1369.
3) Cosby, J. H., and L. H. Sutherland, Proc. A.P.I. III **22** (1941) 13; Schliessler, R. W., J. H. Cosby, D. G. Clarke, C. S. Rowland, W. S. Sloatman, and C. H. Herr, Proc. A.P.I. III **23** (1942) 15; Schliessler, R. W., D. G. Clarke, C. S. Rowland, W. S. Sloatman, and C. H. Herr, Proc. A. P. I. III **24** (1943) 49.
Schliessler, R. W., C. H. Herr, A. W. Rytina, C. A. Weisel, F. Fischl, R. L. Mc Laughlin, and H. H. Kuehner, Proc. A.P.I. III **26** (1946) 254.
4) Bingham, E. C., and R. A. Stephens, Physics **4** (1933) 206.
5) Joglekar, R. B., and H. E. Watson, J. Soc. chem. Ind. **47** (1928) 365.
6) Bried, E. M., H. F. Kidda, C. M. Murphy, and W. A. Zisman, Ind. eng. Chem. **39**, (1947) 484.
7) Bingham, E. C., and H. J. Fornwalt, J. Rheology **1** (1930) 372.
8) Nederbragt, G. W., and J. W. M. Boelhouwer, Physica **13** (1947) 305.
9) Kramers, H. A., Physica **11** (1944) 1.
10) Thorpe, T. E., and I. W. Rodger, Phil. Trans. roy. Soc. **185** A (1894) 397.
11) Bingham, E. C., and L. C. Darrall, J. Rheology **1** (1930) 174.
12) Bingham, E. C., and H. J. Fornwalt, Phys. Rev. **36** (1930) 381.
13) Titani, T., Bull. chem. Soc. Japan **2** (1927) 95.