NCLOSURE (B) 27

STUDIES ON THE OILINESS CHARACTERISTICS OF PURE HYDROCARBONS BASED ON STATIC FRICTION DETERMINATIONS FOR STEEL ON STEEL

by

CHEM. ENG. COMDR. DR. I. KAGEHIRA

CHEM. ENG. LIEUT. M. HIRATA

Research Period: 1944

Prepared for and Reviewed with Authors
by U. S. Naval Technical Mission to Japan

December 1945

ENCLOSURE (B)27

LIST OF TABLES AND ILLUSTRATIONS

ENCLOSURE (B)27

SUMMARY

The oiliness of various cyclic hydrocarbons and a few chain hydrocarbons were measured and the following results were obtained.

1. If aromatic hydrocarbons are hydrogenated step by step, the oiliness of the compounds becomes first poorer and then better.

2. Qualitative correlations seem to exist between the oiliness of the compounds and their molecular volumes and molecular cohesion, i.e., melting point, boiling point, viscosity, etc.

3. The compounds in which the benzene nuclei are combined by single bonds were better lubricants than these having the benzene nuclei combined in condensed form.

4. The oiliness of a cyclic compound was better than that of a chain compound having the same number of carbon atoms.

I. INTRODUCTION

It has been reported in the literature that paraffinic hydrocarbons have better oiliness characteristics than naphthenes (Ref. 1.), and that in the case of straight chain hydrocarbons the oiliness improves as the molecular weight increases (Ref. 2), and that chain hydrocarbons are better lubricants than cyclic compounds (Ref. 3), but almost no systematic studies on the oiliness of pure cyclic hydrocarbons have been published. The molecules of mineral lubricants are said to have a cyclic structure with side chains of various lengths, and a systematic study of the oiliness of the pure cyclic hydrocarbons is important in this branch of the investigation of lubricants.

II. DETAILED DESCRIPTION

Studies on these problems were conducted during 1944.

A. Test Procedure and Samples Used in the Test

1. Test Apparatus. The three test pieces of the Dooley machine were changed and three steel balls (dia. ¼ inch) were substituted. The test plate was made of cast steel.

2. Preparation of the Test Plate and the Test Pieces. The test pieces and the test plate were first washed with pure petroleum ether and ethylether, polished with 0.5 emery paper, and then washed with distilled water.

They were next purified by means of electrolytic reduction, applying 20 mA. current, for 30 minutes in a 2% NaOH solution using a carbon anode. Thus treated, the test plate and pieces were washed with water and alcohol, and dried in vacuum.

The oil test sample was rubbed on the surface with a piece of filter paper, and measurement was made 30 minutes after the test pieces were wetted with the oil.

3. Test Procedure. Static coefficients of friction of various

ENCLOSURE (B)27

pure hydrocarbon oils, alone and in 5% benzene solution, were measured at room temperature or at temperatures higher than their melting points.

4. Compounds Used for the Test. Marketed samples of benzene, cyclohexane, naphthalene, tetralin, decalin, and anthracene were purified and used in the test.

Diphenyl and diphenyl benzene were prepared through the thermal condensation of benzene (Ref. 4), and the hydrogenation products of diphenyl, anthracene, and diphenyl benzene were prepared by high pressure hydrogenation (Ref. 5).

The compounds used and their characteristic properties are summarized in Table I(B)27.

B. Results

The results are summarized in Table II(B)27 and are represented graphically in Figure 1(B)27.

1. The substances which had better oiliness were also better oiliness compounds in a benzene solution containing 95% by volume of benzene.

2. Benzene Series:- Benzene, cyclohexane. Cyclohexane had better oiliness than benzene as already reported (Ref. 6).

3. Naphthalene Series:- Naphthalene, tetralin, decalin. Contrary to the case of the benzene series, naphthalene had better oiliness than tetralin. Such results may be due to the greater molecular cohesion of naphthalene. In the case of the benzene series, benzene has a greater molecular cohesion than cyclohexane, but the former had poorer oiliness, and such results are attributed to the smaller molecular volume of benzene. Decalin, however, had better oiliness than tetralin. This is similar to the relationship between cyclohexane and benzene. In brief, if naphthalene is hydrogenated step by step, its oiliness becomes first poorer and then better.

4. Other Series

a. Diphenyl Series:- Diphenyl, phenylcyclohexane, dicyclohexyl.

b. Anthracene Series:- Anthracene, tetrahydroanthracene, decahydroanthracene, perhydroanthracene.

c. Diphenyl Benzene Series:- Diphenyl benzene, perhydrodiphenyl benzene.

The change of oiliness resulting from stepwise hydrogenation of these other compounds gave results which resembled those of the naphthalene series.

5. General Remarks on the Above Results

a. From the above results, it may be said that, in general, if aromatic hydrocarbons are hydrogenated step by step, the oiliness of the compounds becomes poorer at first and then improves when hydrogenation is complete. Also, qualitative correlations seem to exist between the oiliness of the compounds and their molecular volumes and molecular cohesion, i.e. melting point, boiling point, viscosity, etc. Such relations are given in Figures 1(B)27 and 2(B)27.

b. The oiliness of the hydrocarbons becomes gradually better in the following order:

Benzene series → Naphthalene series → Diphenyl series
Anthracene series → Diphenyl benzene series.

c. The compounds having the benzene nuclei combined with single bonds were better lu.ricants than the compounds having the same number of nuclei combined in condensed form.

6. Comparison With Chain Compounds. The oiliness of n-hexane, i-hexane, and n-octadecane were measured and the results were compared with those of cyclic compounds having the same number of carbon atoms.

The characteristics of the compounds and the results are given in Table III(B)27 and Figure 3(B)27.

It appears that the oiliness of a cyclic compound is better than that of a chain compound having the same number of carbon atoms.

III. CONCLUSIONS

From the above results, it was concluded that naphthalene, diphenyl, anthracene, diphenyl benzene, perhydrodiphenyl benzene had good oiliness characteristics, and of these, completely hydrogenated diphenyl benzene was the best.

References

1. Kadmer, Schmierstoffe und Maschinenschmierung, 313 (1940)
   Finch, Congress d. Inst. Mech. Eng., Oct. (1937)
2. Hardy, Proc. Roy. Soc., A 101, 561 (1922)
   J. Chem. Soc., 77, 1219 (1925)
3. AKAMATSU, Bl. Chem. Soc. Japan, 9, 288 (1940)
4. Schmidt, Ann., 203, 118 (1880)
5. KAGEHIRA, Report of the Imperial Naval Fuel Depot, No. 128, June (1938)
6. cf. (3)

ENCLOSURE (B)27

Table I (B)27
PROPERTIES OF THE RELATED COMPOUNDS

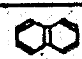
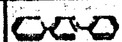
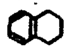
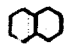
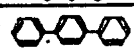
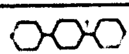
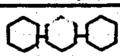
Group	Compounds	Molecular Structure	M. P. Obs.	M. P. Lit.	B. P. Obs.	B. P. Lit.	Elementary Analysis C Obs.	C Cal.	H Obs.	H Cal.
Benzene Series	Benzene		5.4	5.5	79-80	79.6				
	Cyclohexane		4.5	4.5	80-81	80.7				
Naphthalene Series	Naphthalene		79-80	80	217-219	218				
	Tetralin		liq.	-31	204-200	206				
	Decalin		liq.	-125	188-193	189-191				
Diphenyl Series	Diphenyl		69-70	68.5-69.5	-	248-249				
	Phenylcyclohexane		liq.	7	234-236	234-236				
	Dicyclohexyl		liq.	4	229-235	225-233				
Anthracene Series	Anthracene		217-218	217-218	-	351-342				
	Tetrahydro-anthracene		104.5-107	103-105	-	309-313	92.86	92.26	6.76	7.74
	Octahydro-anthracene		39	73-79	-	292-295	89.31	90.25	9.63	9.75
	Perhydro-anthracene		liq.	liq.	-	270 272-277	86.42	87.41	13.26	12.59
Diphenyl-benzene Series	Diphenyl benzene		211.5-212	212-213	-	253	-	-	-	-
	Perhydro diphenyl benzene		160-161.5	162-163	-	-	85.32	87.03	12.36	12.97

Table II(B)27
STATIC FRICTION COEFFICIENTS AND OTHER PROPERTIES

Compounds	Molecular Structures	Percentages of Compounds 100% Static C.F.	100% Temp. (°C)	5% Solution in benzene Static C.F.	5% Solution in benzene Temp. (°C)	1/M.W.	1/M.P. (°C)	1/Vis. (Poise) of 5 mol solution in benzene
Benzene		0.170	13	0.168	22	0.0127	0.00358	164.5
Cyclohexane		0.153	13	0.160	22.5	0.0118	0.00358	168.1
Naphthalene		0.144	90	0.147	22.5	0.00980	0.00272	140.5
Tetralin		0.159	90	0.159	24.2	0.00956	0.00413	145.1
Decalin		0.154	90	0.153	23.2	0.00723	0.00676	148.5
Diphenyl		0.134	75	0.152	25.2	0.00649	0.00292	132.0
Phenylcyclohexane		0.149	14	0.155	22.8	0.00625	0.00357	138.9
Dicyclohexyl		0.156	75	0.153	23.0	0.00601	0.00361	141.1
Anthracene		0.121	230	0.129	17.8	0.00561	0.00204	—
Tetrahydro-anthracene		0.135	105	0.153	18	0.00557	0.00204	122.1
Decahydro-anthracene		0.139	105	0.156	9.8	0.00536	0.00302	123.9
Perhydro-anthracene		0.142	105	0.162	27.8	0.00520	0.00370	129.9
Diphenyl benzene		0.122	160	0.141	23.5	0.00442	0.00206	—
Perhydro diphenyl benzene		0.104	170	0.128	25.2	0.00403	0.00230	105.2

ENCLOSURE (B)27

Table III(B)27
COMPARISON OF OILINESS OF CHAIN AND CYCLIC COMPOUNDS

Name	Chemical Structure	Density (d_4^{20})	M.P. (°C)	B.P. (°C)	Static Coef.*	Temp. (°C)
n-Hexane	$CH_3(CH_2)_4CH_3$	0.6592		68-70	0.161	12.8
i-Hexane		0.6630		57-59	0.160	12.6
Cyclohexane		0.7783		79-81	0.153	13.0
n-Octadecane	$CH_3(CH_2)_{16}CH_3$		28	158-162 15.5mm	0.132	45.0
Perhydrodiphenyl benzene			160-161		0.104	170

*By modified Deeley machine. Steel ball on steel plate.

ENCLOSURE (B)27

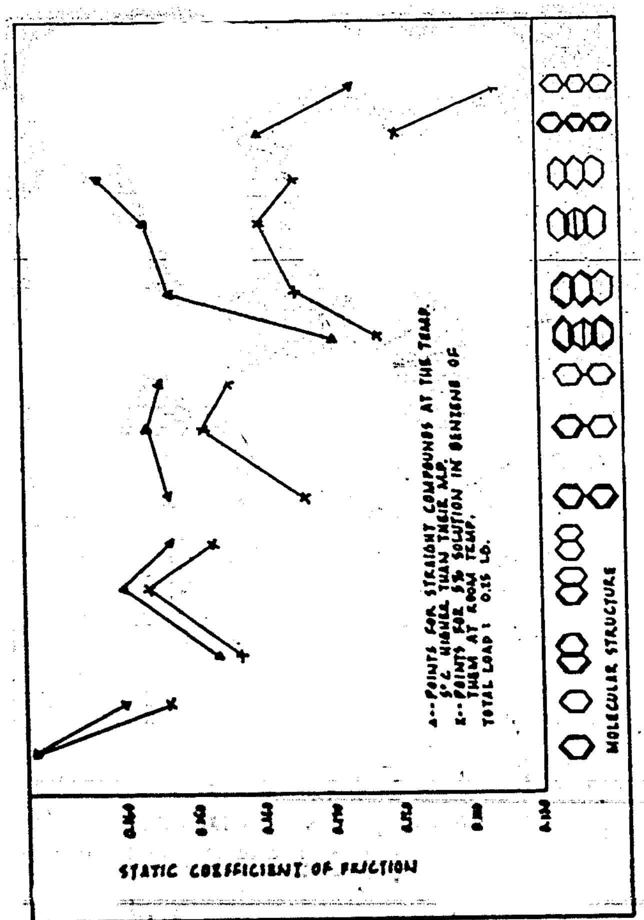


Figure 1(B)27

STATIC COEFFICIENT OF FRICTION BY MODIFIED DEELEY MACHINE

(Point Contact, Steel on Steel)

ENCLOSURE (B)27

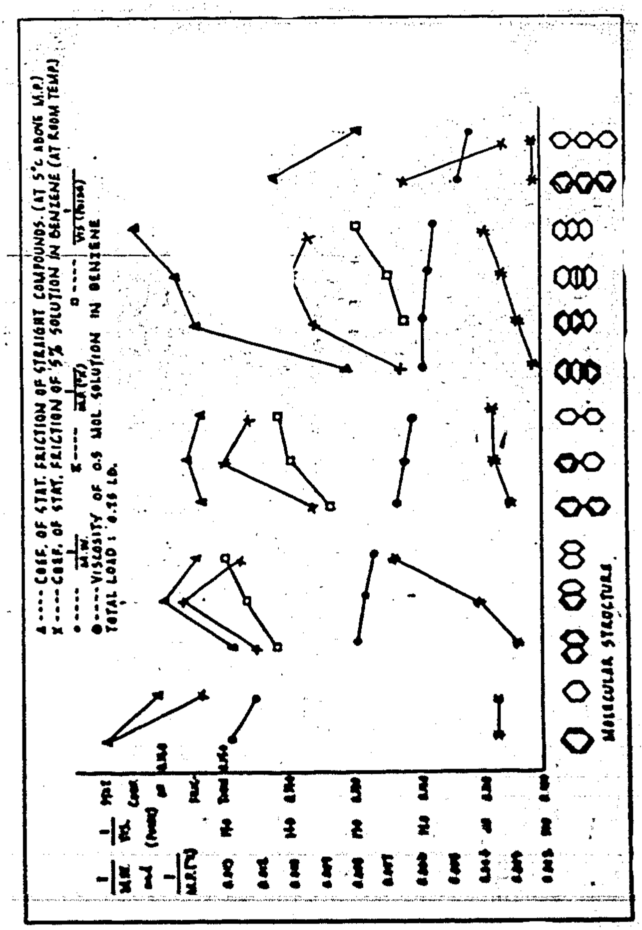


Figure 2(B)27

CORRELATION OF THE STATIC COEFFICIENTS OF FRICTION BY DEELEY (MODIFIED) MACHINE

(Point contact, steel on steel--with the molecular weight and viscosity of the compounds).

ENCLOSURE (B)27

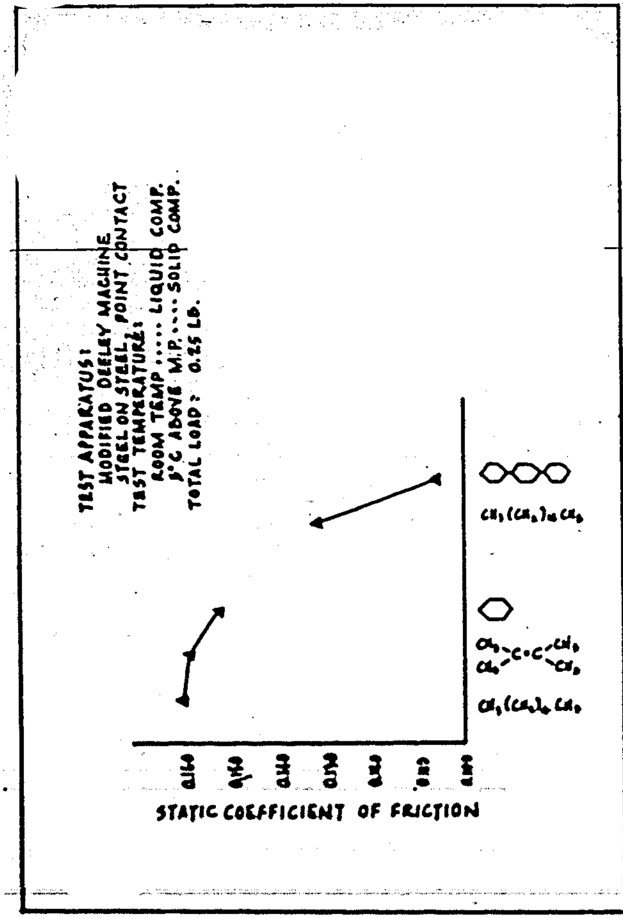


Figure 3(B)27

COMPARISON OF CHAIN COMPOUNDS WITH CYCLIC COMPOUNDS

(Static Coefficient of Friction)