Studies on the Oiliness of Liquids. VIII. Measurements of the Static Friction Coefficients for Silver Surfaces.

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The measurements of the coefficients of static friction of some pure chemical compounds as well as mixtures for glass surfaces were described in the preceding papers.[1] In the complete or film lubrication the surfaces are entirely separated by a thick film of lubricant and the friction depends only upon the nature of the lubricating liquid. It seems that the nature of surface material has no or little effect in this case. In boundary lubrication, however, the surfaces are in contact except for thin film which may be thick by only one molecule layer and the effect of the nature of the solid material can hardly be overlooked. It is important to measure the static friction coefficients with the surfaces of different materials. In the present paper, the measurement of the static friction coefficient for silver surfaces is described. The friction surfaces used consisted of a silver plate and a silver slider with convex spherical surface.

The experiments were pursued by the balance method. The cleanliness of the surfaces is of the utmost importance for the measurements of the static friction coefficients. The surfaces are cleaned in the following manner before each observation. The silver plate and the slider are polished with *rouge*-paper on a grinder, then with cloth and at last with leather or flannel to remove any scratches on the surfaces as completely as possible. After polishing, the surfaces are cleaned by electrolysis. A mixture of equal volumes of 1% aqueous solution of caustic soda and alcohol is taken as the electrolytic solution. The electrolytic cell consists of a platinum anode and a silver cathode. Electrolysis is conducted at 6 volts and less than 0.2 amp., for 30~60 minutes. After this treatment, the silver plate and the slider are rinsed with distilled water and then with drains of distilling alcohol and dried in a desiccator by passing a current of dry air. The silver surfaces cleaned by such a procedure are readily wetted with water and the friction coefficient of the surfaces with no lubricant is very high and fairly concordant in every experiment. It is a somewhat difficult matter to determine the cleanliness of the surface of silver. The friction coefficient itself is a very good criterion. The clean surfaces stick strongly and show a high friction coefficient. At first, the static friction coefficient of silver with no lubricant was determined. The results are shown in Table 1.

For the measurements of static friction coefficients of organic liquids, the friction coefficient of silver with no lubricant is measured prior to each experiment. If the value of the friction coefficient of silver surfaces

(1) Sameshima, Kidokoro and Akamatsu, this Bulletins, **11** (1936), 659; Akamatu and Sameshima, *ibid.*, **11** (1936), 791; Sameshima and Tsubuku *ibid.*, **12** (1937), 127; Akamatu, *ibid.*, **13** (1938), 127; Isemura, *ibid.*, **14** (1939), 270.

is larger than 0.9, it was assumed that the surfaces are clean. The further measurements were conducted with these clean surfaces.

Table 1.

	W	F	μ
No lubricant	9.10	9.36	1.03
	10.30	10.78	1.05
	14.10	14.02	1.00
	14.90	17.02	1.14
	19.90	22.55	1.13
	20.20	19.88	0.98
	20.25	19.66	0.97
	20.30	21.92	1.08
	30.25	29.95	0.99
	30.25	31.83	1.05
			1.04

As to the cleaning of the steel surfaces, Hardy[(2)] wrote as follows: "Steel plates and sliders were cleaned by washing with soap and water, rubbing vigorously with the finger tips in a stream of tap water until water wetted the entire surface, rinsing with perfectly dry alcohol and allowing to drain in air." However, when the silver surfaces were washed with soap and rinsed with water, the surfaces entirely repelled water. The surface could not be wetted with water by rubbing the surface with finger tips in the stream of tap water. Probably, the soap molecules are strongly adsorbed by the surface and take orientation on it, the polar group being attached to the surface. These surfaces show very low friction coefficients as shown in Table 2. The greater part of soap is removed rinsing the surfaces with alcohol. It is difficult however, to obtain sufficiently clean surface.

Table 2.

	W	F	μ
Both plate and slider are washed with soap.	30.25	6.80	0.22
	60.25	10.23	0.17
	68.65	11.40	0.17
			0.19
Only plate is washed with soap, clean slider.	30.25	5.13	0.17
	38.65	7.18	0.19
			0.18
Only slider is washed with soap, clean plate.	30.30	10.34	0.34

In the present experiment, the friction coefficients have been measured of water, alcohols, acids, hydrocarbons and esters. The purest samples available were used. Alcohols, acids and esters were distilled prior to each expriment, after sufficient drying with the appropriate drying agents. As already reported in the former paper,[(3)] the aliphatic hydrocarbons such as hexane, contain some unsaturated hydrocarbon as impurities.

(2) Hardy and Doublrday, *Proc. Roy. Soc.* (London), A, **100** (1922), 550.
(3) Akamatu, this Bulletin, **13** (1938), 127.

These impurities cannot be removed merely by distillation. The samples containing these impurities give somewhat lower friction coefficients. So the hydrocarbons used in the present experiment were purified by shaking with fuming sulphuric acid for several days, dried over sodium metal and distilled.

The results obtained are shown in Table 3. The values of friction coefficient against the number of carbon atoms are plotted in Fig. 1 and Fig. 2.

Table 3.

	W	F	μ
Water	18.65	16.50	0.88
	20·25	16.85	0.83
	20.30	18.88	0.93
	30.25	28.40	0.94
	41.90	40.10	0.96
			0.91
Hexane	15.20	15.20	1.00
	18.70	16.92	0.90
	20.20	18.50	0.92
	20.30	19.20	0.95
	23.60	24.25	1.03
			0.96
Heptane	14.10	13.00	0.92
	14.80	13.75	0.93
	17.50	16.75	0.96
	18.20	17.13	0.94
	19.10	18.05	0.95
	22.55	20.55	0.91
			0.94
Octane	14.10	14.28	1.01
	14.90	13.72	0.92
	17.30	17.38	1.00
	17.50	16.90	0.97
	19.90	18.50	0.93
			0.97
Benzene	18.65	17.76	0.95
	20.25	19.13	0.95
	22.70	23.60	1.04
	23.20	22.60	0.95
	23.65	24.10	1.02
	25.65	24.10	0.94
	28.20	26.70	0.95
			0.97
Methyl alcohol	14.10	11.82	0.84
	14.90	13.38	0.90
	18.30	16.50	0.90
	18.30	17.05	0.93
	19.90	17.50	0.88
	23.30	21.73	0.93
			0.90
Ethyl alcohol	18.65	16.05	0.86
	20.25	17.73	0.88
	23.65	20.10	0.85
	28.65	26.43	0.92
	30.25	26.20	0.87
			0.88
n-Propyl alcohol	28.64	22.80	0.80
	30.25	25.68	0.85
	30.25	23.98	0.79
	30.30	27.70	0.91
			0.84
n-Butyl alcohol	18.65	15.11	0.81
	19.10	14.90	0.78
	20.25	14.30	0.71
	20.25	15.68	0.77
	30.25	22 52	0.74
	30.25	22.50	0.74
			0.76
n-Amyl alcohol	20.25	13.23	0.65
	23.65	15.30	0.65
	29.90	20.20	0.68
	30.25	18.35	0.61
			0.65
n-Hexyl alcohol	14.10	9.42	0.67
	14.90	10.00	0.67
	17.50	10.82	0.62
	19.10	12.90	0.68
	22.50	14.48	0.64
			0.66
n-Heptyl alcohol	20.25	11.55	0.57
	28.65	15.92	0.56
	30.30	16.85	0.56
	38.70	21.00	0.54
			0.56
n-Octyl alcohol	19.10	10.69	0.56
	22.50	13.30	0.59
	23.70	11.65	0.49
	30.30	15.52	0.51
	30.30	14.73	0.49
			0.53

Table 3.—(*Concluded*)

	W	F	μ
Acetic acid	14.10	12.98	0.92
	18.65	17.78	0.95
	20.30	17.68	0.87
	28.65	25.70	0.90
	30.30	27.66	0.91
			0.91
Propionic acid	20.25	16.40	0.81
	28.65	23.35	0.82
	30.25	25.78	0.85
	38.65	33.42	0.86
			0.84
Butyric acid	20.25	15.10	0.75
	20.30	13.40	0.66
	30.25	21.12	0.70
	30.30	22.10	0.73
			0.71
Valeric acid	19.90	11.85	0.60
	23.30	13.80	0.59
	28.70	17.90	0.62
	29.90	17.20	0.58
	30.25	17.50	0.58
			0.59
n-Caproic acid	20.25	11.20	0.55
	23.65	12.40	0.52
	28.65	14.81	0.52
	30.25	16.44	0.54
	30.25	17.12	0.57
	38.65	21.20	0.55
			0.54
n-Heptylic acid	20.25	8.74	0.43
	28.65	13.02	0.45
	30.25	12.63	0.42
	38.65	18.10	0.47
	41.85	19.70	0.47
	60.25	25.68	0.43
			0.45
n-Caprylic acid	41.85	13.82	0.33
	60.25	18.60	0.31
	68.65	20.40	0.30
			0.31
n-Nonylic acid	41.85	11.44	0.27
	46 90	12.75	0.27
	51.85	14.45	0.28
	55.30	14.92	0 27
	60.25	16.75	0.28
	68.70	18.14	0.26
			0.27
Oleic acid	30.25	7.02	0.23
	38.65	9.54	0.25
	41.95	9.65	0.23
	46.50	12.30	0.26
	51.95	12.70	0.24
			0.24
Ethyl acetate	10.25	8.84	0.86
	20.25	16.30	0.81
	20.30	16.10	0.79
	30.30	24.80	0.82
			0.82
n-Propyl acetate	20.25	15.55	0.77
	23 65	17.15	0.73
	28.65	20 28	0.71
	30.30	21.88	0.72
	38.65	27.20	0.70
	38.65	28.12	0.73
			0.73
n-Butyl acetate	20.25	14.00	0.69
	28.65	19.70	0.69
	28.70	19.98	0.70
	30.25	20.25	0.67
	38 65	24.44	0.63
			0.68
n-Amyl acetate	20.25	13.50	0.67
	20.25	14.90	0.74
	30.25	18.69	0.62
			0.68
n-Octyl acetate	20.30	12.90	0.64
	20.30	13.13	0.65
	28.65	17.48	0.61
	30.30	19.20	0.63
	38.65	22.40	0.58
			0.62
Ethyl propionate	14.10	11.62	0.82
	17.50	14.22	0.81
	18.30	15.18	0.83
	23.30	19.53	0.84
			0.83
Ethyl butylate	20.25	15.46	0.76
	20.30	15.88	0.78
	30.25	22.90	0.77
			0.77

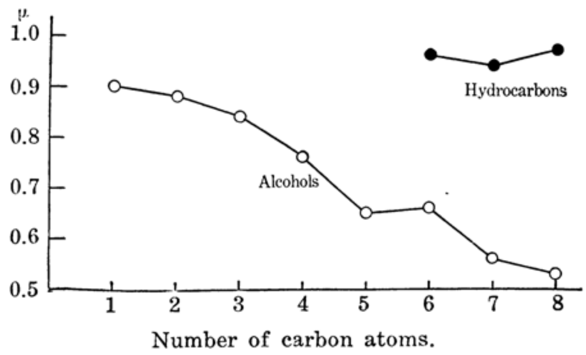

Fig. 1.

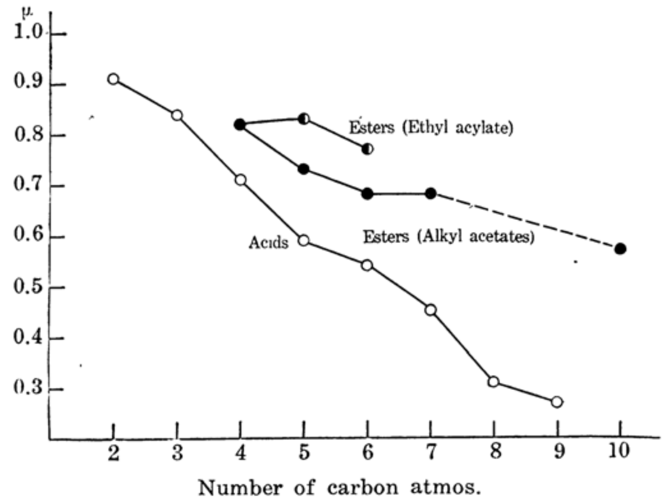

Fig. 2.

Hydrocarbon such as hexane, heptane, octane and benzene give very high friction coefficients. The μ-values are almost the same with the value of clean surface. The lubricating activity is practically nil with these substances. The compounds of low molecular weight such as acetic acid, methyl alcohol, ethyl acetate and water are always poor lubricants irrespective to their species. In the cases of acids, alcohols and esters, the coefficients of friction are diminished as the length of the chains is increased. With lower homologues, there is no appreciable difference between the lubricating activities of acids, alcohols and esters. But with the compounds of fairly long chains acid is most efficient lubricant and alcohol comes next. Ester is most inefficient among the three. The results with alcohols and esters are almost comparable with the results on glass surfaces.[4][5] Regarding to the μ-values of acids, there is a

(4) J. Sameshima, M. Kidokoro and H. Akamatu, this Bulletin, **11** (1936), 659; J. Sameshima and Y. Tsubuku, *ibid.*, **12** (1937), 127.

(5) T. Isemura, *ibid.* **14** (1939), 270.

striking difference between the results obtained on glass surfaces and on silver surfaces. On the glass surfaces, the static friction coefficients of aliphatic acids are nearly constant,[4] while on silver surfaces, they diminish rapidly with the number of carbon atoms in the molecular formulae. For the washing with soap we know that the long chain molecules such as soap adhere to silver surface much better than to glass. The molecules take good orientation on the silver surface. The longer the molecules are, the better the orientation is taken. From these facts the long chain fatty acids serve as good lubricants. The regular arrangement of the molecules on the surface plays an important rôle on the oiliness. The effect of the arrangement of the molecules was already reported in the previous paper.[6] This is probably the reason why the long chain fatty acids shows the low friction coefficients.

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Summary

(1) Measurements of the static friction coefficients have been made to study the oiliness of liquids. The friction surfaces consisted of a silver plate and a silver piece of spherical surface.

(2) The static friction coefficients of water, hydrocarbons, aliphatic alcohols, aliphatic acids and esters have been measured.

(3) The static friction coefficients of these compounds excepting the acids are all comparable with the results obtained for the glass surfaces. The friction coefficients of acids diminish rapidly with the number of carbon atoms in the chain of the molecule for the silver surfaces, while they are nearly constant irrespective to the number of carbon atoms for glass surfaces.

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(6) Akamatu and Sameshima, this Bulletin, **11** (1936), 791.