Electric Charge on Sprayed Oil Droplets 5 (Electrification mechanism of sprayed oil droplets)

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The largest electric charges on sprayed oil droplets of a paraffinic and a naphthenic lubricant and the specific electric conductivities of all lubricants used so far in the measurements of the electric charges on droplets were measured. The result of the electric charges showed no definite difference between the observed largest charges on droplets for both lubricants. The result of the measurements of the specific electric conductivities showed that the largest charge on sprayed oil droplet was larger for the oil with larger electric conductivity.

On the basis of the fact, a hypothesis, the electrification of sprayed oil droplet comes from the fluctuation of ion-density in oil, is proposed.

I. Introduction

In the previous paper[1], it was reported that the most of the electric charge on sprayed oil dtoplet was generated in process of breaking up into droplets. And in the other papers[2)3)], it was reported that the observed largest charge on droplet depends upon the kind of the oil used. For example, the observed largest charges for corvus oil, alcaid oil, SAE 10W with additive and SAE 10W without additive were roughly 7e, 60e, 600e, and 20e, respectively (see Table Ⅱ).

It seems that the difference between the observed largest charges for different lubricant comes from both the additive in lubricant and the chemical structure of lubricant or one of them. Therefore, first, in order to make sure of a definite dependence of the largest charge on droplet on chemical strucsure of oil, electric charges on the droplets having larger charge for a paraffinic and a naphthenic lubricant manufactured by Nippon oil Co. were measured by Millikan's oil drop method. Second, in order to investigate the effect of additive in lubricant on the largest charge on droplet, the specific electric conductivities of the lubricants used so far in the measurements of electric charges on droplets were measured.

II. Experimental

1. Measurement of electric charge on sprayed oil droplet

For a paraffinic and a naphthenic lubricant manufactured by Nippon oil Co., the electric charges on droplets having large charge were measured by using Millikan's oil drop method. The measured values of fall time t_d and rise time t_u of droplet were plotted in t_d-t_u plane and the largest cherge of droplet was estimated roughly in comparison with the theoretical curves represented by following equation:

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$$t_u=\frac{(k/q)\cdot t_d}{(t_d)^{3/2}-k/q}$$

where $$k = 9\sqrt{2}\frac{\pi\eta^{3/2}\cdot \ell^{3/2}}{E(\rho-\rho')^{1/2}\cdot g^{1/2}},$$

η : viscosity of the air (= 1.83×10^{-4} g/cm sec)

ℓ : moved distance of droplet (=0.082cm)

ρ' : density of the air (=0.001g/cc)

g : acceleration of gravity (980cm/sec²)

q : electric charge on droplet in esu

ρ : density of oil (=0.856 g/cc for paraffinic lubricant
=0.916 g/cc for naphthenic lubricant)

E : electric field strength = $\frac{V}{300d}$

where V is the voltage applied to the electrodes and d is the distance between them (=0.636cm).

Table I. Density and viscosity of paraffinic and naphthenic lubricant

	density (g/cc)			viscosity (cp)		
	20°C	30°C	40°C	20°C	30°C	40°C
paraffinic lubricant	0.859	0.852	0.846	70	44	28
naphthenic lubricant	0.919	0.913	0.907	61	38	21

2. Measurement of specific electric conductivity σ of oil

For the measurement of specific electric conductivity of oil, a fixed resistance 50MΩ and two electrodes of 160cm² in area and 0.07cm in distance were connected

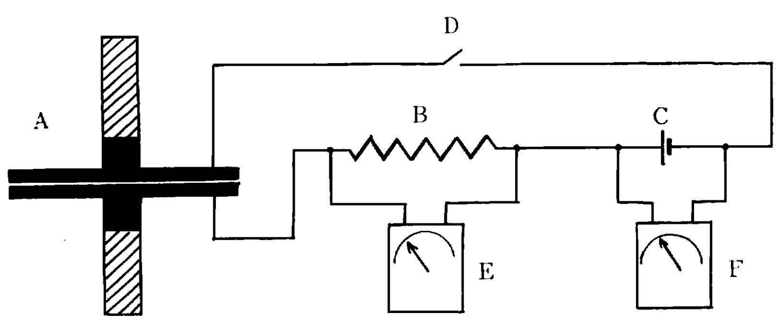

Fig. 1 Electrical circuit for measureing specific electric conductivity of lubricant.
A : electrodes B : 50MΩ resistance C : dry cell
E : valve electrometer F : DC voltmeter

with a dry cell in series (see Fig. 1). And when the space between two electrodes was filled with lubricant and the circuit was closed, the voltage appling to the resistance and the voltage of dry cell were measured by a valve electrometer and a DC voltmeter, respectively. The resistance and the specific electric conductivity of lubriacant were calculated from these voltages (see Table II). The voltage of

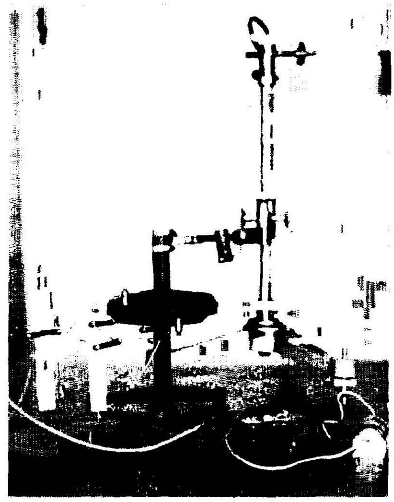

Fig. 2 Electrodes

dry cell was 1.57 V and that appling to the resistance was 0.02 V when they were not filled with any oil. It seemed that the latter was due to the leakage current passed through the insulators attached to the electrodes.

Ⅲ. Results and discussion

The results of the mesurements of large charges on droplets of the paraffinic

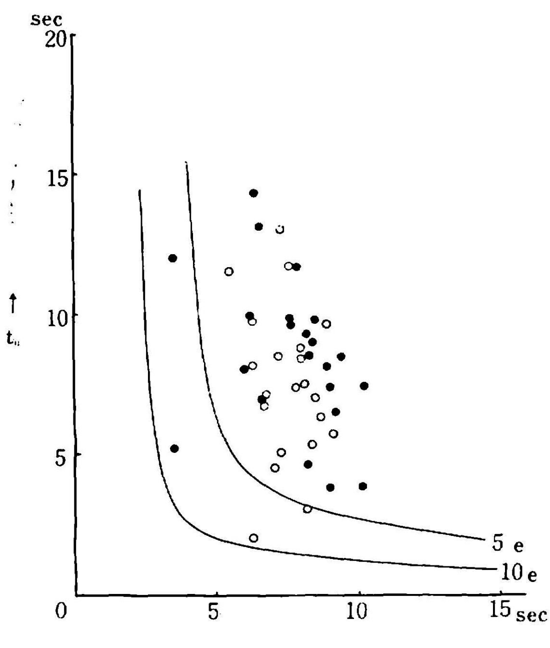

Fig. 3 td and tu of paraffinic lubricant's droplets at 22.3°C and 1000V.

○ : positively charged droplets

● : negatively charged droplets

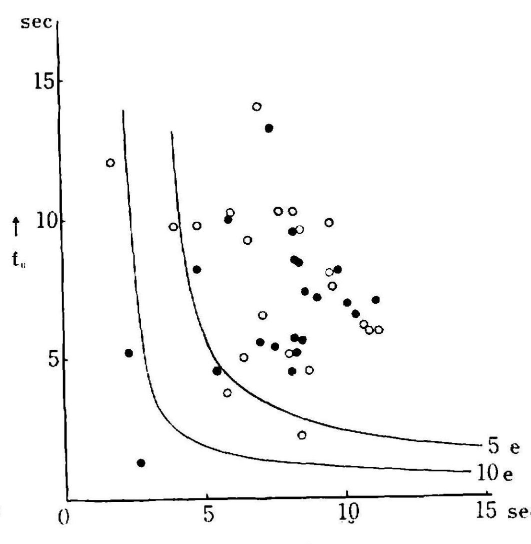

Fig. 4 td and tu of naphthenic lubricant's droplets at 24°C and 1000v.

○ : positively charged droplets

● : negatively charged droplets

and the naphthenie lubricant are shown in Fig. 3 and 4. There is some difference between the largest charges for these two lubricants, but the difference is not so large as the differences between the largest charges of the paraffinic and the naphthenic lurbricant groups which were measured before. The difference might decrease when the number of measured droplets were increased. Therefore, it ts not sure whether the difference depends on the difference in chemical structure of the main constituents of two lubricants or not.

The results of the measurements of specific electric conductivities are shown in Table Ⅱ and Ⅲ. The relation between the specific electric conductivity and

Table Ⅱ. Specific electric conductivity and observed largest charge

	electric resistance (Ω)	specific electric conductivity (℧/cm)	observed largest charge (e)
SAE 10W	3.4×10^{6}	1.3×10^{-10}	600
SAE 20W	6.4×10^{6}	6.8×10^{-11}	450
SAE 30 with additive	1.9×10^{7}	2.2×10^{-11}	400
SAE 40	2.4×10^{7}	1.8×10^{-11}	350
SAE 50	2.3×10^{7}	1.9×10^{-11}	350
SAE 10W, 30, 40 and 50 without additive naphthenic lubricant	7.8×10^{9}	5.6×10^{-14}	20
SAE 20W without additive paraffinic lubricant			10
corvus oil	$>10^{10}$		7
algol oil	9.4×10^{8}	4.7×10^{-13}	60
alcaid oil	1.8×18^{8}	2.5×10^{-12}	80
winter black	6.3×10^{7}	6.9×10^{-12}	80
ursa oil	6.1×10^{8}	7.2×10^{-13}	45

Table Ⅲ. Specific electric conductivity and observed largest charge of the mixed oil made by adding SAE 10W with additive to SAE 10W without additive.

	electric resistance (Ω)	specific electric conductivity (℧/cm)	observed largest charge (e)
0%	7.8×10^{9}	5.6×10^{-11}	20
1%			45
5%	1.4×10^{8}	3.2×10^{-12}	120
10%	5.7×10^{7}	7.6×10^{-12}	160
20%	2.4×10^{7}	1.8×10^{-11}	400
100%	3.4×10^{6}	1.3×10^{-10}	600

the largest electric charge on droplet for every lubricant is shown in Fig. 5. From the figure, it is found that the observed largest charge on droplet is larger for the lubricanat with larger specific electric conductivity with a few exceptions.

The fact suggests that the amount of electric charge on sprayed oil droplet comes from the fluctuation of density of charge-carriers that are contained in lubricant. In order to explain the result of the measurement, the following assumption is proposed :

"There are a large number of positive ions and the same number of negative ions in lubricant and every ion is free from others."

1) Specific electric conductivity of lubricant

As the ion behaves as a charge carrier in lubricant, the conductivity of lubricant will be larger when there are much more ions in the lubticant.

It is found in Table Ⅲ that the conductivity of lubricant is roughly proportional to the amount of additive in lubricant. The fact shows that there are much more ions in the lubricant with additive than in the lubricant without any additive, and the number of ion is roughly proportional to the amount of additive in lubricant.

2) The electrification of oil droplet

Suppose that N ion pairs are distributed in lubricant of V in volume, and every ion is monovalent. If m positive ions and n negative ions are found in a very small volume v in V at the same time, the net electric charge in v will be (m–n)e. The probability that m positive and n negative ions will be found in v at the same time is as follows :

$$P = {}_N C_m \cdot {}_N C_n \cdot [(V - v)/V]^{2N-(m+n)} \cdot (v/V)^{m+n} .$$

The values that must be given to m and n in order to make the charge in v equal to qe are q and 0, q+1 and 1, q+2 and 2, ... N and N−q, respectively. Therefore, the probability that the charge quantity in v is (m−n)e will be as follows :

$$p = \sum_{\substack{m=q \\ n=o}}^{\substack{m=N \\ n=N-q}}{}' \; {}_N C_m \cdot {}_N C_n \cdot [(v-v)/V]^{2N-(m+n)} \cdot (v/V)^{m+n}, \qquad (1)$$

where q = m − n.

Equation (1) shows the followings :

(a) When V, v and N are constant, P increases with decrease of q.

(b) When V ,v and p are constant, q increases with increase of N.

(a) means that the droplet with smaller charge such as e or 2e is more frequently observed than one with larger charge for every lubricant. Practically, more droplets with smaller charge were observed when higher voltage was applied to the electrodes of Millikan's apparatus than the dropets with larger charge when lower voltage was applied. The result of the measurement of the small charge on droplet was reported before.[4)]

(b) means that the quantity of the largest electric charge on droplet for the lubricant with larger electric conductivity is larger than that for the lubricant with smaller conductivity. In order to see whether (b) agrees with the results of the measurement or not, the values of q for various N were calculated by equation (1). In the calculation, $v = 10^{-12}$cc, $p = 5 \times 10^{-5}$ and V = 1 cc were used, because the mean value of the volume of droplets was about 10^{-12}cc, about $10^4 \sim 10^5$ droplets were observed in the measurements of the largest charge on droplet for every lubricant and 1 cc is considered to be large enough volume in which there are same number of positive and negative ions.

The solid curve in Fig. 5 is one of q vs. N and it is drawn in such a way that $N = 10^{14}$ coincides with $\sigma = 6 \times 10^{-13} v/\text{cm}$. Fig. 5 shows that the calculation curve

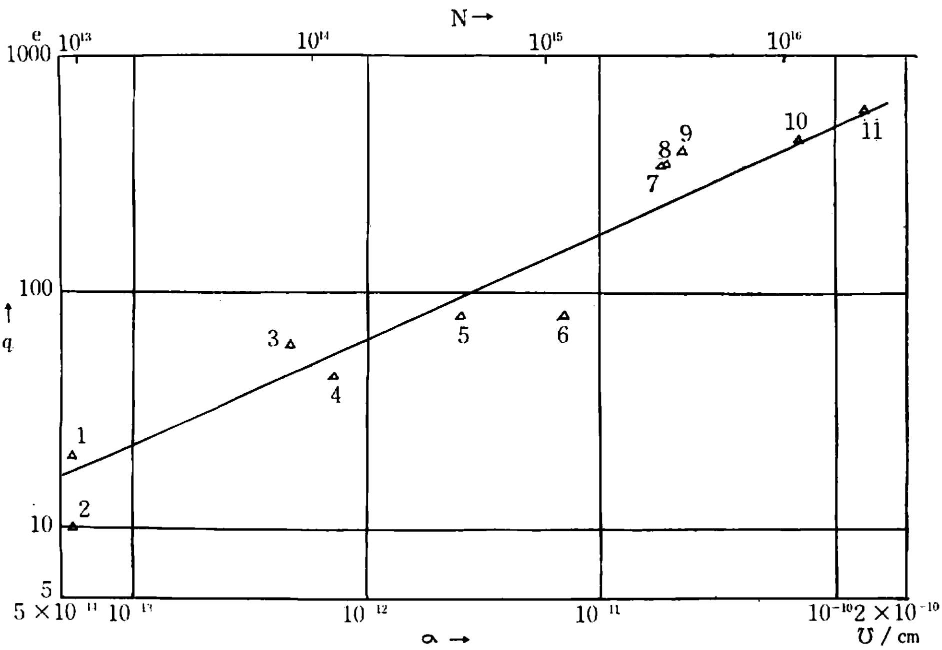

Fig. 5 Specific electric conductivity dependence of the observed largest charge.

1 : SAE 10W, 30, 40 and 50 without additive and naphthenic lubricant
2 : SAE 20w without additive and paraffinic lubricant
3 : algol oil   4 : ursa oil   5 : alcaid oil   6 : winter black oil
7 : SAE 40 with additive   8 : SAE 50 with additive
9 : SAE 30 with additive   10: SAE 20w with additive
11: SAE 10W with additive
Solid curve shows the dependence of calculated largest charge on the number of ion pairs N at the probability 5×10^{-5}.

represents the result of the measurement, that is, (b) agrees with the result of the measurement.

From the above, it is shown that the equation (1) explains the electrification of oil droplet satisfactorily. Therefore, it is concluded that "the electrification of sprayed oil droplet is due to the fluctuation of ion-density in lubricant."

Besides, it is suggested that the hypothesis should be extended to the electrification mechanism of droplet of any kind of liquid, because equation(1)has no restriction that it should be applied to lubricant only.

Reference

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