Impulse Corona on the Surface of Water Solutions

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CONTENTS

I. Introduction

When an impulse voltage is applied between a needle point electrode which is closed to the surface of liquid dielectrics and another plate electrode immersed in the liquid, the surface discharge spreads over the liquid surface from the needle point electrode. The discharge figure is not so clear on the liquid with low conductivity as on the transformer oil, but on water or water solutions with high conductivity a beautiful surface figure is obtained. Some characteristics of the latter discharge and its figure has already been reported by Toriyama and the author.[1] In the present paper the researches that have continually been made since, are described here together with the previous ones.

In general these surface discharges on such electrolytes have been studied after the method of the spectroanalysis of solutions, for the researches of arc on liquid that aims at electric circuit breaker, and for the foundamental researches about discharge on wetted surface, such as a fog-proof porcelain insulator, and so on. But these researches or experimental methods treat of the phenomena at the Direct current and the Alternating current with 50 or 60 cycles, and the author thinks the researches on such a peculiar figure by the impulse voltage have not yet been reported.

(In this report this surface discharge shall be called the "Impulse Corona" from its figure alone.)

2. Discharge Figures and Characteristics of Impulse Corona on the Surface of Water Solutions

(1) The apparatus and method of the experiments

Firstly, the author explains the apparatus and method of this experimental research. As is shown in Fig. 1, $E-G-C-R$ is an impulse generator and $N-W-Q$ is the part of electrodes. Liquid such as water supplied from the waterworks was filled into Q, an iron vessel having 20 cm diameter. This water W was an earth side electrode and a needle N was another electrode. Between them an impulse voltage was applied under the various conditions. The depth of the water was fixed about 1 cm or more.

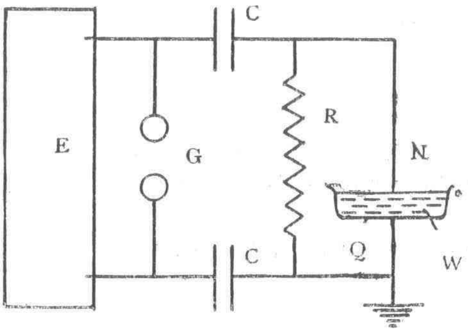
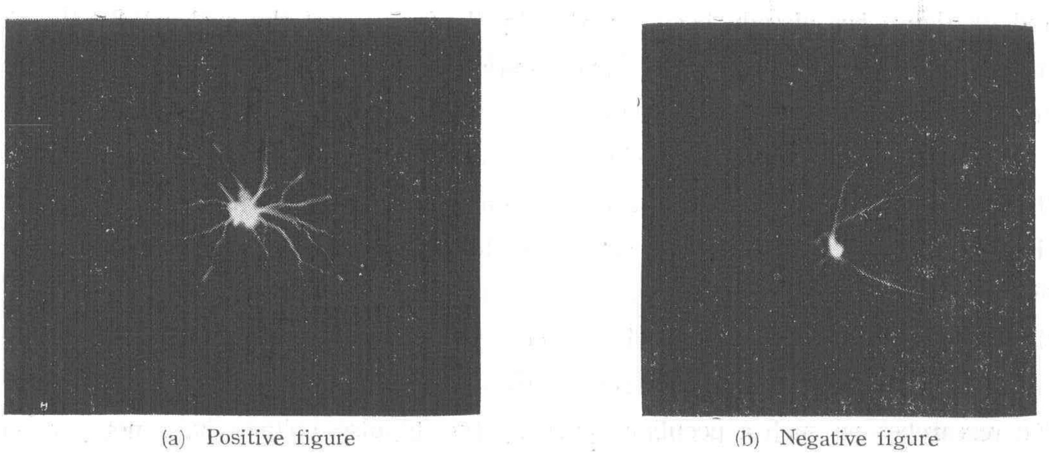


Fig. 1 Apparatus for experiment

In some experiment other thin liquid film, such as gasoline or transformer oil was floated on the water surface, and also in another experiment the vessel Q was put into another enclosed vessel for the research under the low pressure.

(2) The figure of the impulse corona and the difference by its polarity.

when the needle electrode N was contacted to the water surface W (there was no difference when a little distance was kept between N and W) and the positive or negative impulse voltage was impressed between them, the figures were obtained as shown in Fig. 2 (a) and (b). (a) is one of the positive figures, and many branches are seen similar to the surface brush discharge which is obtained on the ebonite plate.



(a) Positive figure (b) Negative figure

Fig. 2 Impulse corona on surface of water

On the other hand in the negative figure (b) very few branches are seen when compared with (a).

The part of lighting center directly below the electrode N (Aluminum) showed a bright blue and the part of branches was reddish. The positive figure was seen to extend longer than the negative one at the same voltage, and if any dust was floated on the water surface it was drawn towards the electrode everytime the positive voltage was applied, but at the negative voltage the dust was repelled back from the electrode.

(3) Diameter of figures

Next the relation of the applied voltage and the diameter of the figure and the effect of a distance between N and the water surface were measured. When the applied voltage was increased with N contacted to the surface of W, the diameter of the figure increased as in Fig. 3.

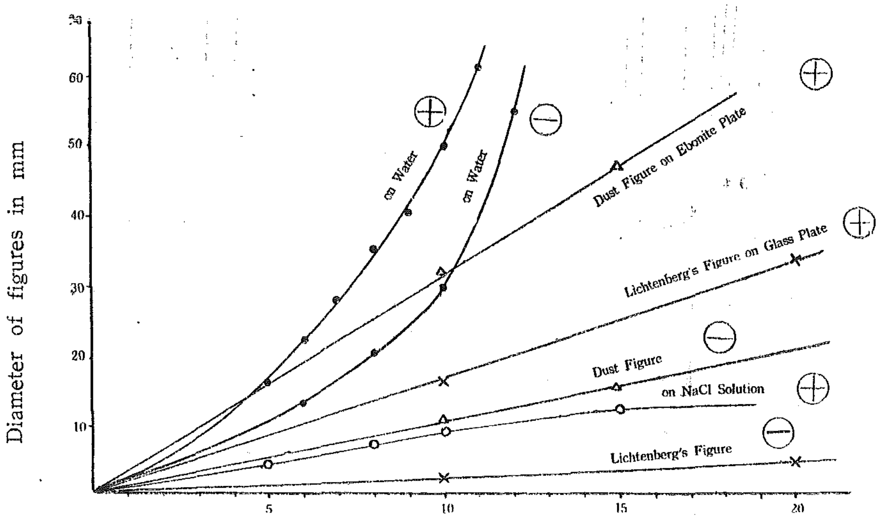
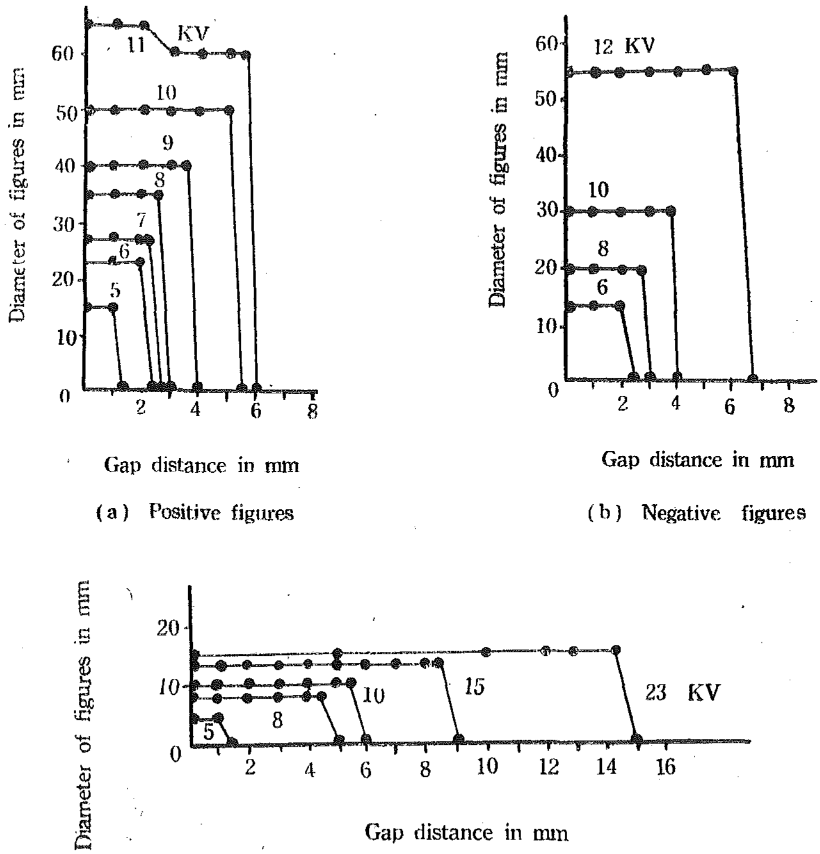


Fig. 3 Diameter of electric discharge figures

From the results of Fig. 3 it is clear that the positive figure is larger than the negative figure as mentioned above, and compared with the Lichtenberg's figures obtained on the photo-plate and also with the dust figure on ebonite plate, these figures on the water surface, are very large. But on the solution of $NaCl$ 100 g in 1 litre of water the diameter of impulse corona decreased as seen in Fig. 3. It means the conductivity of the water solution has a great effect upon the magnitude of figure.

About the effect by change of distance d between N and W, the relation of d and the diameter of figure were measured under the parameter of the impressed voltage. Thus Fig. 4 (a) and (b) were obtained. Here, (a) is positive and (b) is negative. From Fig. 4 it is seen that the diameter does not change at first even if d increases and at some distance the corona is inclined to disappear suddenly. (c) is a case of $NaCl$ solution above mentioned and this also shows the same tendency. After these experiments an impulsive spark over voltage at a needle-plate electrode was measured after substituting a metal plate for water W, and was compared with the voltage at the critical value of electrode distance at which the corona suddenly disappeared and it was seen that both voltages were quite equal.



(a) Positive figures

(b) Negative figures

(c) Positive figures on Nacl solution

Fig. 4

That is to say, when it is compared at the same voltage, the critical distance value at which the impulse corona appear on the water is equal to the sparking gap length of needle-plate electrodes. In other words the impulse corona on the water surface, has quite the same characteristics as spark. This can be considered as a matter of course.

(4) Effect of the surrounding atmospheric pressure.

The experimental results above mentioned were obtained under 1 atmospheric pressure. The results under the lower pressure in an enclosed vessel are shown in Fig. 5. (a) in it is a case of $+8\,KV$ impulse corona under the condition $d = 0$, that is, N and W are just contacting. From this curve it is seen that the diameter becomes larger according as the pressure decreases but when the pressure decreases under 50 mm Hg, the corona becomes gradually indistinct as the glow discharges. (b) is a case of $d = 7\ mm$ and at a longer distance like this the corona didn't appear at 1 atmospheric pressure, but appeared at about 600 mm Hg. This pressure in which the impulse corona appeared for the first time was not constant at a given value of d, but was irregular in the hatched band of this Fig. However, the other characteristics were the same as mentioned previously at the part (1) of this Section.

(c) and (d) are the case of $d = 7\ mm$ in the $NaCl$ solution, and (c) is one of $+ 8\ KV$, (d) $- 8\ KV$. In those cases the particular phenomena were that the irregular band obtained at the positive voltage was broader than the band at the negative voltage and also broader than the band on the water from the waterworks under the same experimental condition.

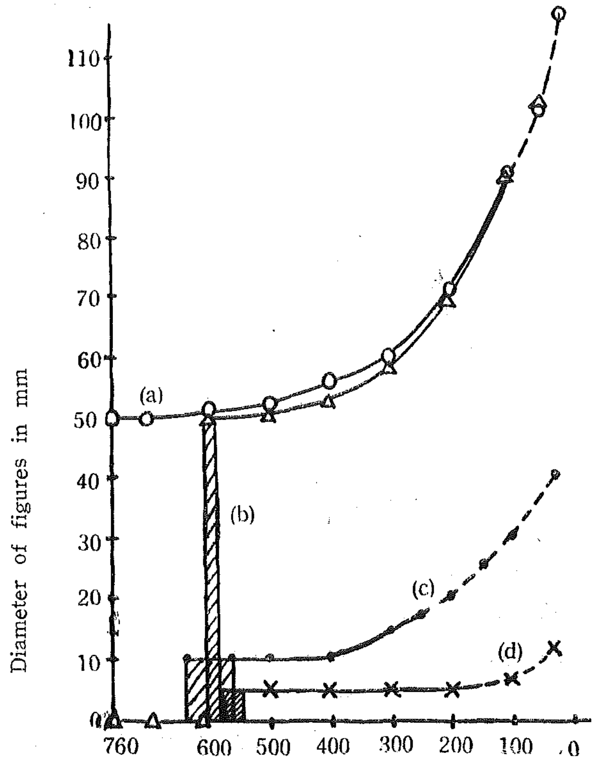


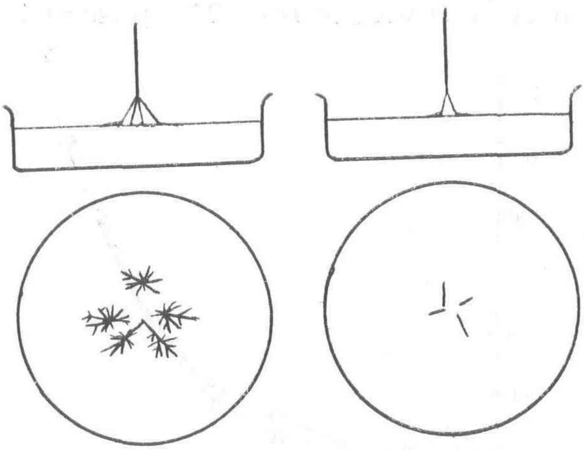
Fig. 5 Effect of surrounding pressure to diameter of figures

The difference in the impulse corona between the positive and negative voltage was also seen at the time of changing the pressure and when the negative voltage was applied the diameter of the figure didn't change at all until about 100 mm Hg and at the lower pressure than 100 mm Hg it was observed that the figure became somewhat larger but very indistinct. In this case the foot of the positive corona discharge under the needle on the water was observed as Fig. 6 (a) at the low pressure; that was just like a foot-trace of a bird, and at the negative corona the number of the trace of discharge decreased as is shown (b). This fact shows that the mechanism of both discharges is quite different.

3. Ignition Characteristics of the Impulse Corona to Combustible Liquid and Gas

(1) Ignition to a thin film of gasoline floated on the surface of the water

A matter which may be reduced from the experiments in the Section II is that such an impulse corona on the water solution has a characteristic of spark or arc discharge on the whole, and this reduction will be ascertained, too, from the next experiments on the thin film of gasoline or transformer oil.



(a) Positive figure (b) Negative figure

Fig. 6 Impulse corona at low pressure of 100 mm Hg

First in the same method as mentioned in Section II the film of gasoline was floated on the surface of water, and in this case there disappeared the difference of the figures between the positive and negative voltage which was seen on the water but it was the same as in the previous case in which the positive figure showed a tendensy to extend further than the negative one. When the corona extended on the gasoline film, it ignited to the film and made it burn if it was of a suitable thickness. Fig. 7 is an example of the ignition state in which the ignition of gasoline performed by the twig-like streamer of the corona is seen distinctly. This indicates the characteristics of ignition by such a streamer.

In this experiment the condition for the ignition of gasoline film was the thickness of film and the distance of needle N and the surface of liquid, and when the thickness and the distance were over or under the condition the ignition didn't occur. This condition obtained by the experiment is shown in Fig. 8 in which the applied

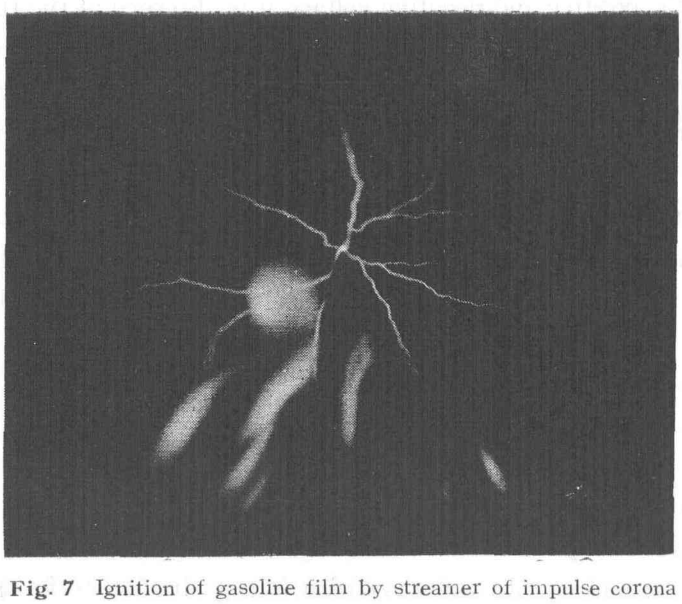


Fig. 7 Ignition of gasoline film by streamer of impulse corona

voltages are $+22\,KV$ and $-15\,KV$ respectively and the hatched part is a suitable ignition band. Comparing it with the result of seeing directly by the eye, there always accompanied the ignition with the streamer on the gasoline film, but when the distinct streamer didn't appear, the ignition didn't occur, too. This means that when the distance between the needle and the liquid becomes greater, the streamer from the tip of the needle does not reach the liquid surface and also it is difficult to ignite on the film. Above all as the negative streamer is difficult to extend longer, so the tendensy is large. Also it is interesting to note that at a suitable distance of N and W, ignition becomes easy at the greatly thick band of gasoline film.

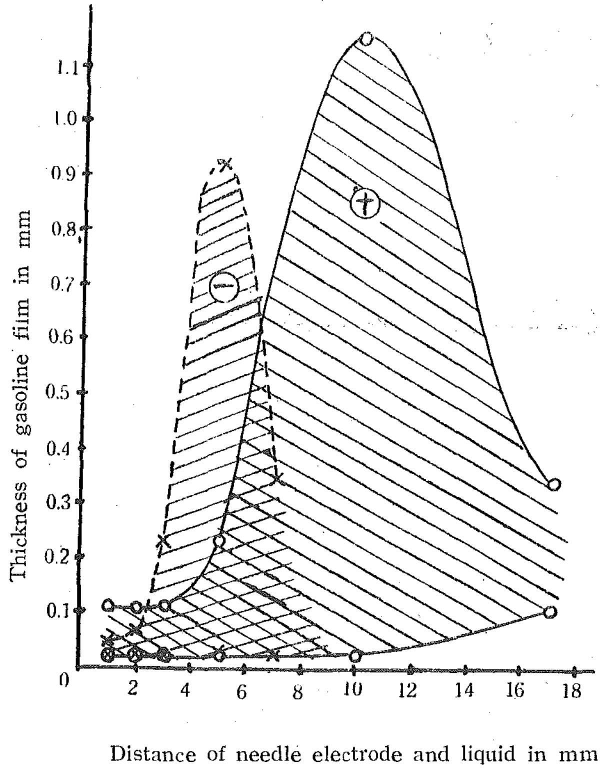


Fig. 8 Ignition of gasoline film at various thickness and distance of electrodes

(2) Ignition to the thin film of transformer oil floated on the surface of the water.

When the thin film of the transformer oil was floated on the water surface the figure of the impulse corona was different from the above cases and it assumed a rosary-like figure. When the film of oil was thick, the extension of streamer gradually decreased as the thickness increased and was only seen directly below the needle electrode, rather taking a sparkish figure.

The characteristics of ignition as appeared on oil were the same as the above cases, that was, the ignition was performed by the streamer, but as compared with thc case of gasoline the flame didn t spread and it vanished at once because of the higher flashing point of oil. According to the repetition of the impulsive discharge, the oil became little oil drops and diffused into the water and this time the rosary-like streamer was able to appear very easily. In Fig. 9 there is an example of the ignition state of oil by the impulse corona.

(3) Ignition to methane- mixed air by the impulse corona.

In the part (1) and (2) of this Section were mentioned the characteristis of the impulse corona for the ignition to the combustible liquid and next the characteristics

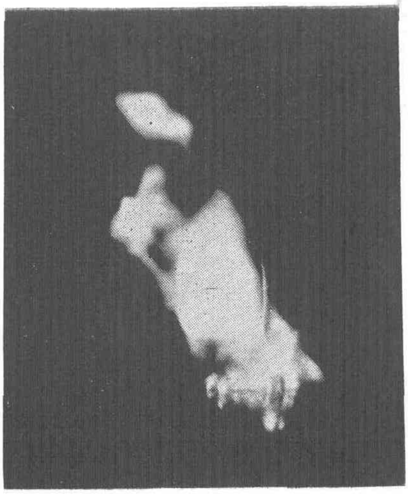


Fig. 9 Ignition of thin film of transformer oil

to the combustible gas are as follows. The above explained apparatus *N W Q* was put into a wood-made vessel, which was filled with the methane - mixed air. The percentage of methane to air was fixed as 9, which was most explosive and detective on ignition. For the safety at the time of explosion a cellophane paper was stuck to one of the sides of the vessel and the explosive gas was let to escape.

Changing the distance between the needle and the water surface and increasing the applied voltage, the author measured the ignition voltage to the gas by the impulse corona. This is shown in Fig. 10. From this Figure it will be seen that when the voltage is negative the gas is ignited at a very low voltage compared with the positive voltage. However, the larger the gap length the more difficult it becomes to ignite, by the same reason as shown in Fig. 8. Through these experiments, it was recognized clearly that whenever the reddish streamer appeared on the water surface explosion always happened, but no explosion happened by the blue corona under the needle electrode alone.

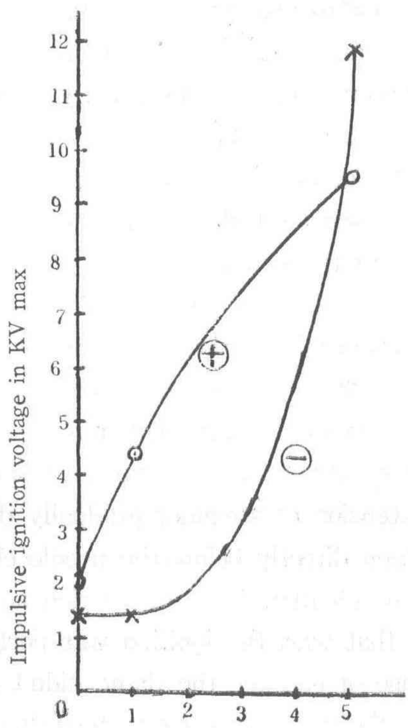


Fig. 10 Ignition voltage to CH_4 mixed air

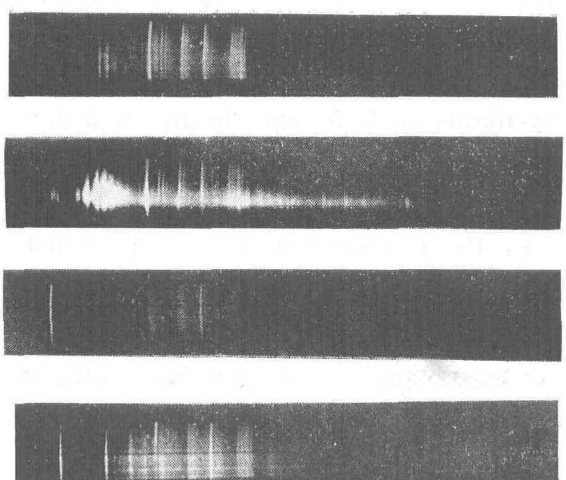
Next the author obtained an intersting result, that was the variation of the ignition characteristics by the thickness of oil film on the water. The distance between *N* and *W* was taken 1 *mm* and when the film was very thin the mixed gas was ignited and explode by one or two impulse coronas, but when the film was 2 *mm* thick it was difficult to ignite by the positive impulse corona and it was seen to ignite only after about fifty times continued trial. When the film was more than 2 *mm* thick there was no ignition at all. On the contrary when the voltage was negative, the ignition happened only once when the thickness was the same as above mentioned and it was difficult to ignite when the thickness of oil film was 5 *mm* or more. (of course, the applied impulse voltages were kept constant during these experiments.) This means clearly the great ignition ability of the negative corona and it may be considered that this experimental method is the powerful means whereby to give a solution for the discussion on the polarity effect to electric ignition of gases.

4. Spectrum of the Impulse Corona

In addition to the experiments about the figures and the characteristics as above mentioned, the spectra of the corona were taken by a spectroscope in order to research the mechanism of the discharge. Aluminium electrode was used as a needle N and the spectra were taken directly below the electrode and at the tip of the streamer.

(1) Spectrum of the impulse corona on the surface of water.

Fig. 11 shows the spectra of the impulse corona on the water and (a) and (b) in it show the bright blue part directly below the electrode, and in them Al eloctrode lines and N_2 2nd positive band appear strongly. (a) is by the positive impulse voltage and (b) is negative, and though there is not much difference between them in (b), the strong electrode lines, weak OH band and H_2 line are found. But at the reddish part of the tip of the streamer apart from the electrode the obtained spectra are as (c) and (d), and here the electrode lines are hardly recognized, but the strong Balmer series of H and N_2 2nd positive band were seen. In this case, too, there is not much difference between positive and negative corona, except in (d) the weak Al lines appear. Of course these spectra were taken at the same voltage and exposure. In this figure (e) is the spark spectrum in the air between Al electrodes and it is added for comparing it with (a) to (d).

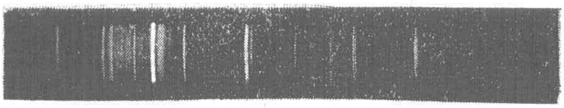


(a) Positive Spectrum
(directly below of electrode)

(b) Negative Spectrum
(〃)

(c) Positive Spectrum
(tip of streamer)

(d) Negative Spectrum
(〃)

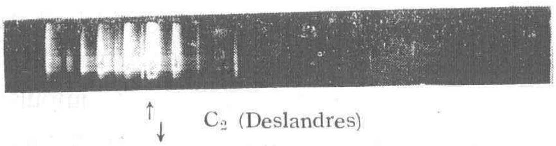


(e) *Al* spark lines

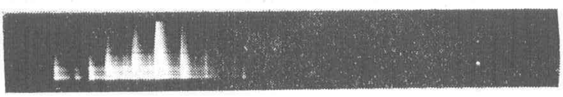
Fig. 11 Spectrum of impulse corona on water.

(2) Spectrum on the thin film of gasoline floated on water.

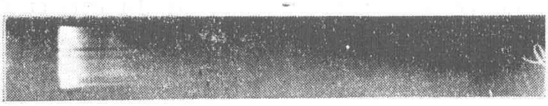
Next, by floating the thin film of gasoline on the water the spectra were taken by the same method. This is shown in Fig. 12, in which (a) is the spectrum by positive voltage and (b) is by the negative, and both are taken directly below the electrode. In this case are seen the Al electrode lines, C_2 Deslandres band, C_2 Swan band, CH band, H Balmer series, C line and air lines, and in them C_2 Deslandres band appears especially strongly. There is not much difference between the positive and negative voltage.



(a) Positive spectrum.
(directly below of electrode)



(b) Negative spectrum.
(〃)



(c) Flame of burning gasoline.

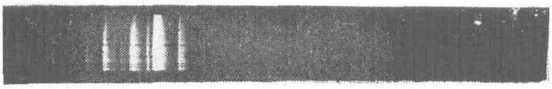
Fig. 12 Spectrum of impulse corona on thin film of gasoline floated on water.

At such a discharge on the gasoline film the ignition occurred by the streamer as mentioned in Section III and when the film of gasoline was thick it continued to burn after the ignition, so it was regulated not to let into the spectrograph the light from the flame of burning gasoline, by means of decreasing the film to a suitable thickness. The spectra from the light of burning gasoline are shown in (c) and as there is the weak C_2 Swan band in the continuous spectrum from red to green, so it may be distinctly seen whether the gasoline burned strongly or not when the voltage was impressed.

(3) Spectrum in the case of transformer oil being floated on the water

In this case, too, quite the same spectra are obtained as the gasoline. This is shown in Fig. 13 and (a) is by the positive one, (b) by the negative. There is no difference between (a) and (b). Continuous spectrum during the burning of oil was the same as in the case of gasoline.

(a) Positive spectrum



(b) Negative spectrum

Fig. 13 Spectrum of impulse corona on transformer oil floated on water

5. Summary and Discussion of Results-Mechanisim of Discharge of the Impulse Corona on the Surface of Water Solutions

Some considerations which may be obtained from these experimental results in Section I — IV are as follows.

(1) The impulsive surface corona discharge on the liquid such as water or water solution is different from the one on the general insulating liquid dielectrics and has a characteristics of spark or arc discharge. This is considered as a matter of course and is also ascertained from the many experimental results under given. First, as is shown in Fig. 4 a critical distance value on which the impulse corona appeared on the water was exactly equal to the sparking gap distance of the needle point to plane, secondly in the spectrum directly below the electrode the spark lines of electrode appeared strongly, thirdly, by decreasing the surrounding atmospheric pressure the corona appeared easily even at a large gap length, and the current density of the streamer of the impulse corona was so large as to ignite the gasoline or oil film on the water, etc.

(2) Such a figure of corona is a special one and is different from an ordinary corona, and the mechanism about the spreading of this twig-like streamer may be explained somewhat in the following manner. When the impulse voltage is suddenly applied on the needle electrode, the part of the high potential gradient will be produced below the electrode and will immediately move outward along the water surface and there the streamer will spread.

At the tip of the streamer the spectrum of the Hydrogen and the Nitrogen appear. It shows that the streamer on the water surface spreads along the boundary surface of air and water, exciting the water and air molecules, and especially in the case of the negative streamer, the excitation of water molecule is larger and it seems that the electrons from the electrode ionize the water molecules by violent collision.

On the contrary in the case of the positive voltage the streamer extends longer and the figure becomes greater, and according it is effected greatly by the state of the air and the water. Especially in the case of low pressure, as the excitation of air molecules is held easily, so the discharge figure becomes still larger. These are shown clearly in Fig. 5 in which the atmospheric pressure has no effect on the negative figure first and when the conductivity of the water solution is higher the difference between the positive and negative figure becomes larger.

From the characteristics above mentioned it may be concluded that this streamer is a conductive one with a high current density, and owing to the impulsive electric source it takes a figure of "impulse corona" as here temporarily termed and spreads along the water surface losing its charges.

(3) Next, concerning the ignition characteristics of the impulse corona to the combustible liquid or gas. When a thin film of gasoline or transformer oil was floated on the water surface and the impulse corona was applied to it, the film was ignited by the surface streamer. In this case C_2 Deslandres band appeared strongly in its spectrum. But almost none of this spectrum appeared in the results which had been previously researched by the authers [(2)] on the liquid dielectric, and it should be considered that it has some relation with the ignition. According to the researches made by Yumoto, Nakaya and Fujioka,[(3)] on the 3 parts sparks the spark in which the band spectrum appears has a larger ignition abilty to the combustible gas than the spark that shows line spectrum, so it should be considered that the impulse corona showing such a spectrum which is acompanied with strong ionization as this C_2 Deslandres band also has a large ignition ability.

It was ascertained, too, that the ignition of combustible gas as methane-mixed air was performed by this surface streamer. Above all it is an interesting problem that it is hard to ignite the gas if there is a film of oil thicker than $2 \sim 5\ mm$. About this phenomenon it may be considered that the streamer extends to the boundary part of water and oil, and so, as it doesn't contact the gas directly, the streamer can not excite the gas and consequently can not ignite it. But it should be researched in detail on another occasion.

It was also seen that when the oil film was floated on the water it was hard to ignite by the positive corona but easy by the negative corona. On the polarity effect to the ignition it has been said hitherto that the ignition ability exists on the positive side, or on the negative side, and else in the middle part, but these have not been made clear. However, it seems that it is greatly effected in the experimental condition, and in the experiment which was performed by the author it was made clear that "the negative corona has a large ability to ignition".

(4) Lastly the author thinks that these impulse coronas may be used as an experimental method on the research of ignition by the electric discharge and of suppressing gas explosion and else of the discharge on the surface of wetted porcelain insulator, and so on.

Bibliography

1) Toriyama & Sakamoto : J. I. E. E. of Japan (1944—11, 12)
2) Toriyama & Sakamoto : J. I. E. E. of Japan (1944—9, 10)
3) Nakaya & Fujioka : Proc. Imp. Acad. Tokyo 2,536 (1926)
〃 〃 4,464 (1928)
Yumoto & Yamamoto ; Proc. Imp. Acad. Tokyo 5,125 (1929)