A GREASING METHOD FOR IMPROVING THE PERFORMANCES OF POLLUTED INSULATORS

BY

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ABSTRACT:

The present experimental work reports an investigation of the effect of artificial pollution on tho performance of suspension insulators. It was found experimentally that the greasing of suspension insulators by silicone grease improve their performancos oven undor heavy pollution conditions. A silicono grease layer of comparatively small thickness reduces the effect of dirt accumulation and incrsases the flashover voltage. The leakagecurrent of greased insulators is very lower than that of ungreased insulators. It was found also that the flashover mechanism of polluted insulators under both d.c. and a.c. voltagos depends mainly on the formation of dry-bands, formed by the leakage current. As the applied voltage is increased, these bands extend in width causing partial sparkings across them and leading finaliy to a totally flashover over the insulator.

1. INTRODUCTION:

In the transmission technique of electrical power, it is well known that the transmission voltage has a great effect on the performances of the transmission lines, especially for long distances. Higher voltages give better line performances. It is well known also that high-voltage direct-current(HVdc)transmission, is more efficient and economic than high-voltage a.c. transmission. HVdc transmission lines are well established in many countries and reported elsewhere in the technical litorature. In both types of transmission natural pollution has a fatal effect on the insulators used.

In Egypt, natural pollution forms a very dangerous problem for the insulators used in high-voltage installations. Chemical analysis had indicated that pollution deposites on insulator depend on the location of the transmission installations. As example, the insulators used in the electrical installations in Talkha Substation must be washed twice monthly because of the heavy pollution deposites especially after the operation of El-Nasr Fertilizer at Talkha. The heavy deposites are produced

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due to than natural pollution formed by the smoke pouring from the fertilizer chimneys. The main compositions of this smoke was found chemically to be Ammonium Nitrate (NH_4NO_3), Ammonia (NH_3), Nitric Acid (HNO_3) and particles of nitro-chalk. A chemical analysis of the natural pollution deposited on the surface of insulators showed that the main component is Ammonium Nitrate, which is very hygroscopic salt.

Efforts have been directed in this work to improve the performances of insulators under both d.c. and a.c. voltages and artificial pollution conditions. Great attention has been directed to study the performances of suspension type insulators under artificial pollution conditions using watery solution of Ammonium Nitrate. The present work was aimed also to study the effect of silicone grease, as a greasing material, on the performances of insulators. As a comparative study, the experimental tests were done on both greased and ungreased insulators. To get a greasing layer on the insulator, it was immersed in silicone grease solutions having different concentrations and for different periods of time. An experimental investigation was carried out to study the effect of greasing on both leakage current and flashover voltage under both a.c. and d.c. voltages. In addition, an attempt has been made to explain the flashover mechanism of polluted insulators by means of very careful inspections of insulators under test during and after flashovers.

2. Test Installations and Experimental Technique

2.1. High-Voltage Generating Circuits

All tests were carried out under both a.c. and d.c. voltages. A.C. test voltage was generated by means of a high-voltage generating circuit consisting of a 8 kVA, 220V: 80kV high-voltage transformer with low-voltage control unit. This is supplied from the 220-V supply and consists of an autotransformer and a self-resetting relay. The last switches off the main switch immediately when any flashover of the insulator under test occurs. The a.c. test voltage can be increased or decreased smoothly at constant rate in the range of 0 up to 80 kV (r.m.s.) using the control unit. Flashover voltages were measured by means of a resistive potential divider and an electrostatic voltmeter having multi-reading-scales. The windings of the both sides of the transformer are electrostatically shielded to avoid any induced surges. The d.c. test voltage was obtained from the same a.c. high-voltage circuit connected with a metal-rectifier unit and high-voltage capacitors. The metal rectifier unit is oil-immersed and has a maximum current rating of 50 mA for one hour or 30 mA continuously. A capacitor doubler was used to get a voltage doubling. To reduce the voltage ripples in the output voltage, a smoothing capacitor was connected in parallel with the rectifier. A check of the d.c. output voltage showed a voltage ripple not exceeding 0.1% /mA at 120 kV, which was in excess of the highest voltage used in this experimental work. The d.c. output voltage can be controlled smoothly and measured by means of the same arrangement mentioned before. The leakage current under both a.c. and d.c. voltagee was measured by means of an ammeter having different scales to indicate leakage current ranging from some micro-amperes to some milli-amperes. This current is pure resistive under HVdc instead of capacitive and resistive under HVac. Therefore, the instrument was connected by a shielded wire between the cap of the insulator under test and the earthing network of the high-voltage laboratory to prevent any interference in the test appartus. Two pin electrodes having air gap of 2mm length were connected across the ammeter to protect the instrument against any high-voltage surges when a flashover of the insulator occurs.

2.2. Experimental Procedure

All experimental rssults given here were obtained using suspension cap and pin insulators of type CW 1, British Made. These have been selected because they are mostly used in Egypt in high-voltags transmiseion systems especially in 220 kV, Delta Network. This type of insulators has the following main parameters

dimensions	250 x 150	mm
leakage path length	310	mm
dry flashover voltage	80	kV(r.m.s.)
wet flashover voltage	50	kV(r.m.s.)
puncture voltage	110	kV(r.m.s.)

Different contaminations were used in the testing of artificially polluted insulators in many experimental works reported elseashere in the technical literature. For the first time, Ammonium Nitrate is used here as artificial pollution, because it forms the main component of the atmoshperic pollution at Talkha Substation. This pollution is formed by the smoke pouring from the chimneys of El-Nasr Fertilizer at Talkha. This was the actual cause for many flashovers taken place across many insulators installed in Talkha Substation. A series of research works were planned to study this phenomenon under both a.c. and d.c. voltages to find the solution of such troubles. These works were aimed also to serve the planuing and extension in Talkha Substation not only in the a.c. installations but also if HVdc installations will be established in the futur.

A chemical analysis was carried out using some samples of the smoke pouring from theechimneys of the fertilizer. This analysis showed that the smoke contains mainly Ammonium Nitrate (NH_4NO_3), Ammonia (NH_3), Nitric Acid (HNO_3) and particles of Nitro-chalk. Thus the main component of the pollution produced is Ammonium Nitrate. This salt is very hygroscopic and very easily dissolved in water. It is ionized under the effect of heat to positive (NH_4^+) and negative (NO_3^-) ions. The salt was solved in distilled water in bottles having a capacity of 500 c.cm. The prepared alty solution was used as spraying solution to get a uniform solty coating layer on both upper and lower surfaces of the insulators under test.

The prepared insulators were washed carefully with a solvent such as benzene and then with tap-water to remove any traces of grease. After drying in an electric oven, the insulators were sprayed by means of a bottle of 50 m/capacity and having a hand-spray mechanism. The spraying was done carefully on the upper and lower surface of the insulator. Spraying was done in the same manner after coating the insulators with silicone grease solution. The insulators were immersed in silicone grease solution having different ratios of silicone grease. These were adjusted by dissolving a certain amount of grease in the corresponding amount of Ethyle-Acetate as a solvent. The insulators were immersed in the solutions for different periods of time in the range of 15 sec to 180 sec. The thickness of the formed greasing layer depends of course on the immersion time and on the concentration of the silicone grease solution. The greased insulators were left to dry forming homogeneous greasing layer of silicone grease. This was selected as greasing material because it reduces the effect of pollution by encapsulating the dirt particles in the grease and isolating them from each other. In addition it has a very high water repellency leading to preventing the formation of conductive layers and reducing the external leakage currents. Silicone greaee has also good insulating properties, high dielectric strength and very high surface tension. The last physical property is the cause of the high water repellency of the grease.

3. Experimental Results and Discussions

3.1. General

This chapter reports the results of numerous experimental tests carried out to investigate the effect of greasing of insulators on both the leakage current and flashover voltage under artificial pollution of different deposite densities. Silicone grease was selected as greasing material because it has good in sulating and physical properties. The artificial pollution was obtained by using prepared alty solutions containing different amounts of Ammonium Nitrate dissolved in distilled water. The tests were done under d.c. voltage and as a comparison a.c. flashovere were carried out. The applied voltage was increased smoothly at constant rate of 1 kV/sec until the flashover occured.

The insulators under test were prepared for testing as explained previously. The spraying and greasing of insulators were done carefully. For each slat content 10 insulators were prepared for testing by spraying 5 of them and testing successively 5 times for each. The other 5 insulators were coated with silicone grease and sprayed before doing any flashover test. Each given value represents the mean value of 25 successive readings with a standard deviations up to 20% depending on the solution concentration. The salt concentration in the solty solution was ranged from low-to heavy-concentration. The low salt concentration was taken as up to 50 g/litre, while the heavy salt concentration was considered up to 500 g/litre of distilled water. These two concentrations gave slaty coating layers on the insulators having surface conductivity of up to 20 µS and higher up to 60 µS respectively. For example a surface conductivity of 10 uS was obtained from a salty solution having specific conductivity of 1500 µS/cm and containing 25 g Ammonium Nitrate dissolved in 500 c.cm distilled water. To obtain higher surface conductivities, the salt content must be increased in the same amount of water. A surface conductivity of 50 µS was obtained by dissolving 200 g Ammonium Nitrate in 500 c.cm distilled water.

The greasing method can be explained briefly as follows. The silicone grease was dissolved in Ethyle-Acetate as a solvent for 3 different concentrations namely 3 : 4, 1 : 1 and 4 : 3 by weight. These valuos represent three concentrations of grease solution namely low-, medium-and heavy concentration. Clean insulators were immersed in the grease solution for varied time periods ranged from 15 sec to 180 sec for each grease eolution. The immersed insulators were left until the deposited layer is well dried before doing any test. The formed coating layer on the insulator had thickness depending of course on the concentration of grease solution and on the immersion time. It was found that this method gave layers of silicone grease on the insulators having thickness ranged from 0.5 mm to 2 mm, depending on the concentration of grease solution and on the immersion time. The experimental results shown in the given figures indicate the effect of coating suspension insulators of type CW 1, with silicone grease on the performances of insulators under artificial pollution conditions. The artificial pollution was selected as Ammonium Nitrate to investigate its effect and to find the practical solutions to overcome its troubles and disturbances in the operation of HV installation in Talkha Substation. The test results given here demonstrate the effect of greasing layer on the performances under artificial pollution conditions. The leakage current and the flashover voltage of

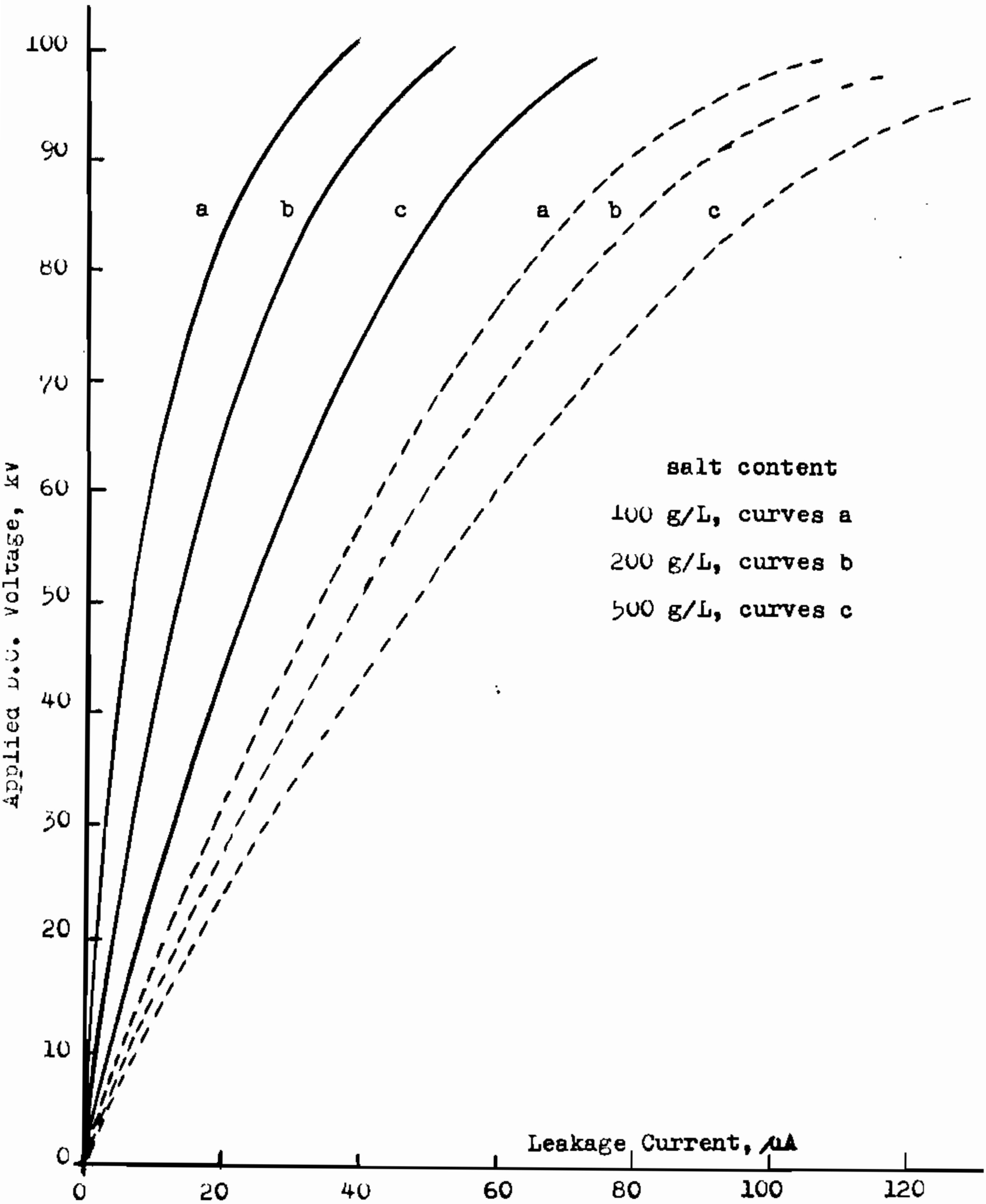

Fig. 1: The dependence of leakage current of greased insulators on the d.c. applied voltage and salt content for immersion time 180 sec. in grease solution having 1:1 (solid lines) and 3:4 (dotted lines) ratio of silicone grease.

greased and ungreased insulators were investigated using different solutions of silicone grease in Ethyle-Acetate as a solvent.

3.2. Greasing effect on leakage current

The results shown in Fig. 1 were obtained by testing suspension insulators coated and uncoated by a greasing layer of different thickness. Fig. 1 shows the effect of greasing of insulator on its leakage current under pollution conditions and HVdc. It is clearly seen in Fig. 1 that the coating of insulator with silicone grease has a great effect on the leakage current of polluted insulators. The leakage current increases as the applied voltage is increased. The values of leakage currents of polluted insulators before greasing were in the order of milli - amperes while after greasing only in the order of micro-amperes. For example, ungreased insulators had leakage 23 mA at applied d.c. voltage of 20 kV and salty solution of 200 g/L. At the same applied voltage, the leakage current was increased to 37 mA as the salt content was raised to 500 g/L. These two salt contents correspond surface conductivities of 25 uS and 60 uS respectively. After greasing, a greasing layer was formed on the insulator surface. This layer is water-repellent and owing to its higher surface tension, no conductive watery path can be produced. Water alone or salty solution takes the form of individual droplets after spraying on the greasy layer on the surface of insulator under test. For these two reasons, the surface resistance of insulator after greasing is much higher and of course the leakage current will be much lower. The leakage current of greased insulators depends on the concentration of silicone grease solution, the higher the grease concentration, the lower the leakage current. This conclusion is clearly seen in Fig. 1 where the results were obtained for two grease concentrations namely 1:1 (solid lines) and 3:4 (dotted lines) by weight silicone grease in solvent. As a comparative example, at an applied d.c. voltage of 70 kV, the leakage current of greased insulator with 1:1 concentration ratio is 12.8, 21.6 and 36 uA using three salt contents 100, 200 and 500 g/L respectively. For a lower grease concentration (3:4) and at the same applied voltage and for the same salt contents, the corresponding leakage current were 50.4, 57.6 and 71.2 uA respectively.

3.3. Greasing Effect on Flashover Voltage

The experimental results given here were obtained for greased and ungreased insulators to demonstrate the effect of greasing on the flashover voltage (FOV) of suspension insulators under pollution conditions. The insulators under test were prepared carefully as discussed previously. It was found experimentally that the effect of greasing depends strongly on different factors such as the concentration of silicone grease in the greasing solutions, immersion time of insulators in thesolutions, salt content in the spraying solution and the presence of voids

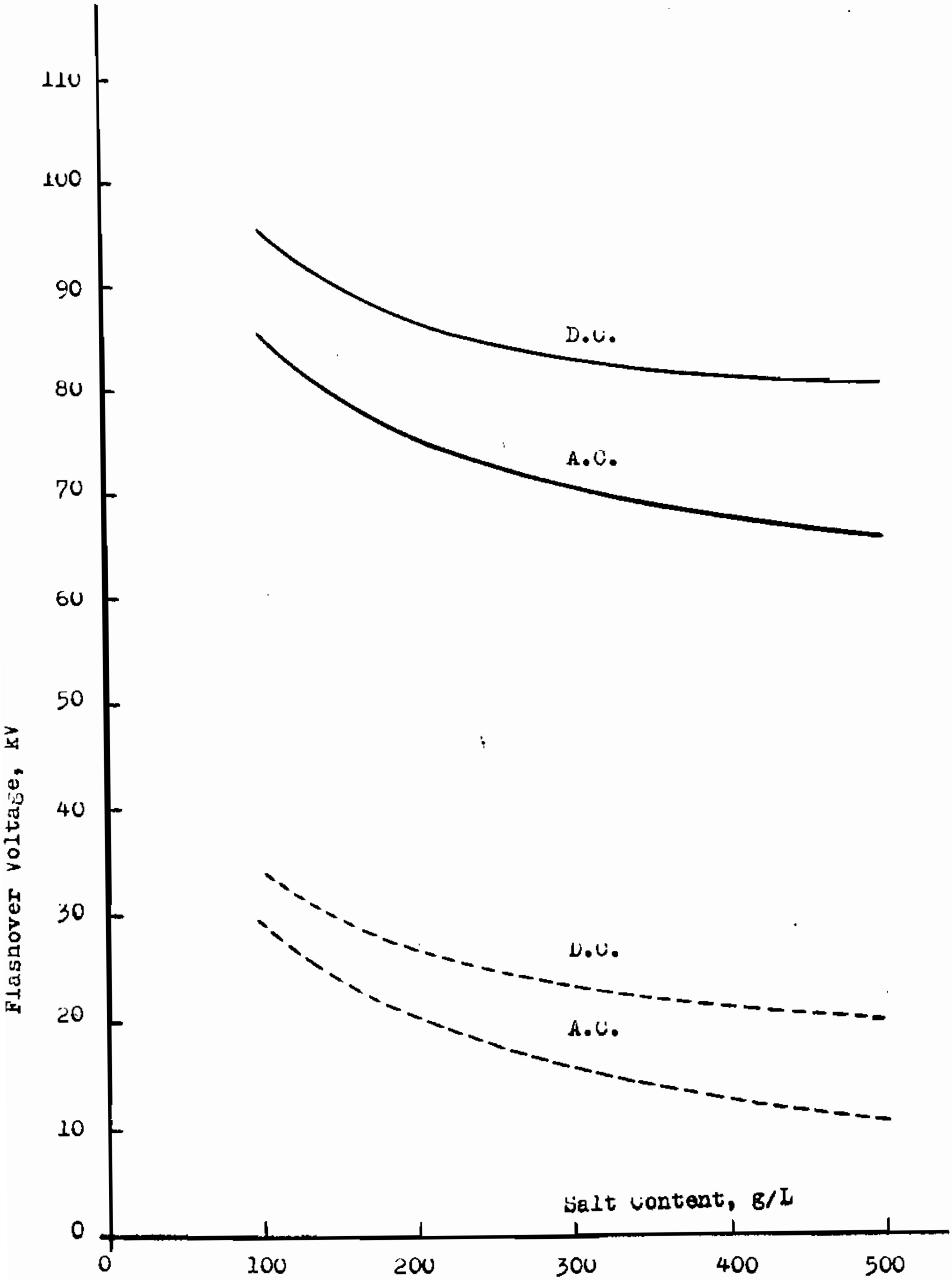

Fig. 2: Comparison between the (FOV) under d.c. and a.c. against salt content for both greased (solid lines) and ungreased

or air bubbles in the formed greasing layer. Each of these factors was investigated to prove its effect on the (FOV) of polluted insulators.

The first factor, i.e. grease concentration, has a great importance and a great effect on the (FOV) as discussed below. The greasing solutions were prepared to have three different concentrations namely, light, medium and heavy grease concentration. The greasing solution of light concentration is considered as solution which has a weighty concentration of 3:4 silicone grease to solvent. The medium has concentration of 1:1 of the same mentioned materials, while the heavy solution has grease concentration of 4:3.

As a comparison between (FOV) under a.c. and d.c. voltages, a number of experimental tests were carried out on greased and ungreased insulators under wet contamination. The greasing lager was obtained by immersion the insulators under test in silicone grease solution of medium concentration for 30 sec. only. All tests were done under artificial wet pollution by using solty solutions having salt content of up to 500 g/L. For each salt content 25 successive flashovers were carried out and each result shown in Fig. 2 represents the mean value with standard deviation of up to 20% depending on the salt content. It can be clearly seen from Fig. 2 that (FOV) under d.c. voltage is higher than that under a.c. voltage (r.m.s). In both cases it is clearly seen that greasing of insulators increases their (FOV) even under wet contamination. The (FOV) of greased insulator is about 3 times that of ungreased insulator under both a.c. and d.c. voltages and at the same solt content.

The d.c. (FOV) of polluted insulator depends strongly on the salt content in the spraying solution. This dependence is shown clearly in Fig. 3, where can be clearly seen that the (FOV) of greased insulats is much higher than that of ungreased. The increase in (FOV) due to greasing depends mainly on the concentration of greasing solution and immersion time in it. The (FOV) of greased insulator is about 250% of that of ungreased at salt content of 100 g/L for both. The growth in (FOV) due to greasing is higher as the salt content is increased. The (FOV) of greased insulator is 350% of that of ungreased insulator at salt content of 500 g/L. In conclusion, the greasing of insulators raises their (FOV) und pollution conditions. The effect of pollution and water, in its different forms, on the (FOV) is less in the presence of greasing layer on the surface of insulator. The thickness of this layer depends mainly on the concentration of the greasing solution and on the immersion time in this solution. To investigate the effect of the immersion time, the insulators under test were immersed for various periods of time in two different greasing solutions having weighty concentration

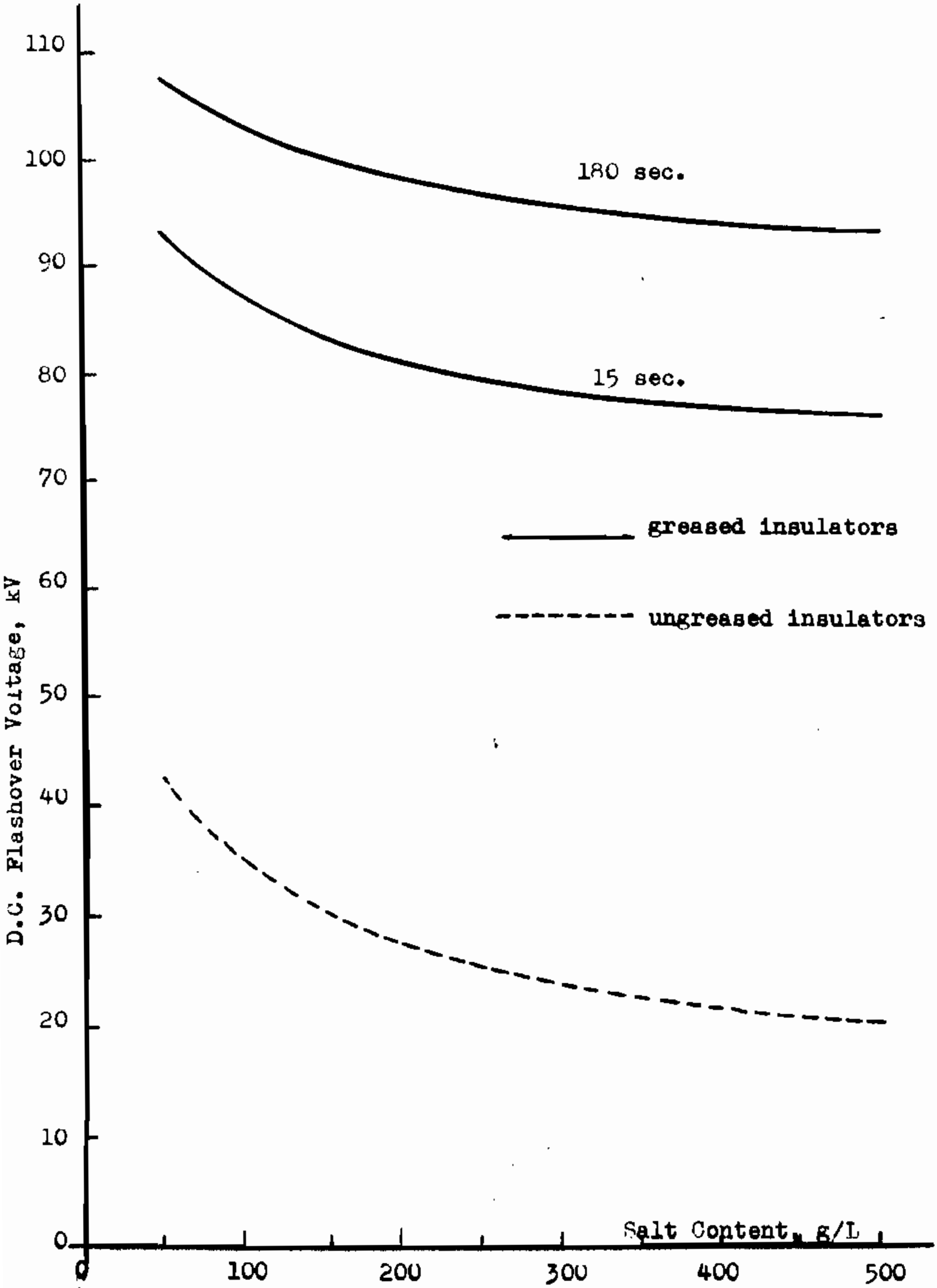

Fig. 3: The effect of greasing and salt deposite on the d.c. (FOV) of suspension insulators of type CW 1.

of 1:1 and 3:4 silicone grease and solvent. In the same time a number of different spraying solutions were used to show the effect of salt content on the (FOV) of greased insulators. Fig. 4 shows the dependence of d.c. (FOV) of greasedinsulators on the immersion time for three different salt contents namely 100, 200 and 500 g/L. It is clearly seen that as the immersion time isincreased the (FOV) increases and the effect of salt content decreases. The curves shown in Fig. 4 demonstrate that the (FOV) increases as the concentration of the greasing solution is increased for the same immersion time and the same salt content. As a comparative example, the (FOV) of greased insulators increases generally as the immersion time is increased for the same salt content. For salt content 100 g/L in the spraying solution, the (FOV) of greased insulators increases from 35 kV to 105 kV as the immersion time is increased from 0 to 200 sec using greasing solution of concentration 1:1. If a greasing solution of lower concentration is used, the increase in the (FOV) will be less. For greasing solution of 3:4 concentration ratio, the (FOV) of insnlator under test increase from 35 kV to 95 kV as the immersion time is increased from 0 to 200 sec. for salt content 100 g/L (Fig. 4). Finally this discussion can be concluded by a very important result, that is the (FOV) of greased insulators is much higher than that of ungreased insulators depending on the immersion time. The salt content in the spraying solution has a slight effect on the (FOV) of greased insnlators. For salt content 500 g/L and for the two mentioned greasing solutions, the (FOV) increased from 25 kV to to 93 kV and 86 kV respectively as the immersion time is increased from 0 to 200 sec (Fig. 4). In other workds, the ealt content has a slight effect on the (FOV) of greased insulators and has a great effect on that of ungreased insulators. These experimental results can he applied in the practice of high-voltage engineering to increase the (FOV) of insulators by greasing. The greasing of installed insulators can be done manually or by using a spraying spparatus. Immersion method ie unsuitable for the installed insulators but it gives uniform greasing layer on the surface of insulator and therefore it is used here. All greasing methods can use greasing solutions of different concentrations, but the medium concentration is more suitable because it given no voids or air bubble in the grsasing layer formed on the surface of insulators.

Not only the immersion time affects the (FOV) of greased insulators but also the concentration of the grearing solution. This effect was investigated experimentally for three different concentration ratios of greasing solution. The obtained results are ehown in Fig. 5, where each value represents the mean value of 25 successive (FOV)s with a standard deviation of up to 14%. The three greasing solutions were prepared to cover a wide range of grease concentration. This can be classified into light-, medium-and heavy concentration. The greasing solution of light concentration is considered as the solution which has a grease

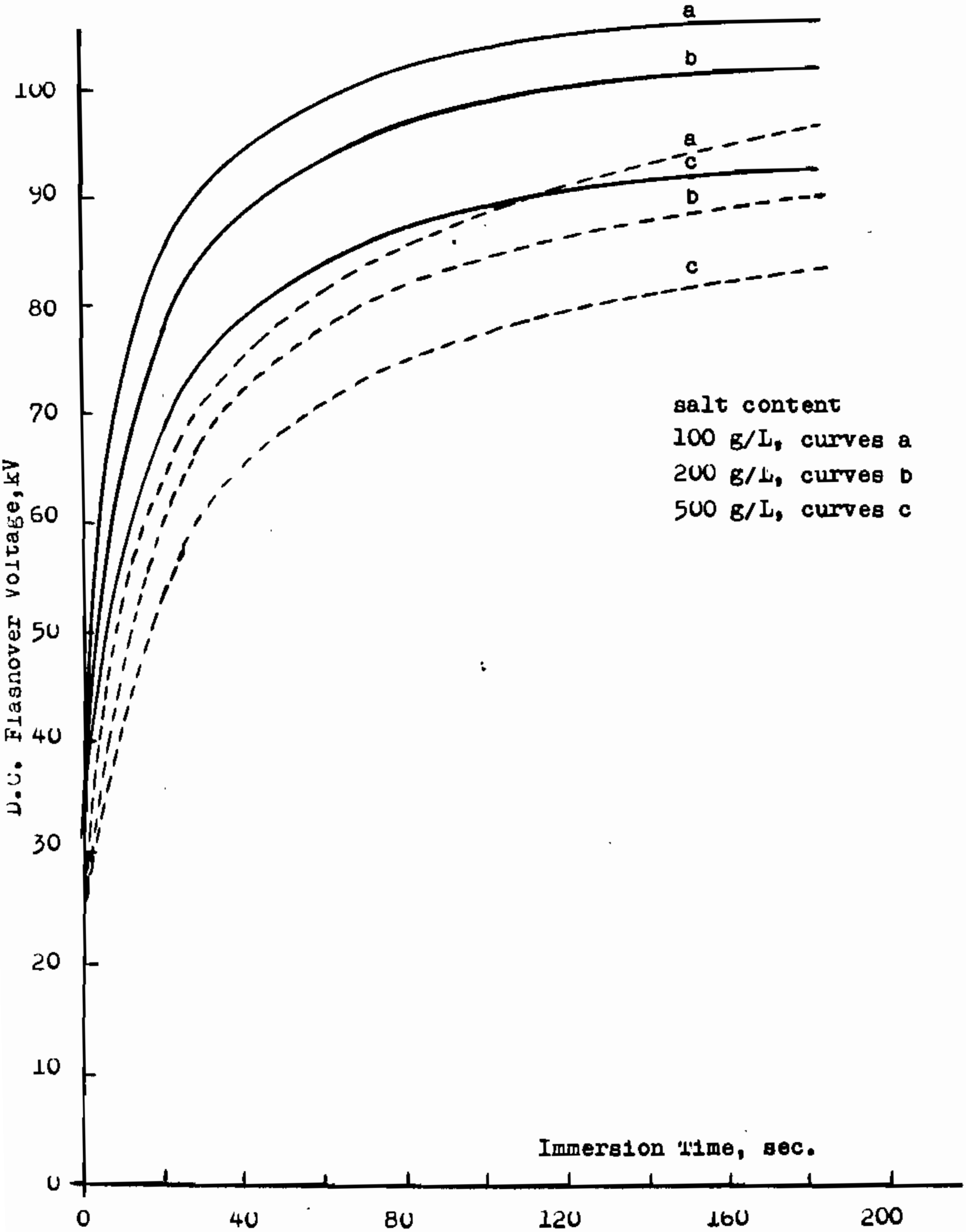

Fig. 4: The variation of d.c. (FOV) of greased insulators with the immersion time in silicone grease solution of concentration ratio 3:4 (dotted lines) and 1:1 (solid lines).

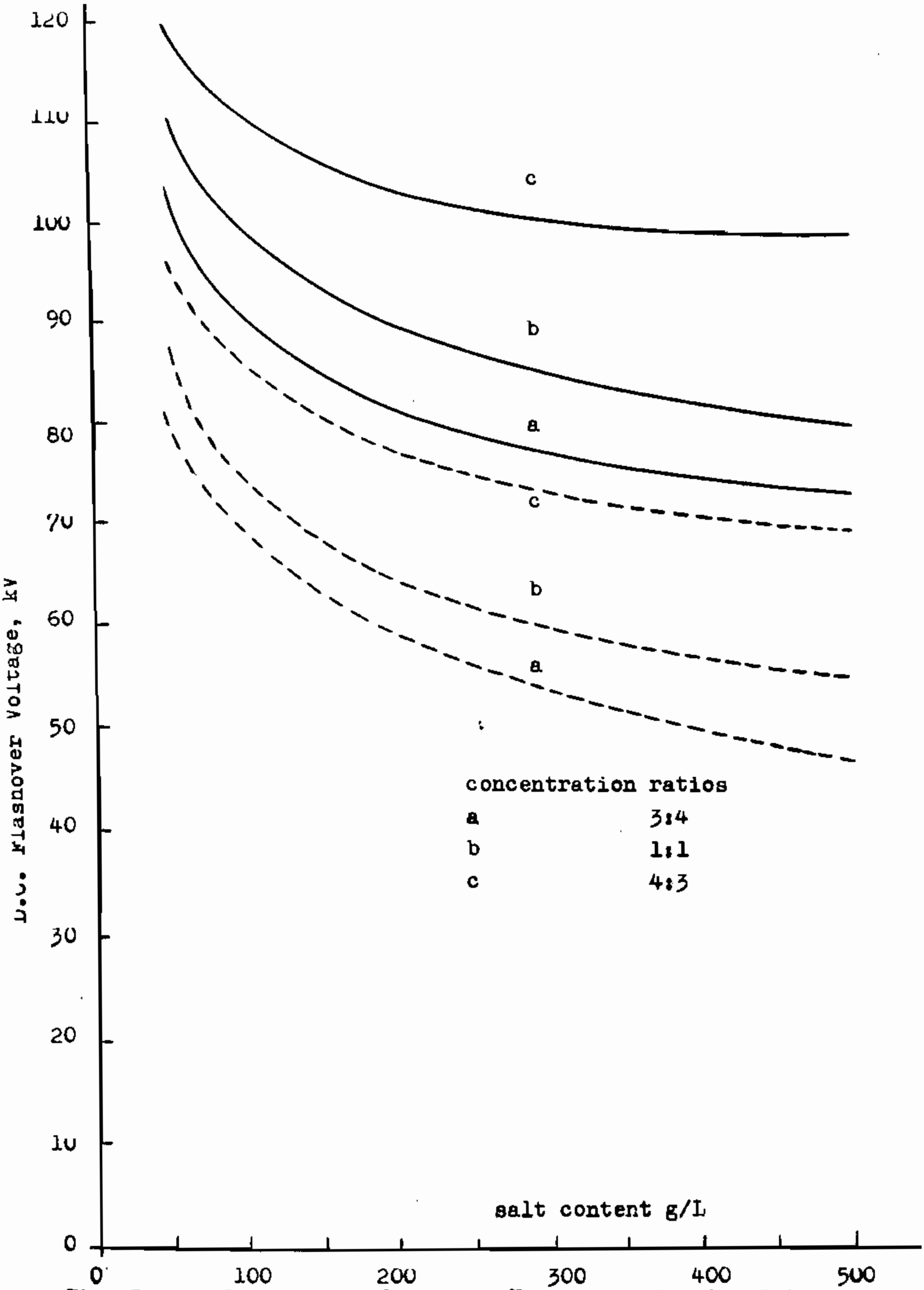

Fig. 5: The dependence of d.c. (FOV) of polluted insulators on the salt content in the spraying solution for different concentrations of greasing solution and immersion time 180 sec. (solid lines) and 15 sec. (dotted lines).

concentration of weighty ratio 3:4 silicone grease to solvent. The medium and heavy concentrations have weighty ration 1:1 and 4:3 respectively of the same mentioned materials. It is clearly seen in Fig. 5 that the grease concentration has a great effect on the (FOV) of greased insulators. This effect depends mainly on the grease concentration. All concentrations gave a very noticeable increase in the (FOV) of insulators in a same manner. Of course this increase depends on the grease ratio in the greasing solution. Heavy grease concentration ratio gave higher (FOV) than that obtained by using light and medium concentrations. As an example, the greasing of insulator increases its (FOV) from 35 kV at solt content 100 g/L to 117 kV and 90 kV by immersion in greasing solution of heavy concentration for 180 sec. and 15 sec respectively (Fig. 5c). This increase in (FOV) of greased insulator expressed in per cent of (FOV) of ungreased insulator is about 340% and 259% respectively at the same salt content (100 g/L). As the salt content is increased the percentage increase in (FOV) of 25 kV. This was increased to 70 kV and 100 kV after greasing for immersion time 15 sec and 180 sec in the same mentioned grease solution. The respective percentage increase in (FOV) are about 280% and 400%. Medium grease concentration gave a lower percentage increase in (FOV) of greased insulator. At the same mentioned salt contents, the respective percentage increase in (FOV) were about 220% and 300% for both immersion times. Grease solutions of medium concentration are more suitable inspite of lower percentage increase in (FOV) of greased insulators. This opinion was formed because such grease solution gives an uniform grease layer on the surface of insulator, having less air bubbles and voids. The formation of such bubbles and voids has a harmful effect on the improvement of (FOV) of greased insulator. This effect was also examined and ths obtained results are shown in Fig. 6. To get a layer having air bubbles and voids, the insulator under test was immersed rashly in the greasing solution, while all tests were done using greased insulators immersed gradually in the greasing solution. It is clearly seen in Fig. 6, that the increase in (FOV) of greased insulatore depends on the presence of air bubbles and voids in the greasing layer. If this layer is free of air bubbles and voids, the (FOV) will be higher (Fig. 6a). The presence of such bubbles or voids in the greasing layer decreases the (FOV) of greased insulators. The (FOV) of greased insulator in this case will be lowertthan when the layer is free of air bubbles but is still higher than that of ungreased insulators. The presence of air bubbles and voids in the greasing layer decreases the surface resistance of the layer leading to an increase in the leakage current. This increase in leakage current depends on the number and size of the present air bubbles and voids. The potential gradient across each air bubble or void will be higher than its breakdown strength leading finally to the occurence of micro-discharges through these air bubbles or voids. The decrease of the surface resistance together with the occurence of micro-discharges decrease the (FOV) of the greased insulator (Fig. 6b).

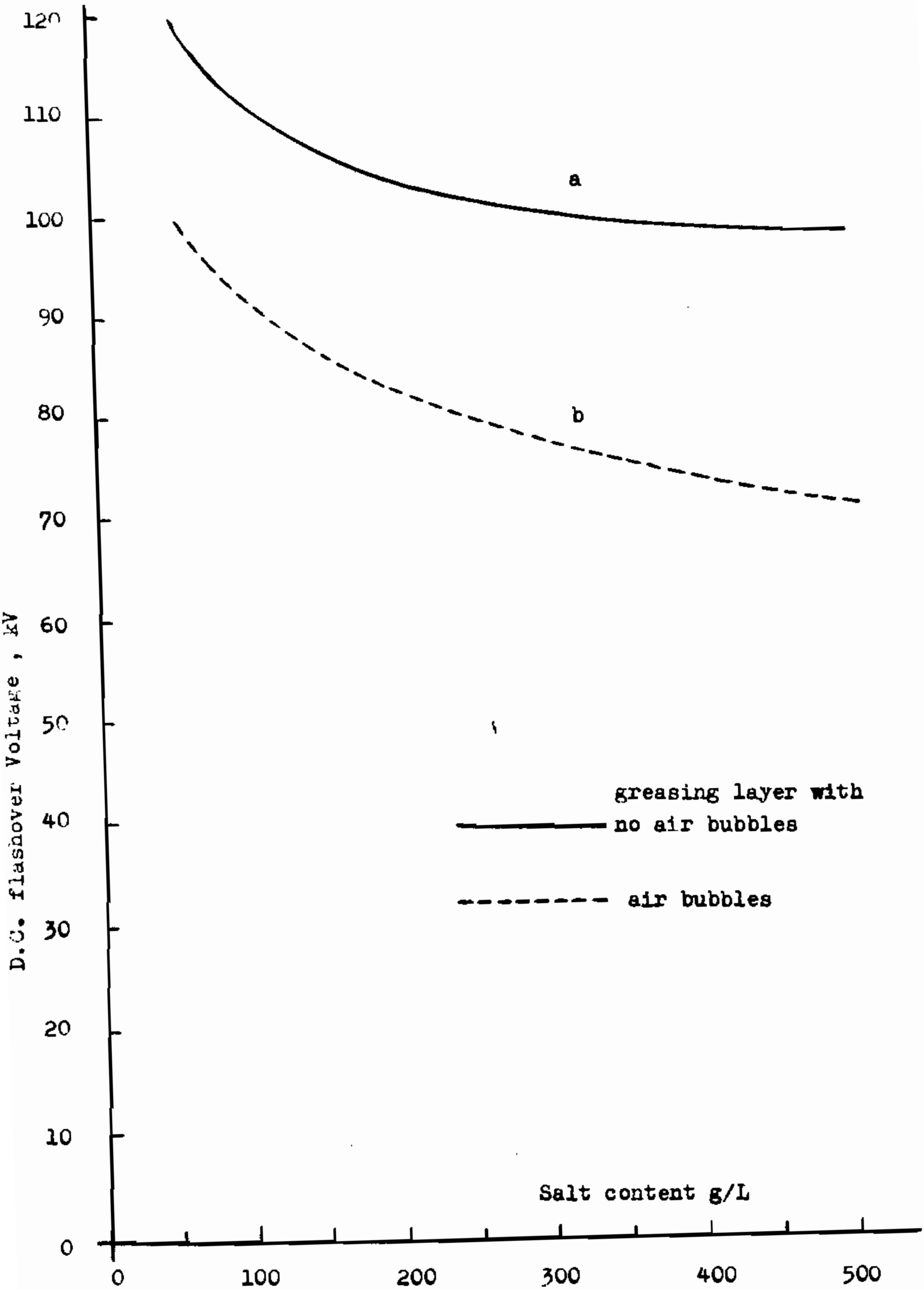

Fig.6 : The dependence of (FOV) of greased insulator on the presence of air bubbles in the greasing layer formed by immersion in grease solution of heavy concentrotion for 180 sec.

The flashover mechanism of polluted insulators under d.c. voltage is similar to that under a.c. voltage. In both cases, it depends mainly on dry-band formation and on partial sparking across the formed dry bands. For salty coating layer of low deposite density, these dry bands are formed at a higher rate and the insulator withstands comparatively higher voitages than these in the case of heavy salt deposite density where no dry-band was observed to be formed. The leakage current depends strongly on the salt deposite, the larger the salt deposite, the higher the leakage current. This increase in the leakage current leads to partial sparking across the formed dry bands and finally to a totally flashover across the surface of the insulator. The leakage current density will be highest near the pin of the insulator causing an effective drying in this area.

It was found experimentally that to increase the (FOV) and to reduce the effect of dirt accumulation on it, a greasing layer must be applied on the eurface of the insulator. Different kinds of petroleum grease can be used but silicone greases are more effective because of their high repellency of moisture. It was found that silicons grease in a 0.5- to 2-mm - thick layer on the surface of insulator can be used to give a sufficrent higher(FOV). Such layer can be obtained by using a silicone grease of medium concentration and immersion time of 180 sec. This coating layer reduces the external leakage currents consid rably by encapsulating the dirt particles in the grease and isolating them from each other. When the grease however, has absorbed a certain quantity of dirt, its effectiveness is reduced suddenly and flashover may occur without warning at a much higher voltage. In high-voltage practice the grease must be replaced regularly because coatings of such kind can be helpful in high-pollution districts. The time between greasings of insulators can be ranged from few monthes in an extremely dirty areas to a few years in cleaner areas. Greasing in now applied in Talkha - Substation manually and gave very good results to improve the performances of installed insulators.

4. Conclusions

It was found experimentally that to improve the performances of a suspension insulator under wet pollution conditions, a greasing layer must be applied on the surface of the insulator. Such layer reduces the effect of dirt accumulation on the (FOV) of insulator. The effect of salt deposite on the (FOV) of greased Insulator is much lower than its effect on that of ungreased insulator. The (FOV) of greased insulator is much higher than that of ungreased insulator under the same conditions. This increase in (FOV) due to greasing depends mainly on the concentration of greasing solution and immersion time. The growth of (FOV) of greased insulator will be less lower, if the greasing layer has gas bubbles or voids resulted from rashly immersion of insulator in greasing solution.

The flashover mechanism of polluted insulators under d.c. voltage does not differ from that ander a.c. voltage. Under both voltages the leakage current increases as the salt deposite is increased on the surface of insulator. This leads to the formation of dry-bands and partial sparking across them and finally to flashover. The leakage current of greased insulator is much lower than that of ungreased. The wet salt deposite has a slight effect on both (FOV) and leakage carrent of grease insulators, In the presence of silicone grease layer, the effectiveness of pollution will be reduced and flashover may occur without warning at a much higher voltage. As a practical application of the obtained results, manual greasing is used now in Talkha Substation to improve the performances of installed insulators in the presence of natural pollution especially Ammonium Nitrate and moisture resulted from the operation of the fertilizer at Talkha.

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