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ANALYSIS OF ELECTRICAL DISCHARGES IN THE AIR – SOLID MOLECULES MIXTURE

Summary. The air in many regions in the world for example in industrial or desert area is contaminated by grains of the dust. The insulation medium of air gaps of h.v. electrical devices is a mixture of air and grains of the dust. The insulation air gap in h.v. lines and industrial devices often work in conditions quite different than in clean air. The dust grains in an electrical field of air insulation gaps create new conditions for ignition and development of electrical discharges. The theoretical analysis and laboratory investigations carried out by authors show that dust grains inserted into electric field operation zone influence on the electric strength level of insulating air gap. Simplified analyses as well as selected results of laboratory investigations of electric strength as a function of concentration of the dust grains and humidity have been presented in the paper.

ANALIZA WYTRZYMAŁOŚCI ELEKTRYCZNEJ POWIETRZA ZANIECZYSZCZONEGO PYŁEM PRZEMYSŁOWYM

Streszczenie. Powietrze jako materiał izolacyjny jest zanieczyszczone w wielu rejonach, np. okręgach przemysłowych, pustynnych lub nadmorskich. Izolacja wysokonapięciowych odstępów izolacyjnych urządzeń elektrycznych stanowi mieszaninę powietrza, ziaren pyłów i drobin wody –elektrolitu. Odstępy izolacyjne w.n. urządzeń elektrycznych często pracują w warunkach całkowicie odmiennych w porównaniu do powietrza czystego. Ziarna pyłu w powietrzu odstępu izolacyjnego tworzą nowe warunki dla zapłonu i rozwoju wyładowania elektrycznego. Analiza teoretyczna i badania laboratoryjne wykonane przez autorów pokazują, że ziarna pyłu przemysłowego przy zmiennej wilgotności powietrza wpływają na poziom wytrzymałości elektrycznej odstępów izolacyjnych. Wyniki analiz teoretycznych i badań laboratoryjnych wytrzymałości elektrycznej mieszanki pyłowo-powietrznej przedstawiono w niniejszym artykule.

1. INTRODUCTION

Insulation air gaps in h.v. lines and industrial devices often work in conditions of air with considerable contamination of industrial dust or sand particles at different wetting of the air.

The working conditions of insulating gaps in industrial regions are quite different than conditions in clean air. The dust grains in an electrical field of air insulation gaps create new conditions for ignition and development of electrical discharges.

As before, the state of knowledge and regulations of international standards have not taken into account these various conditions of the work of insulating gaps in the assessment of their exploitation.

The fact that the problem has not been discerned can be due to considerable faults in the evaluation of the electric strength of the air and also overhead h.v. insulators. During the exploitation time a flashover can also be in the air surrounding the insulator.

The authors, basing on the first results of laboratory investigations of this problems [1], considering the mechanism of electrical discharges in gases put forward the thesis, that the electric strength of air contaminated by industrial dust depends on the concentration of the dust grains in the air.

2. CHARACTERISTICS OF INSULATING MEDIUM

The mixture of air molecules and dust grains as a insulating medium in a static electric field can make very interesting new conditions for ignition and development of electric discharges. The selected main physical and chemical properties of industrial dust are presented in table 1.

Table 1

Properties of the industrial dust

Most popular. grains diameter µm	**Conductivity of soluble comp. µS/cm**	**Density kg/m³**	**Mass fraction of soluble grain %**
40,6	1800	2260	13,74

The dust grains in the insulating distance between the electrode created quite new conditions for the transportation of free charges in electrical field and for cumulative ionization and deionization molecules of the air. The dust grains as solid materials contain compounds soluble and insoluble in water.

The energy ionization level of this chemical element in dust grains is different and lower then chemical elements of the air.

The results of chemical analysis of composition of the industrial dust grains and their ionisation potential are presented in table 2.

Table 2

Chemical compounds and ionisation potential of the electric power plant

Chemical compounds , % Ionisation potential U_i, V							
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO_2	P_2O_5
46,5	17,2	11,0	7,38	4,34	3,28	1,05	0,21
8,14	5,96	7,83	6,25	7,4	10,3	6,80	10,3

The ionisation potential level of compounds of the dust grain is lower than the one of chemical elements of the air.

The molecule of electrolyte in the air is the result of the dissolution of soluble particles in dust grains. As a results of electrolytic dissociation of the solid soluble particles surrounding dust grains form micro spaces having high density of free charges.

The analysis of physical properties of dust grains has shown that the majority (60%) of the grains have the diameter of about 40.6 μm. This showns that the free path of electric charges is much lower than the diameter of the dust grain (about 10^3).

3. MEANING OF THE DUST GRAIN IN ELECTRICAL DISCHARGES

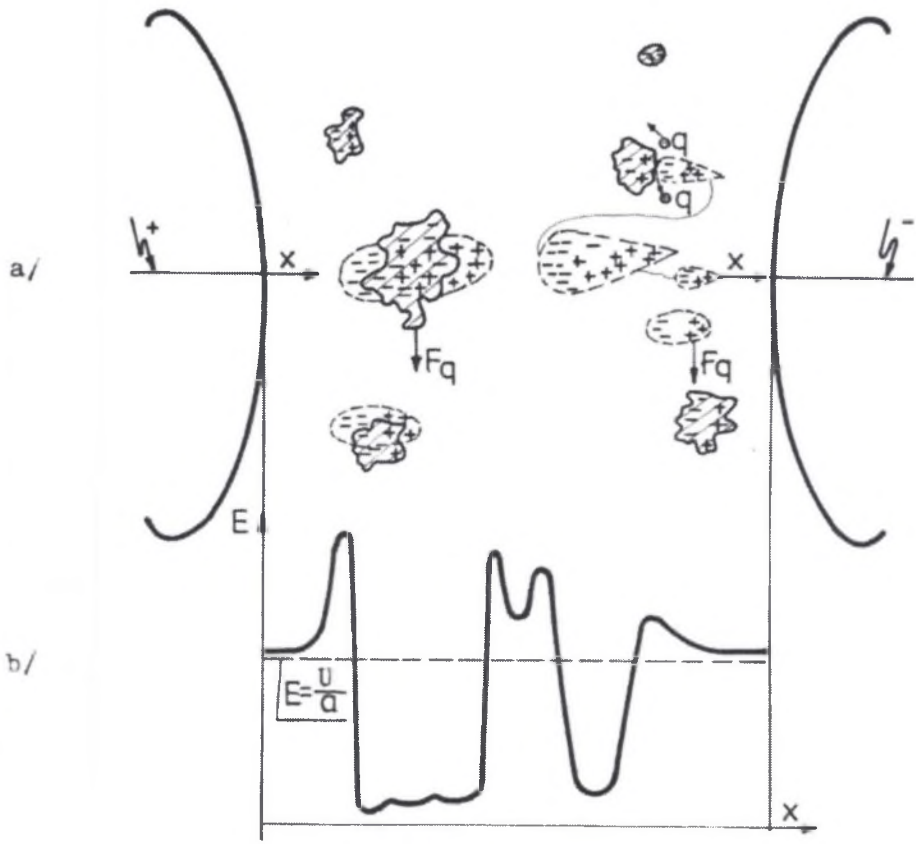


Fig.1. The illustration of the dust grains influence: a) on the development of electric discharge, b) on electric field distribution

Rys. 1. Ilustracja wpływu ziaren pyłu: a) na rozwój wyładowania elektrycznego, b) na rozkład pola elektrycznego

The analysis of ionization processes of aerosol mixture in electric field we shows that dust grains are subjected to the influence of the exterior ionizing agent and collision ionization.

All kinds of ionization: photoionization, thermoionization, autoionization, dissociative ionization and collision ionization take part in the generation of new electric free charges.

The dust grains cause changes of conditions of collision ionization and distribution of electric field intensity on the discharge path. Exemplary drawing showing the influence of the industrial dust grains on electric discharge mechanism is presented on figure 1.

4. RESULTS OF EXPERIMENTS

4.1. Procedure of measurements

The quantities of dust to be put into the test chamber (1,2 m^3) as a mixture of air and industrial dust was prepared outside the chamber. The introduction water vapour changed the humidity in the test chamber. The schematic showing measuring system is presented in fig. 2.

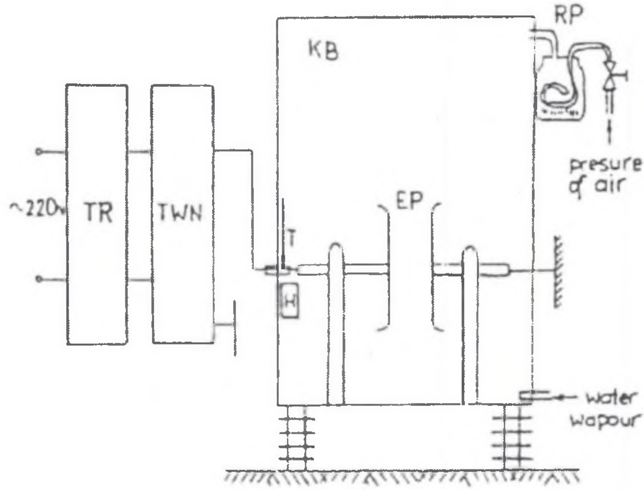


Fig. 2. The schematic illustration of the measuring system
TR - regulation transformer, TWN - high voltage test transformer, H- hygrometer, KB - test chamber 1,2 m^3, EP- measuring electrodes, T – thermometer
Rys. 2. Schemat systemu pomiarowego

After ensuring proper conditions in the insulating gap the voltage was regulated with a constant rate of about 1 kV/s was introduce into measuring electrodes ϕ 125 mm until a complete discharge occurred.

The level of high voltage of flashover was measured in two series and each of them had five measurement for the same conditions. We tried to eliminate the influence of measurement errors by repeated measurements and statistical processing of measured results [3].

Discussion of the experimental results

The results of the investigation involving the influence of the dust grain on the electrical strength in an insulating gap is presented in figures 3 and 4. There we present the results of investigation concerning the electrical strength in a uniform electrical field in air contaminated by different concentration of dust grains Z (g/m^3) and with variable air humidity. This results show, that for a short insulating distance (a < 15 mm), industrial dust in a uniform electric field bring about an insignificant decrease of the level of discharge voltage due to the increase of the concentration of dust grains. The degree of the decrease of the discharge voltage depends on the humidity of the air. In these conditions the level discharge voltages increases. In foggy conditions only with high concentration of dust (Z > 6 g/m^3) a decrease of voltage discharges can be observed.

The results presented in Fig. 3 and 4 shown that with the increase of the length of the insulating distance, the mean concentration of dust grains increases in the mechanism of electrical discharges.

Influence of industrial grains inside the insulating gap on a non-uniform field electric strength by different.

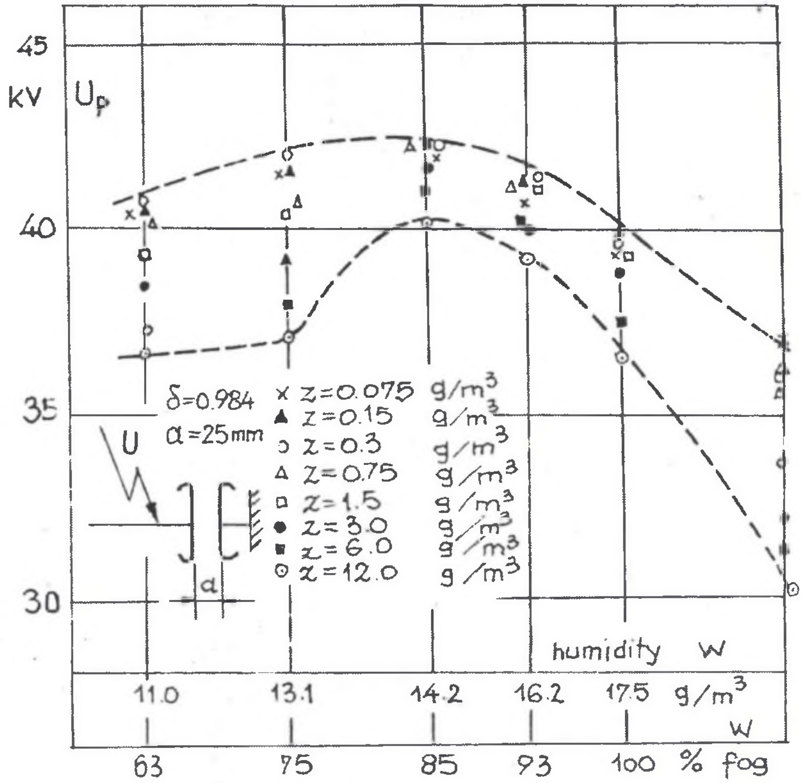


Fig. 3. The influence of concentration of dust and humidity on electrical strength in uniform electrical field

Rys. 3. Wpływ koncentracji pyłu i wilgotności na wytrzymałość elektryczną w jednorodnym polu elektrycznym

The results presented in Fig. 3 and 4 show that with the increase of the leigth of the insulating distance, the significance of the concentration of dust grains increases in the mechanism of electrical discharges.

The influence of industrial dust grains inside the insulating gap on the electric strength of a non-uniform electric field with different concentration of dust grains, air hmidity and length of the gap is presented in Figs. 4 and 5.

As it can be seen in Fig. 4 electrical strength inside the air gap depends on the air humidity and length of the insulating distance. With the presence of dust grains and water paricles inside the insulating gap, the electrical strength significantly decreases when the leigth of the insulating distance increases.

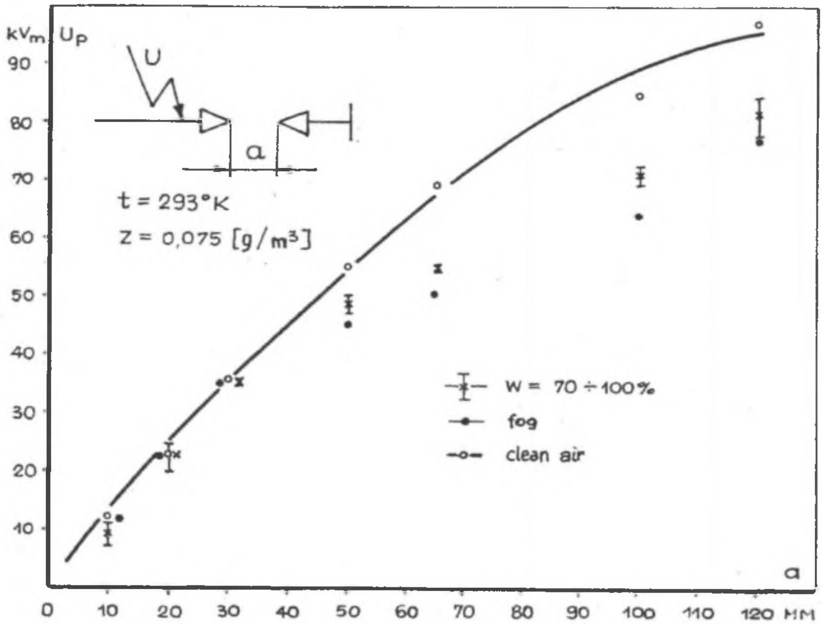


Fig. 4. Comparison of electrical strength values in a clean and polluted air as a function of air humidity and distance of electrodes

Rys. 4. Porównanie wytrzymałości elektrycznej w powietrzu czystym i zanieczyszczonym w funkcji wilgotności i odległości między elektrodami

Fig. 5 shows the results of investigation on electrical strength in a non-uniform electrical field. The curves show the values of the flashover voltage as a function of the dust grains' concentration in the moistened air with varying length of the insulation gap. These results are especially interesting because for the same grain concentration various levels of flashover voltage were measured for small insulation gaps. The width of the dust grains' concentration range, where flashover voltage variability is possible, decreases together with the increase of the distance between electrodes. The theoretical analysis [4] of main agents of electrical discharges in the air–solid mixture allowed to formulate a mathematical model of electrical strength of insulating gap according to the equation: (1).

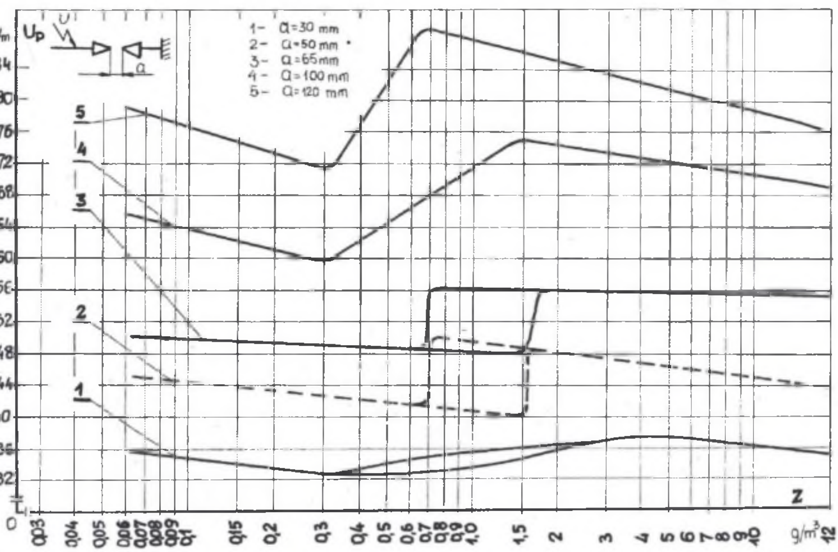
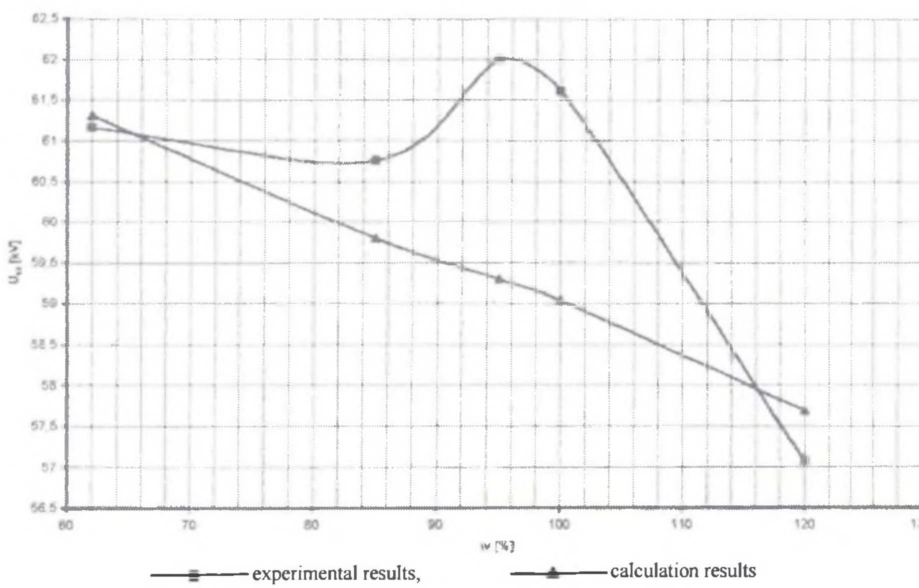


Fig. 5. Insulation gap's electrical strength as a function of the dust grains' concentration at different distances between electrodes
Rys. 5. Wytrzymałość elektryczna przerwy izolacyjnej jako funkcja koncentracji ziaren pyłu przy różnych odległościach pomiędzy elektrodami



concentration of dust grains $N_d = 5 \cdot 10^9$ [m^{-3}]
Fig. 6. Comparison of the experimental and calculation results of electrical strength in insulating gap.
Rys. 6. Porównamie wyników pomiarowych i obliczeniowych wytrzymałości elektrycznej przerwy izolacyjnej

$$U_o = \frac{U_j\pi\left(N_a r_a^2 + N_d r_d^2\right)a_o\left\{1 - d_d\sqrt[3]{N_d\left(1 + 10\left[1 - \exp\left(-\frac{m_r}{11}\right)\right]\exp\left(\frac{w-100}{63,5}\right)\right)}\right\}}{\frac{X_{ja}}{N_a + N_d}\left(\frac{N_a}{l_{ea}} + \frac{0.3N_d}{l_{ed}}\right)}[V], \quad (1)$$

where: U_o- flashover voltage in air gap, V_I – ionisation potential of the air, N_a concentration of air molecules in normal conditions, r_a, r_d - radius of air molecules and dust grains, N_d- concentration of dust grains, a_o-distance of air gap, m_r-mass fraction of soluble grain, w - relative humidity, X_{ja}-minimal free path of electrons with collision ionisation, l_{ea}- mean free path of electrons in air, l_{ed}- mean free path of electrons among the dust grains in airs.The primary verification of the analytical results was based on the laboratory investigations. The comparison of experimental and calculation results is presented on figure. 6.

We can see from this comparison that the analysis and calculations are in a relatively good sufficient for engineering practice. The differences between experimental and calculation results are within the range 0-15%. It is highly dependent on humidity of air and concentration of dust grains in electric field.

5. CONCLUSIONS

The results of a theoretical analysis and of experimental investigations into the influence of contamination in the air caused by industrial dust grain on the electrical strength in an insulating gap show that:

1 The electrical strength of an insulating gap with uniform electric field significantly depends on the concentration of the grain dust.

2 The electrical strength of the contaminated air, sharply decreases with the humidity in the air more than 85% .

3 The influence of dust grains on electrical strength of insulating gap is increasing with the rise of the distance between the electrodes.

REFERENCES

1. Kałużny A.J.: Wpływ pyłów przemysłowych na wytrzymałość elektryczną odstępów izolacyjnych powietrznych. Science Book of Silesian Technical University of Gliwice, s. Elektryka, z. 127, 1992.
2. Kałużny A.J., Kałużna U.: Electric strength of high voltage insulating gap in polluted air. Proceedings of the 9th International Symposium on High Voltage Engineering, Subject 1995 r., rep.2155.
3. PN-75/E-04060, „High Voltage Measurements. Test with Alternating Voltage".
4. Siewiec F.: Analiza pomiarowo-teoretyczna wpływu ziaren pyłu przemysłowego na mechanizm wyładowania elektrycznego w izolacyjnych odstępach powietrznych. Praca magisterska, Politechnika Śląska, Gliwice 2001.

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