Investigation of the Influence of Plastic Evaporation on Pressure Rise due to Fault Arcs in Electrical Installations

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Internal arcs in electrical installations cause a sudden pressure rise due to heating of the gas surrounding the arc. The pressure rise may endanger personnel, the electrical installation and even the switchgear building. Based on the need to design switchgear more compact, plastic materials are used. The interaction of the arc with these materials releases gases by evaporation and thereby influences the pressure rise within the installation as well as the energy balance of the arc. In order to analyse these effects in detail, some commonly used plastics are exposed to a high current arc. In this contribution the pressure development in a closed vessel equipped with different plastic materials, their mass losses and the portion of electrical energy causing overpressure, known as thermal transfer coefficient or k_p–factor, are determined at three values of the filling pressure of the vessel. The plastic materials under investigation are epoxy, polyamide 6.6, polybutyleneterephtalate, polycarbonate and silicone rubber. With the information provided, the influence of the different plastics on pressure development can be predicted.

Keywords: Internal arcs, plastic evaporation, pressure calculations

1 INTRODUCTION

Internal arcs are high current fault arcs, which occur e.g. within electrical installations such as metal-clad switchgear. They are initiated e.g. by surges in power grids, insulation failure, malfunction of equipment, and human error. In average, one arc fault occurs per 10,000 switchgear and year in Germany [1]. As a consequence, thermal and pressure effects of fault arcs are a real challenge, which can endanger people, electrical equipment and even switchgear buildings.

In compact switchgear plastic materials are increasingly used to avoid access to live parts e.g. to insulate busbars, cables, measuring transformers, as partition panels etc. In case of an internal fault, the pressure rise within the installation is influenced by the evaporation of plastics in the compartment with the arc and by that the energy balance of the arc and the thermal transfer coefficient known as k_p-factor (the portion of electric arc energy contributing to overpressure). The value of k_p and its dependence on gas density must be known for reliable pressure calculations.

The plastics used can be roughly divided into three categories, in thermosetting plastics, thermoplastics and elastomers. The composition in air-insulated switchgear is e.g. 74, 21 and 5 mass percent (9.5 of total mass percent [2], figure 1).

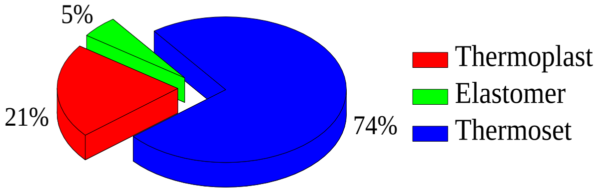

Fig.1: Example of plastics used in air-insulated switchgear in mass percent [2]

Up to now the interaction of high current arcs with plastic material is not well investigated. There exists only some experience on the interaction of switching arcs with insulation panels with the focus on change of arc voltage, arc energy and the dielectric recovery of the electrode gap after current zero [3]. Furthermore the fire emergence of plastics, when exposed to electric arcs is considered [4] and additionally the mechanical behavior in the case of polymer [5]. The focus in this contribution is on the change of pressure rise due to plastic evaporation.

2 TEST SETUP

To investigate the influence of plastic evaporation on pressure rise, experiments are performed in a closed vessel. The mass loss, the pressure rise and k_p depending on the filling pressure (gas density) are determined for selected plastic materials. The vessel (volume 71 L; electrode distance 10 cm; Cu electrodes) is initially filled with atmospheric air. The test circuit is an LC resonant circuit (L = 314 µH, C = 36 mF, charging voltage up to 4 kV) with a stored energy of 272 kJ in maximum. The arc bending in the test vessel is reduced by the magnetic field of the return conductors, which surround the arc like a cage. A typical current and voltage curve is provided in figure 2. Due to the discharge of the capacitor bank, the current amplitude decreases with time. The number of half cycles varies with the filling pressure. The arc voltage is nearly constant during the half cycles. The filling pressure has been varied between 250 mbar and 2 bar.

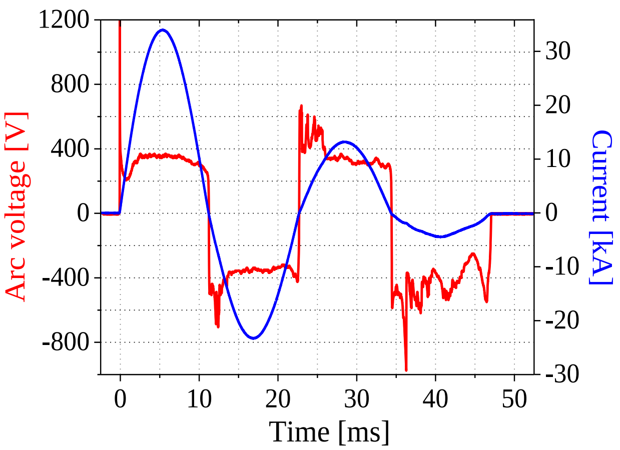

Fig.2: Typical current and arc voltage development (filling pressure in the vessel 1 bar)

To get comparable measurement results, the same arrangement was chosen for all evaporation experiments with the electrodes put in parallel to the plastic plates in a distance of 3 cm (figure 3). The size of the plates is 20 cm x 20 cm.

Fig.3: Electrode arrangement with the plastic plate below the arc

The following materials have been investigated:

Table1: Investigated plastics

Thermoplastics	
Polybutylenterephthalat, portion of fiber glass 30 %	PBT
Polybutylenterephthalat, portion of fiber glass 25 % with flame retardant	PBT (FR)
Polyamide 6.6	PA 6.6
Polyamide 6.6 with flame retardant	PA 6.6
Polycarbonate	PC
Thermoset	
Epoxy (Araldite®/Aradur® casting resin)	EP
Elastomer	
Wacker SilGel 612	Silicone

3 EXPERIMENTAL RESULTS

The results of the mass loss measurements are summarized in figure 4. Three to five measurements have been performed with each material at three values of the filling pressure.

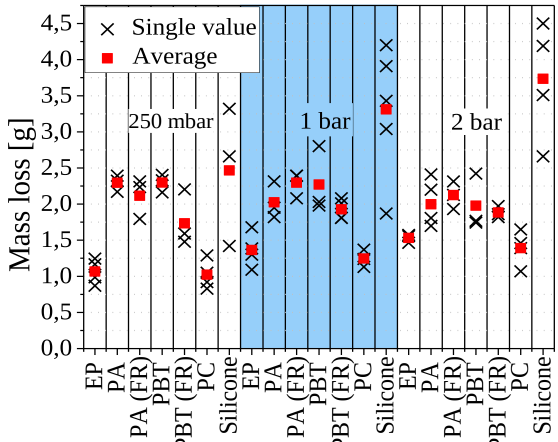

Fig.4: Measured mass loss of the plastics at different initial pressures (arc energy between 159 and 187 kJ)

The lowest average mass losses are obtained exposing PC and EP to the arc. In the case of EP the results can be explained with the close-meshed crosslinking, where the matrix requires a large amount of energy to decompose the material. The molecules in PC have a limited mobility raising its temperature resistance [6]. The mass losses of PA and PBT in the versions with and without flame retardant are much higher and of more or less comparable size. In this group PBT (FR) has the lowest average mass loss at all filling pressures. The flame retardant seems to reduce the mass loss.

Silicon exhibits the highest (average) mass loss, but also the largest divergence of the measurement values. This can be explained by the way, in which the arc reacts with the surface of silicone plates. The surface bursts and small silicone fragments are spread in the whole test vessel making the exact determination of the mass loss difficult.

Apart from the mass losses, the pressure rise in the vessel has been measured at different values of the filling pressure and with and without plastic plates exposed to the arc. In figure 5 the maximum pressure rise (related to the filling pressure) is shown. Three groups of results can be distinguished depending on the filling pressure. In each group the value of energy input is comparable.

In the first group (250 mbar filling pressure; ~ 163 kJ) the maximum overpressure is between 1.6 and 2.1 bar; in the second group (~ 178 kJ) it is in between 3.1 and 3.6 bar and in the third group (~ 186 kJ) between 3.9 and 4.9 bar.

The upper values in the groups are caused by the influence of plastic evaporation. The percentage increase due to plastic evaporation is about 14 % in average and independent on filling pressure.

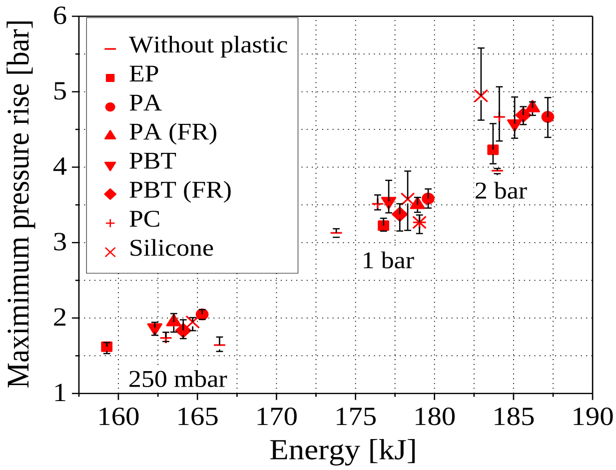

Fig.5: Maximum pressure rise as function of energy for different filling pressures

In each group the influence of the evaporation of the different plastic materials on pressure rise corresponds to the mass losses.

The scatter of the pressure values increases with filling pressure except for the plastics with flame retardant.

The energy input between the groups is caused by the dependence of the arc voltage on gas density. The difference of energy input between the groups is only in the order of 10 %. The large differences in the maximum pressure rise in the groups cannot be explained by the difference of the energy input.

4 DISCUSSION

In order to understand the strong pressure rise with filling pressure in figure 6, it is necessary to look at the portion of energy, which causes overpressure, i. e. to look at k_p.

k_p is determined by adapting calculated to measured pressure curves. The calculations have been performed with gas data neglecting the contamination by decomposition products of the plastics.

In figure 6 the thus determined k_p-factor is provided for the tests with silicon and epoxy plates as well as without plastics depending on filling pressure. All k_p-values increase with filling pressure, which explains the strong increase in overpressure in figure 6.

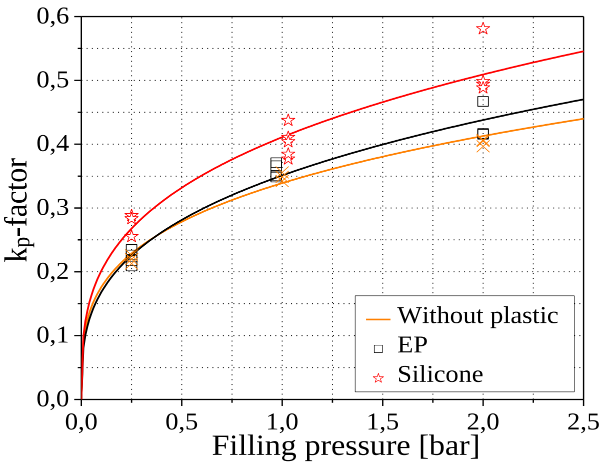

Fig.6: k_p-factor as a function of filling pressure for EP and silicone

The rate of rise of k_p decreases with filling pressure and the influence of the plastic evaporation on the k_p-values increases. While EP evaporation has only a small influence on k_p, the influence of silicone evaporation is much stronger.

The k_p-values derived from tests with the group of thermoplastics are depicted in figure 7. The tests have been performed at the same filling pressures as before, however, the results in this figure are shifted around the correct value for clarity. k_p for thermoplastics is between that for EP and silicone.

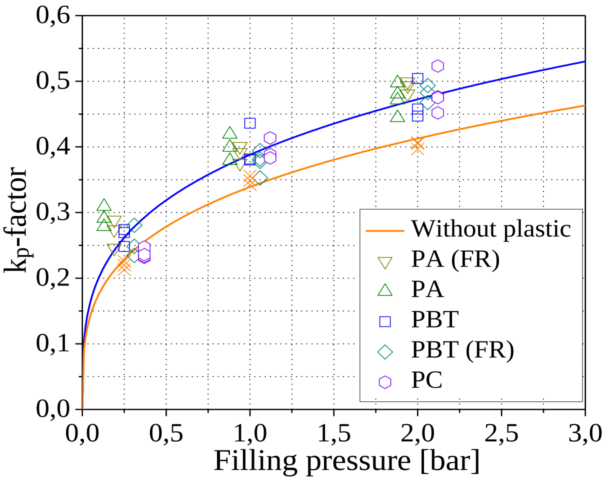

Fig.7: k_p-factor as a function of filling pressure for thermoplastics

In order to analyze the effect of the evaporation of plastics on k_p, its increase (related to tests without plastics) is examined. It is defined as:

$$\Delta k_p[\%] = \frac{k_{p\,with\,plastic} - \bar{k}_{p\,without\,plastic}}{\bar{k}_{p\,without\,plastic}} \; x \; 100$$

where $\bar{k}_p$ is the average value at a certain pressure.

In figure 8 Δk_p-values of single tests and their mean value at different filling pressures of the arrangement are provided for all plastic materials under investigation. If EP is exposed to the arc, Δk_p is smallest, in between 2 and 8 %.

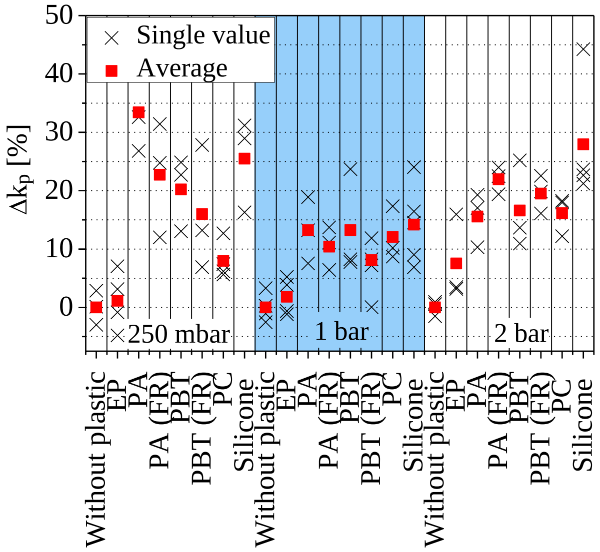

Fig.8: Δk_p for different type of plastic with variation of filling pressure

Using PA and PA (FR) Δk_p increases up to 13 to 33 % and 10 to 24 %, respectively. In the case of PBT and PBT (FR), the values of Δk_p increase up to 13 to 20 %. In the group of thermoplastics the evaporation of PC has the smallest influence on Δk_p (up to 8 to 16 %). Silicone increases the average Δk_p by 14 to 28 %. All values provided are based on the measurements at all filling pressures. The change of k_p exposing thermoplastics to the arc is in average in between that of silicone and EP, with the exception of PA at 250 mbar. Δk_p for all plastics is in average 18 %.

5 CONCLUSION

The evaporation of plastic due to internal arcing causes an increased pressure rise in a closed vessel. The lowest increase results by using epoxy (2,9 %) and the highest by silicone (19,3 %). The pressure increase from thermoplastics is in between. The values have been obtained independent on the filling pressure of the test vessel.

Apart from pressure increase due to the presence of plastic materials in the test arrangement, the value of the thermal transfer coefficient k_p depending on the filling pressure has been determined. With this information, reliable pressure calculations, including the effect of plastic evaporation, are possible.

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