MIE experiments and simultaneous measurement of the transferred charge

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Abstract. Using the apparatus commonly utilized for the determination of the minimum ignition energy a series of experiments have been carried out in ethene/air as a representative of explosion group IIB. Thereby, the transferred charge as a criterion to judge the ignition potential is determined to verify the threshold of 30 nC of transferred charge given in the standard IEC 60079-0. The stored charge in a capacitance before the discharge is compared to the transferred charge in the spark. Furthermore, the correlation of ignition energy and transferred charge is examined. Based on the results presented here, the threshold of the transferred charge for explosion group IIB is discussed. Moreover, the MIE value of an ethene/air mixture is reviewed taking into account the measurement uncertainty.

1. Introduction
The minimum ignition energy (MIE) is determined using a capacitive spark discharge [1]. Thereby, the energy of the spark discharge is assumed to have the amount of energy stored in the capacitance before the discharge. The MIE is determined by varying the capacitance, the charging voltage, the electrode diameter, the electrode gap width and the mixture composition in order to find the lowest energy necessary to ignite the given mixture.

Gibson and Lloyd [2] found in 1965 that there is a correlation between the incentivity of a brush discharge and the charge transferred by it. Eisfeld [3] proposed in 1984 a test method based on this finding and applied for a patent for a coulombmeter he had developed [4]. Later, in 1988, Gibson and Harper too stated that the charge transferred in a discharge provides guidance on its incentivity [5]. Based on MIE measurements, von Pidoll et al. [6] have calculated the charge stored in the capacitance in order to obtain an estimation of the transferred charge. By correlating the MIE with the lowest calculated charge, von Pidoll et al. [6] have suggested transferred charge thresholds in order to judge if electrostatic discharges are potentially incendive or not. These threshold values are now defined in the standard IEC 60079-0 [1].

Even if the criterion of transferred charge is more often used to assess the incentivity of brush discharges the criterion is also applicable and used for the assessment of spark discharges. However, in a recent study, Langer et al. found that these thresholds are sufficient concerning brush discharges regarding explosion groups IIA and IIC. But in case of explosion group IIB, the achieved results were close to the threshold of 30 nC. For the 8 % ethene/air mixture used, the lowest transferred charge leading to ignition of the mixture was 31.5 nC ± 1.0 nC [7]. Since spark discharges are known to be more incendive than brush discharges it is consequent to recheck the thresholds using spark discharges.

Since the validation of the transferred charge threshold can only be reliably performed near the MIE, another objective of this work is to recheck the MIE of ethene. Furthermore, using the “Guide to the expression of uncertainty in measurement” [8], the received values are examined concerning the measurement uncertainty. The considerations concerning the uncertainty should lead to an estimation as to how accurate the results given in the literature can be expected to be.

2. Experimental set-up
A schematic view of the test set-up is presented in figure 1. A defined charging voltage is given to the capacitance until spark discharges occur. The experiment runs until an ignition of the mixture is observed. The corresponding voltage is noted and the ignition energy is calculated. Additionally, the transferred charge is measured using the coulombmeter. Furthermore, the originally stored charge in the capacitor \( Q \) is calculated. Reducing the ignition energy was attempted by varying the capacitance, the charging voltage and the gap width, respectively. Thereby, for a given electrode gap and given
capacitance the minimum voltage leading to a spark discharge was determined by varying the voltage. The diameter of both electrodes is 2.0 mm. For the tests the flammable gas/air mixture prepared was in the most ignitable range for ethene according to [9], since this is the most hazardous situation one can examine in matters of explosion protection. Hence, a concentration 8.0 % ethene in air was used for the experiments. A detailed description of the test set-up is given in [10].

**Figure 1.** Schematic view of the experimental test set-up.

3. Results

In figure 2 the correlation between the transferred charge $Q_t$ and the calculated charge $Q_c$ is presented. Thereby, the transferred charge was measured in 8 % ethene/air mixtures during the ignition tests. The calculation of the measurement uncertainty is described in more detail by Langer et al. in [10]. The expanded measurement uncertainty (coverage factor $k=2.0$) is used here assuring that all results have a probability of 95 % of being within the resulting expanded measurement interval. The uncertainty in $Q_t$ results from the coulombmeter, the uncertainty in $Q_c$ is mainly influenced by the measurement of the capacitance. The straight line represents $Q_t = Q_c$. It can be seen in figure 2 that the measurement of $Q_t$ gives reasonable values. The tendency of $Q_t \leq Q_c$ can be explained by the fact that there are residual charges in the capacitance [6]. This result shows, on the one hand, that the coulombmeter is suitable to measure the transferred charge during the discharge and, on the other hand, that $Q_c$ is not an ideal value to determine the thresholds of transferred charge due to the fact that there are residual charges.

In the following, the transferred charge $Q_t$ in dependence of the ignition energy for the observed ignitions of the 8 % ethene/air mixture is presented in figure 3. Thereby, the results are from different electrode gap widths. The criterion of the transferred charge can only be suitable for judging the safety of test items when - for all ignition energies - a transferred charge higher than the threshold value given in [1] is found. In figure 3 the threshold value according to the explosion group given in the standard [1] is drawn. Additionally, the hatched box represents the interval of ignition energy which is under the MIE given in [11].

For ethene/air mixtures which represent explosion group IIB, sparks with a transferred charge less than the threshold of 30 nC ignited the mixture. The lowest transferred charge $Q_t$ igniting the mixture was 26.6 nC ± 1.1 nC. The corresponding calculated charge $Q_c$ was 29.5 nC ± 3.5 nC. For this result, a gap width of 1.2 mm at a voltage of 6.00 kV and a capacitance of 4.90 pF was used.

In the last part of this paper, the MIE value of ethene given in [11] is reviewed. Thereby, the measurement uncertainty, in particular, is the focus of this study. The ignition energy is calculated using $W=0.5\cdot C\cdot U^2$. For 8.0 % ethene/air mixtures (figure 4), an MIE of 80.8 µJ ± 9.7 µJ was found at
a gap width of 1.2 mm at a voltage of 5.80 kV and a capacitance of 4.80 pF. The biggest influence with respect to the expanded measurement uncertainty originates from the determination of the capacitance. The transferred charge was 26.9 nC ± 1.1 nC, the calculated charge 27.9 nC ± 3.3 nC. Regarding the measurement uncertainty, the MIE is the same as the value of 82 µJ given in [11].

**Figure 2.** Correlation between transferred charge and calculated charge.

**Figure 3.** Transferred charge in dependence of the ignition energy for an 8.0 % ethene/air mixture.
4. Conclusion
Using the apparatus commonly utilized for the determination of the minimum ignition energy (MIE), a series of experiments have been carried out in the most ignitable 8% ethene/air mixture. Thereby, the transferred charge as a criterion to judge the ignition potential is determined to verify the thresholds of transferred charge given in the standards. The stored charge in the capacitance before the spark discharge is compared to the transferred charge in the spark. The measurement of the transferred charge performed with a coulombmeter gave reasonable values. It was found that the transferred charge is less than or equal to the stored charge within the measurement uncertainty budget. Furthermore, the correlation of the ignition energy and the transferred charge is examined. For ethene/air mixtures - as a representative of explosion group IIB - a minimum transferred charge of 26.6 nC ± 1.1 nC led to ignition which is lower than the current threshold of 30 nC. The MIE of ethene/air mixtures was determined to be 80.8 µJ ± 9.7 µJ which matches well with the given value of 82 nC in the literature. In summary, especially concerning the determination of MIEs and their corresponding transferred charge, it seems essential to give the corresponding measurement uncertainties in order to compare the achieved results. The measurement of the capacitance seems to be the main challenge in this context.

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