Does charge transfer correlate with ignition probability?

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Flammable or explosive atmospheres exist in many industrial environments. The risk of ignition caused by electrostatic discharges is very real and there has been extensive study of the incendiary nature of sparks and brush discharges [1-3]. It is clear that in order to ignite a gas, an amount of energy needs to be delivered to a certain volume of gas within a comparatively short time. It is difficult to measure the energy released in an electrostatic discharge directly, but it is possible to approximate the energy in a spark generated from a well defined electrical circuit. The spark energy required to ignite a gas, vapour or dust cloud can be determined by passing such sparks through them. There is a relationship between energy and charge in a capacitive circuit and so it is possible to predict whether or not a spark discharge will cause an ignition by measuring the charge transferred in the spark. Brush discharges are in many ways less well defined than sparks. Nevertheless, some work has been done [2,3] that has established a relationship between charge transferred in brush discharges and the probability of igniting a flammable atmosphere. The question posed by this paper concerns whether such a relationship holds true in all circumstances and if there is a universal correlation between charge transfer and ignition probability. Data is presented on discharges from textile materials that go some way to answering this question.

1. Description of experiments
Two systems for determining the charge transferred in brush discharges are described: one similar to the system used by Wilson [3], the other similar to the system developed by von Pidoll [4]. Garments are tribocharged whilst being worn and electrostatic discharges from their surfaces are recorded. Ignition tests are then carried out to determine if the discharges are incendiary. The ignition apparatus is similar to that used by Gibson & Lloyd [2] and Wilson [3].

1.1. Charge transfer measuring systems
A discharge is initiated by a spherical metal electrode. In the Wilson system the electrode is 30 mm overall diameter with a 20 mm diameter core electrically insulated from the outer part of the electrode. The core forms the signal path whilst the outer part is earthed to provide a shield. This arrangement significantly reduces induction that would otherwise reduce the measured charge. The core is connected to a 22 nF capacitor that collects the charge transferred in the discharge. The potential difference across the capacitor is recorded by a 1 GHz, 5 GS/s digital storage oscilloscope (DSO). Charge is calculated by multiplying the capacitance by the potential difference, i.e. the amplitude of the signal captured by the DSO. The Wilson system is shown schematically in Figure 1.
Figure 1. Wilson system for measuring charge transfer in electrostatic discharges.

The von Pidoll system makes use of a 25 mm diameter solid electrode. The electrode is connected via a shunt resistance of 0.25 $\Omega$ to the same DSO used in the Wilson system. Charge transfer is derived in two ways: by using the measuring function of the oscilloscope to determine the area under the voltage waveform; and using the Math waveform function to integrate the voltage waveform with respect to time and then taking the amplitude of the resulting waveform. In both cases charge is calculated by dividing the respective measurement by the shunt resistance. The von Pidoll system is shown schematically in Figure 2.

Figure 2. von Pidoll system for measuring charge transfer in electrostatic discharges.

1.2. Ignition apparatus

The design principle of the ignition apparatus is to produce a localised flammable atmosphere through which a discharge is passed. Discharges are initiated by an earthed 30 mm diameter spherical electrode positioned at one end of a cylindrical ignition chamber. The diameter of the chamber reduces towards the electrode to direct the flow of gas over the electrode. The gas mixture used is 29% by volume of hydrogen in air, which has minimum ignition energy of 0.027 mJ. The ignition apparatus is shown schematically in Figure 3.
1.3. Procedure
Tests are conducted with a range of garments made from typical examples of fabric used to control static electricity, including: homogeneous insulating fabric, fabric with “antistatic” coating, fabric with surface-conductive fibres, fabric with core-conductive fibres, fabric with conductive yarns in grid patterns and fabric with conductive yarns in stripe patterns. A garment is worn by a test subject and an area across the shoulders of the garment is tribocharged by rubbing with a reference material: polyamide, polyethylene or wool. Charge transfer in a discharge from the charged area of the garment is measured using the Wilson system. This is repeated five times in total with the garment being tribocharged between each approach of the measuring electrode. The sequence of tribocharging and measuring is then repeated using the von Pidoll system. After both systems have been used to measure charge transfer, attempts are made to ignite hydrogen gas by bringing the ignition apparatus up to the charged area of the garment. The garment is tribocharged between each approach of the ignition apparatus. Up to fifty attempts at ignition are made for each garment tested. Testing is stopped for a garment if one ignition occurs.

The atmosphere for conditioning and testing is 23 ± 1°C and 25 ± 2% relative humidity.
2. Results

| Charge Transfer (nC) Wilson System | Charge Transfer (nC) von Pidoll System | Does Ignition Occur? |
|-----------------------------------|--------------------------------------|----------------------|
| -663                              | -1120                                | Yes                  |
| -585                              | -628                                 | Yes                  |
| -557                              | -606                                 | Yes                  |
| -519                              | -685                                 | Yes                  |
| -489                              | -480                                 | Yes                  |
| -447                              | 0                                    | Yes                  |
| -346                              | -229                                 | Yes                  |
| -189                              | -13                                  | No                   |
| -183                              | -145                                 | Yes                  |
| -177                              | -88                                  | Yes                  |
| -79                               | -95                                  | Yes                  |
| -38                               | -2                                   | No                   |
| -27                               | -8                                    | Yes                  |
| -16                               | -12                                   | No                   |
| +296                              | +290                                  | No                   |

The range of negative polarity charge transfer values from garments that produce ignitions is 27 nC to 663 nC for the Wilson system and 0 nC to 1120 nC for the von Pidoll system.

The range of negative polarity charge transfer values from garments that did not produce ignitions is 16 nC to 189 nC for the Wilson system and 2 nC to 13 nC for the von Pidoll system.

3. Conclusions

The overlap in negative polarity charge transfer values for garments that produce ignitions and those that do not indicates that there is no direct relationship between charge transfer and ignition probability. Discharges from insulating materials are brush like whilst those from conductors are generally sparks. Within the selection of garments tested there are fabrics containing both insulating and conducting materials. Both brush discharges and sparks may occur from these materials. The spatial and temporal distribution of energy in a brush discharge is different to that in a spark and therefore one may expect that the ability to ignite a gas may also be different. Spatial and temporal distribution of energy within a discharge is not accounted for by measuring charge transfer. Wilson [3] explained that discharges from positively charge surfaces are different in nature to those from negatively charged surfaces. This explains why in these tests positive discharges of around 300 nC failed to ignite the hydrogen gas. In summary, whilst it may be possible to establish a relationship between charge transfer and ignition probability for specific materials and using a specific measuring system, there is certainly no universal correlation between these two parameters.

4. References

[1] Lewis, B. and von Elbe, G. *Combustion, Flames and Explosions of Gases*, Academic Press, Inc., New York (1951).
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