7. EXAMPLES FROM EXPERIENCE

7.1 Introduction

A number of practical electrostatic studies are described in outline in this chapter. These illustrate the range of approaches and observational techniques that can be involved together and the importance of making continuous recordings of parameters observed.

7.2 Cleanroom clothing

The clothing worn in cleanrooms is basically a polyester fabric. This is needed for avoiding shedding fine fibres and as an effective barrier for fine particles from the body and underclothing. Much clothing used for personal protection is based on the use of artificial fibres. These materials are likely to easily become electrostatically charged when rubbed and to retain that charge for an appreciable time. Antistat surface treatment is not acceptable in the case of cleanroom garments and would involve retreatment after laundering. Conductive threads have been included in the fabrics for these garments to provide a way to control static. Some conductive fibres are surface conductive, others are core conductive (with the conductive component within a polyester sheath). Fabrics with core conductive threads are preferred because they retain performance over longer periods and there is less chance of shedding particles of the conductive component. The question that arises is how to assess the suitability of these materials and these garments for avoiding risks from static electricity? Traditionally the suitability of materials has been assessed by measurement of surface resistivity. This would reject fabrics with core conductive threads. With fabrics including surface conductive threads it is clear that if these threads contact the resistivity measuring electrodes that the measurements will refer to the resistance of the threads and will not provide any information on the areas of fabric between the threads. Corona charge decay measurements (see Chapters 3.4 and 4.9) provide a fair assessment of the ability of the fabric surfaces to dissipate static charge. On this basis it is likely that polyester fabrics with core conductive threads will still be rejected because charge decay times are likely to be long. However, if the problem is approached from the practical use point of view, one asks the question as to what surface voltages are likely to arise from contact and rubbing actions. The assessment is then in terms of whether the surface voltages that arise will be significant. Thinking of the assessment from this point of view made it clear that if charge transferred to a surface experienced a high capacitance then only low surface voltages would arise. The core conductive threads might provide such a high capacitance – and render the fabric and garments acceptable.

A number of studies were carried out that aimed to model practical use of garments [1,2,3]. An operator clothed in the garment to be tested stood on a plate connected to a virtual earth charge measurement unit. A fieldmeter was mounted a set distance (100mm) from the upper arm. Testing involved neutralizing the charge on a Teflon rod and then making a quick tribocharging impact of the rod on the arm in the area directly under the fieldmeter. The observations of the quantity of charge transferred and the local surface voltage created, and how this voltage decayed with time, were recorded. From these studies the surface voltage per unit of charge transferred was calculated as well as the charge decay times. Measurements were also made of the corona charge decay characteristics of these fabrics at the same time under the same environmental conditions using a JCI 155v5. These studies included measurements of the initial peak voltage achieved per unit of corona charge transferred. It was shown that there was a reasonable relationship between the performance exhibited with tribocharging of garments and that exhibited with corona charging [4]. This comparison illustrated the need to take account of the time for separation of surfaces in the tribocharging studies. An example of comparison between tribocharging and corona charging performance is shown in Figure 7.1.

The outcome of this work was the concept that the capacitance experienced by charge on the surface of a material is a relevant feature for assessing the suitability of materials for avoiding risks and problems. These studies showed that it was possible to predict the maximum surface voltage that would be expected from tribocharging in practice from the results of corona charging measurements on the fabric. This approach to the assessment of materials was included in a document drafted for British Standards committee GEL101 [5] and is the subject of a published paper [6].

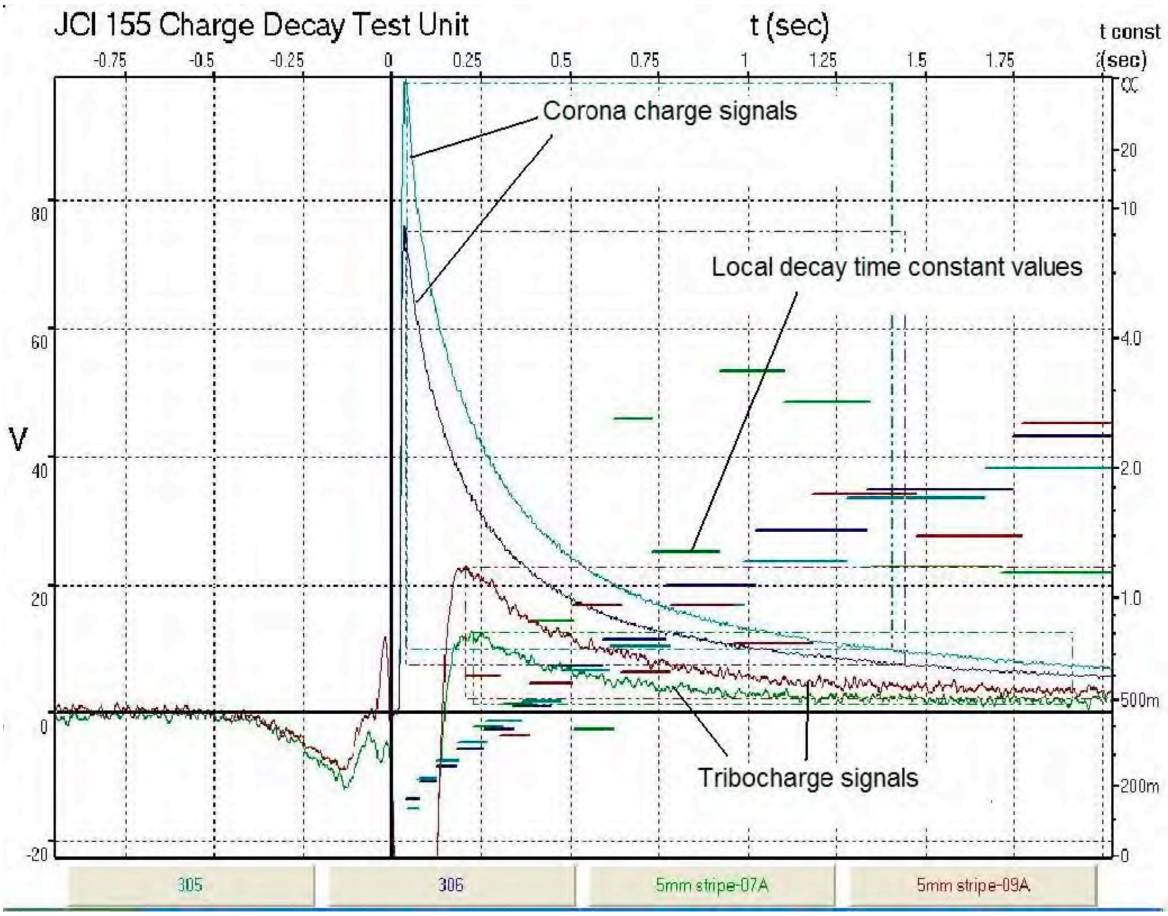


Figure 7.1: Response to corona and tribo charging of cleanroom garment fabric with 5mm stripe pattern conductive threads

A number of studies were also made where stretched and freely supported samples of various materials were tribocharged by impact with a Teflon rod in a similar way as with the inhabited garments. The arrangement for this is shown in Figure 7.2.

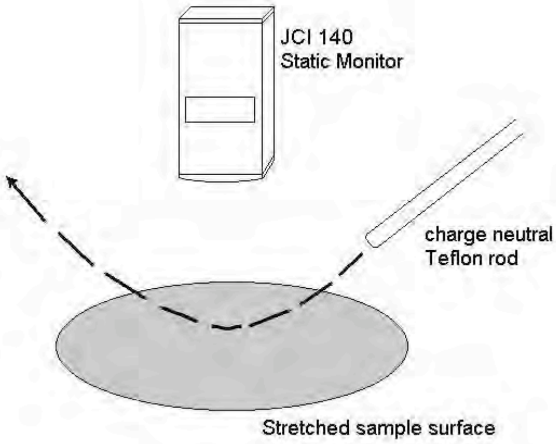


Figure 7.2: Arrangement for impact charging studies

Examples of the relationships between the quantity of charge transferred and the initial peak voltage are shown in Figure 7.2.

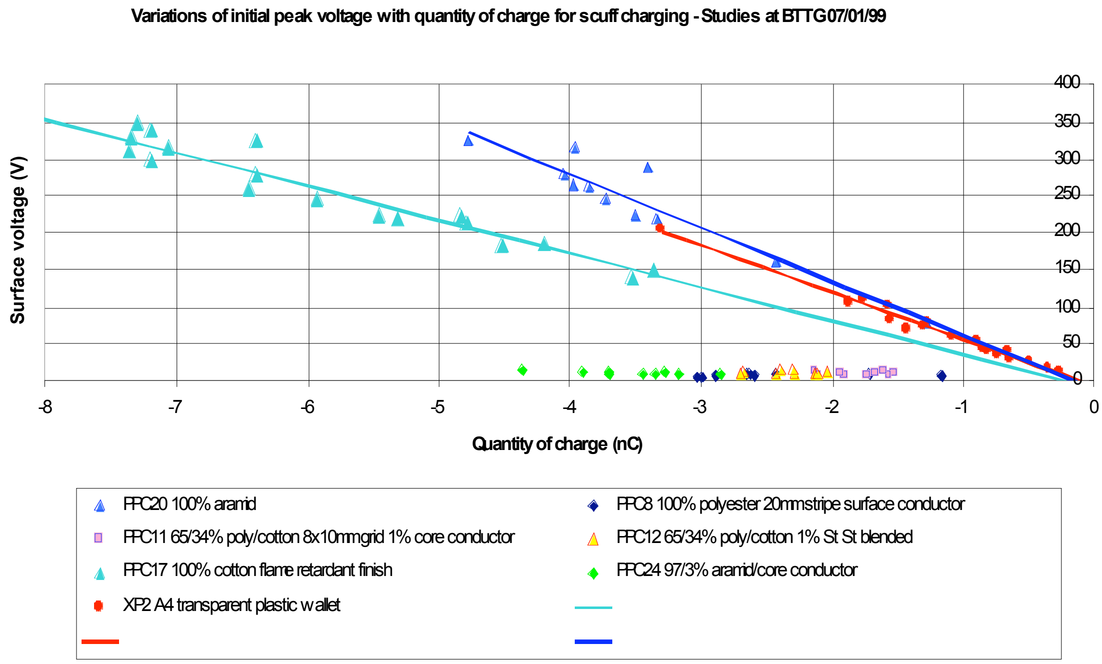


Figure 7.3: Variation of initial surface voltage with quantity of charge transferred

These studies show very clearly in Figure 7.3 that the initial surface voltage varies linearly with the quantity of charge transferred and that the initial sutface voltage is strongly suppressed by the presence of conductive threads in fabrics.

7.3 Tanker studies

In 1967 and 1968 three of the then new very large crude oil carriers (VLCC) suffered major damage from explosions. An investigation was started to find the cause and an appropriate solution. The explosions had all occurred during the ballast return voyage while the cargo tanks were being cleaned with high pressure water jets. Static electricity was suspected as a possible cause. An international research effort was mounted and many of the major oil companies were involved as well as a number of research institutes and universities. As the author, at UKAEA Culham Laboratory at the time, had some experience with static electricity (from PhD work) it was suggested that a contribution might be made as part of the laboratory diversification programme at that time.

Several of the other groups concerned with this problem were pursuing laboratory studies and some others, notably Shell KSLA in Amsterdam [7], were making some shipboard studies. Relevant laboratory facilities were not available at Culham and it was felt that what was important was to try to find out what actually happened in practice on board tankers during tank washing operations. The idea was put forward (perhaps not uniquely) that the mechanism for causing ignition of flammable gases in the cargo tanks was that slugs (lumps) of water created by action of the washing jets were charged by the electric fields formed from mist in the tanks and then being discharged with spark discharges as they reached other parts of the tank structure. It seemed that he occurrence of such spark events should be able to be monitored by radio observations. This proved to be a fruitful line of investigation and laboratory studies soon showed that radio observations at 38MHz were a very sensitive way to monitor the occurrence of spark events – with very low sensitivity to corona [8,9]. It seemed sensible that to avoid risks of making false observation by events local to a single radio aerial that two aerials should be mounted within the electrically shielded test environment and monitored via coincidence circuits with anti-coincidence to any radio signals observed at the same time by external aerials. Test equipment was built and its operation demonstrated in a large test tank at KSLA in Amsterdam and then during a pre-commissioning voyage of a new OBO (oil or bulk ore carrier). This OBO had been built for John Houlder (Houlder Bros) and who was motivated to contribute to the investigation of tanker explosions – not least because problems had also been experienced during ballast sloshing in the full width tanks of OBOs.

The above work lead to several shipboard investigations during ballast voyages [10,11]. The equipment was refined to include fieldmeters suitable for monitoring and interpreting the electrostatic conditions in the tanks during washing [12] (see also Chapter 4.15 on Modelling), radio detection observations on the occurrence of sparks and flash photography to try to photograph the situations in the tanks at the instant of occurrence of individual spark events (as illustrated in Figure 7.4 and 7.5 below). All the equipment had to be suitable for use in what might be a flammable atmosphere and able to withstand the impact of high pressure jets of salt water!

The overall outcome of the shipboard studies was that sparks do occur during tanks washing operations, that there are large numbers of sparks and that they are associated with particular directions of impact of the washing jets around the tank structure. These shipboard studies were backed up by a number of laboratory investigations into the radio emission characteristics of sparks from various isolated bodies, by studies on the incendivity of discharges from bodies approaching a water surface and by a number of computer modeling studies [10,11].

Figure 7.4: Example of flash photograph during washing triggered by occurrence of a spark

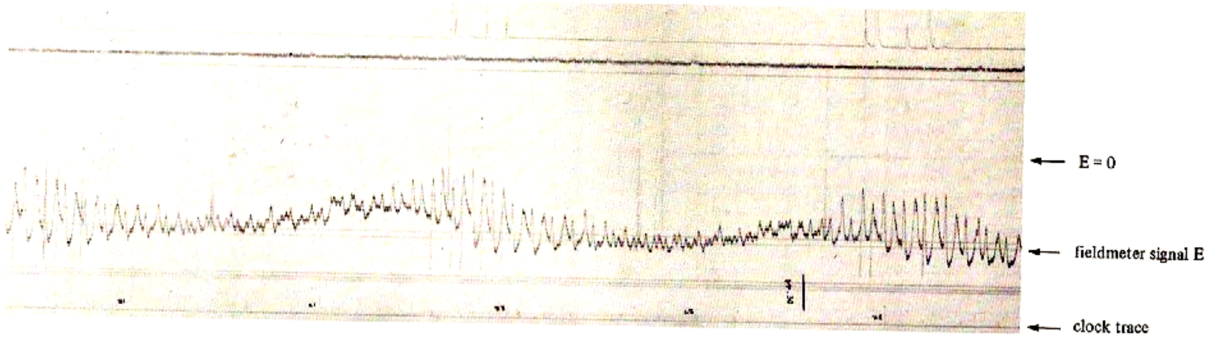


Figure 7.5: Example recording of fieldmeter signal variations during tank washing with associated occurrence of coincident radio signals from spark events (top trace)

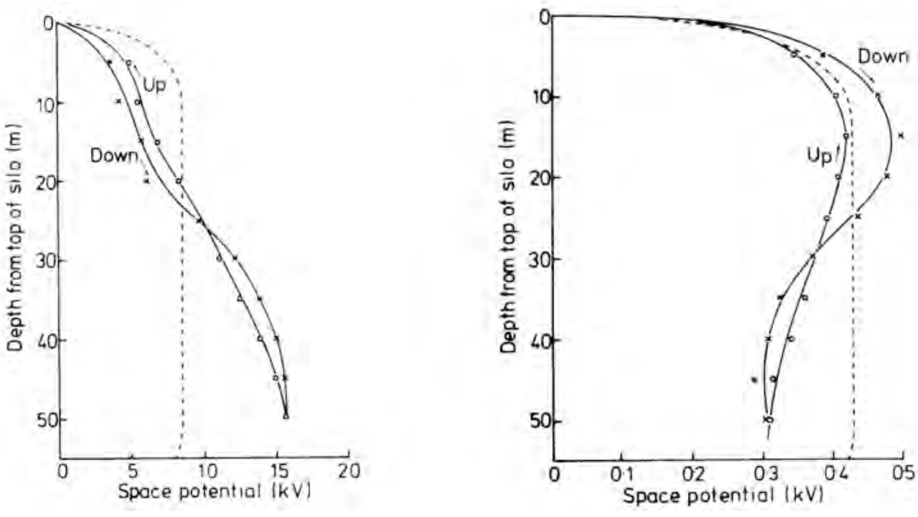
It had been hoped that an understanding of how sparks occurred during tank washing might lead to mechanical design changes to minimize or avoid risks. However, the practical solution adopted by the industry has been to use inert gas (spent boiler gases), that is back filled during cargo discharge, to prevent the occurrence of flammable atmospheres within the cargo tanks.

7.4 Food product silo

Anxiety had been expressed in 1978 about electrostatic safety in the operation of large food product silos following a number of explosions in grain elevators [13] that caused serious damage. A food product company operating a large silo in the UK felt it desirable to have a safety assessment made.

It was appropriate for this to use the instrumentation and approaches we had developed for the studies of tank washing of large crude oil tankers. From the top of the silo a couple of fieldmeters on 50 m connection cables were used to monitor the local potential near the top of the silo volume and to examine the potential distribution within the silo volume during and after filling activity. A couple of radio detection aerials were positioned near the top of the volume of the silo to pick up any occurrence of spark type discharges during silo operation. As in the tanker studies observations were recorded on uv chart recorders.

Examples of potential probe observations in the volume of the silo are shown in Figure 7.6 below during product filling and afterwards [11]. An example of a number of sudden voltage excursions that were observed is shown in Figure 7.7. No mechanism was identified responsible for these voltage excursions.



(during filling) *(after filling)*

Figure 7.6: Potential distributions by lowering fieldmeter though volume of food product silo

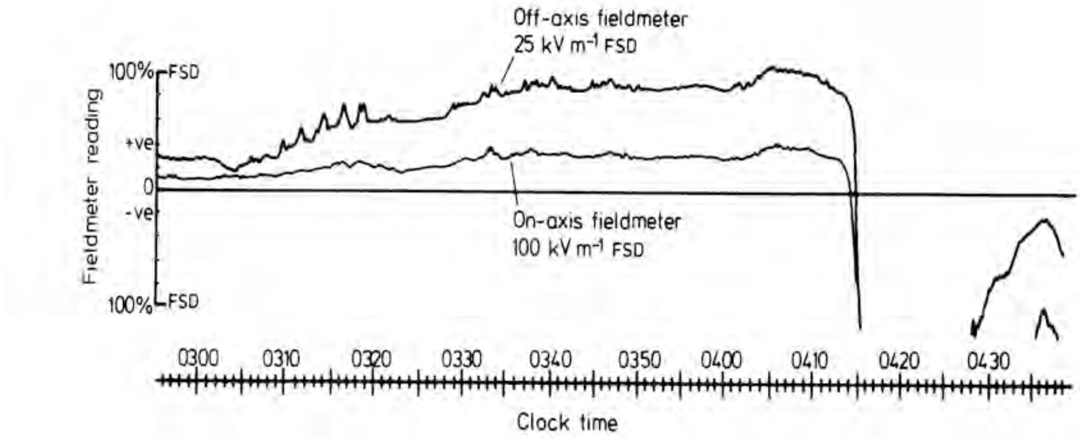


Figure 7.7: Fieldmeter observations made near top of food product silo during 'normal' filling showing occasional very large sudden excursions of space potential (100kV m^{-1} is about equal to 11kV of local space potential).

The outcome of these studies was that there were several of these quite large voltage excursions but no radio signals were observed to indicate the occurrence of any spark discharges. It was concluded that although the sudden voltage excursions were electrostatically interesting there was no reason to be anxious about electrostatic safety.

7.5 Lightning warning

The local risk of occurrence of lightning depends on the local atmospheric electric field. However as this can change quite quickly a practical warning system needs to combine measurement of electric field with measurements of radio noise and lightning impulse activity to provide useful advance warning of risk. Practical systems need to be able to operate continuously in the presence of heavy rain, so instrumentation has to be designed and constructed appropriately and to incorporate operational health monitoring to ensure confidence in observations – as discussed in Chapter 3.2.8.6 [14]. Such a system was installed on the island of St Kilda (about 40 miles into the Atlantic off the Outer Hebrides) and has operated there over the last 10 years.

7.6 Car seats

Many people experience shocks when getting out of their car. This is a nuisance and can be upsetting. The energy involved when the person's body discharges to the car bodywork can be sufficient to ignite flammable hydrocarbon vapour air mixtures. Such discharges have been responsible for a number of ignitions and significant damage in situations where vehicles have been refueled with latching fuel fillers on epoxy painted forecourts. The problem here is that the customer may leave the filler in operation, get back into the vehicle, become charged on leaving the vehicle and create a spark discharge at contact with the filler in the flammable atmosphere issuing from the tank.

Measurements of body voltage were made on getting out of a car with various types of clothing and a number of different seat coverings on to a layer of insulation. An electrostatic voltmeter (JCI 148) was rested on the passenger seat and connected to a digital recording oscilloscope (Picoscope and laptop PC). The 2m high voltage lead was connected to the arm and arranged so that the person could easily get out of the car while still reliably linked to the electrostatic voltmeter. As shown in Figure 7.8 the body voltage rises to a peak and then falls back to a plateau level – the fall being associated with the second foot coming down to rest on the ground and the consequent increase in capacitance. These studies showed that even with normal cotton or wool based clothing and ambient environments around 50%RH it was easy to get body voltages in the 10-15kV range. This is enough to give quite a sharp shock.

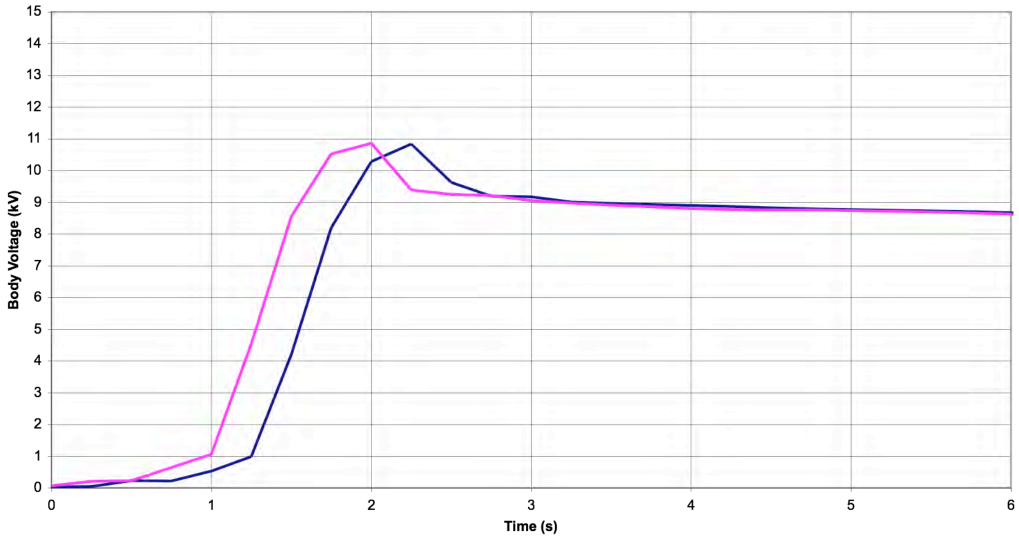


Figure 7.8: Variation of body voltage getting out of a car – normal car seat, wool suit (09/03/97)

The outcome of these studies was first, that body voltage measurements are reasonably reproducible test to test; and second, that there seemed prospects that maximum body voltages could be limited towards a level at which no shock would be felt (and at which there would be no risk of ignition) by using a seat covering that included a pattern of core conductive threads. Further progress depends upon the readiness of vehicle manufacturers to admit there is a problem and that it is worth paying just a little for a solution!

7.7 Electrostatic safety at solvent extraction plant

There have been fires at a number of organic solvent extraction plants associated with the extraction and purification of metals. Such fires have caused extensive damage to processing plant that required serious expense for rebuilding. Static electricity has been suspected as a possible cause of ignition.

On-site studies have been carried out on electrostatic safety at a number of solvent extraction plants around the world involved in the extraction and refinement of copper and other metals. These studies have been required because of the occurrence of fires at several plants. The aim has been to investigate risk prospects and recommend remedial measures. The studies have involved conductivity and charge decay measurements on process liquids sampled from various points around the plant, measurements of surface voltages on pipework and flanges and measurements of body voltages on walkways, etc [15].

Although organic solvent process liquids have high flashpoints any foam on a liquid surface can have a low minimum ignition energy. Foam is present on liquid surfaces in separation tanks, and is likely in part filled pipework so there is need to avoid any risk of electrostatic discharges.

The conductivity of the process liquids plays a major role in keeping voltages low throughout process plant - and so ensures safety in normal plant operation. Conductivity needs to be greater than 300pS m^{-1} (or charge decay times less than 0.05s) for flow velocities up to 2m s^{-1}. At higher flow velocities higher conductivities are needed. Maximum flow velocities need to be kept down to a few meters per second.

On HDPE pipework (used to avoid corrosion problems) only low voltages were observed. This would be expected so long as pipes are full of process liquid because of the capacitance to the liquid suppresses surface voltages. Such pipework hence does not present a significant risk. Metal flanges following pumps, and after any flow restriction, need to be earth bonded because if these were at high voltages there would be opportunity for metal to metal sparks to occur. Discharges to HDPE pipes or to process liquids themselves are not likely to create an ignition risk. Sampling of liquids on open surfaces in settling tanks needs to use insulating cups on insulating cord.

The assessment of plant safety requires proper measurement of the conductivity (or charge decay) performance of process liquids from various points around the operating plant. It is appropriate to also make measurements on feedstock liquids in case there could be a flush though of these at any time. In addition, it is necessary to measure local voltages from time to time on pipework and any isolated metal flanges and valves around the plant. An appreciation needs to be made of the consequences of fault or failure situations, indirect possible sources of risk and how these will be handled. All of this needs to be documented and audited on a regular basis.

7.8 Airborne particles

The influence of electric fields on fine particles suspended in the air can conveniently be studied by photography using dark ground illumination. An exposure of say 1/30s will show both the concentration of particles, via the area concentration on the recorded images and the depth of the field of illumination, and the direction and velocity of movement, via the track length and the exposure duration. Particles down to 5 microns can be tracked in this way.

The above approach was used in PhD thesis work [16] studying the influence of electric field and ionic wind on the behaviour of airborne particles in corona discharge fields. It was also used in an industrial study of the movement of airborne particles liberated at slitting of asbestos based engine gasket material and in a monitor for airborne fibres [17]. More sophisticated studies have been made recently using Doppler laser observations [18].

7.9 Airborne fibre monitor

A novel instrument was developed to enable the concentration and length and diameter information to be obtained on airborne fibres. This was aimed as a basis for a portable instrument for monitoring the risks that might be presented by airborne asbestos fibres in workplace environments.

The approach devised [17] was to use a high frequency electric field to align of any asymmetrical airborne particles with laser light scattering arranged to selectively detect the presence of individual aligned particles in a streamline airstream within a clean air sheath. If a particle was detected by the selective scattering of light into one of two photomultiplier detectors the direction of the aligning field is switched through a sizeable angle. If the particle detected is a fibre then the signal at the first photomultiplier will decrease and after a delay a signal will be observed at the second photomultiplier. The time taken for the second signal to rise relates to the length diameter ratio of the fibre. Experimental studies showed that fibres could be detected well down into the respirable size range with good immunity to other types of particle [17]. While prospects looked good technically, it was clear that a lot of testing would be needed to displace microscope analysis of personal monitor samplers.

7.10 Coated metal sheets

Problems were reported with the handling of stacks of thin steel sheets that had a protective plastic film coating on one side. It was thought that static electricity might be binding the sheets together. Measurements showed that surface voltages on the coated films arising from sheet handling were fairly modest – in the range 100-200V. These measurements also showed that these voltages only decayed away very slowly. Calculations soon showed that although surface voltages were low the area density of charge was quite high – with the surface voltage kept low by the high capacitance between the outer surface of the coating film and the underlying metal surface. Proximity of the surface layer of charge to the smooth reverse surface of the sheet above would easily generate forces of several kilograms – quote adequate to support the weight of a sheet!

Plausible solutions to such problems are a) to ensure that charge on the surface of the coating can dissipate, at least laterally, in a timescale short compared to plate handling times, and b) provide some topographic roughness of the coating to decrease the area of the film charged by rubbing and in close proximity to the neighbouring smooth metal surface.

7.11 Adhesive manufacture

The manufacture of adhesives involves the blending of solvents with a number of materials - of which some generate very high levels of charge during mechanical mixing. Two approaches were developed to avoid the risks of ignition in such operations [19]. First, changing the sequence of mixing so that flammable atmospheres are not present when there are high levels of static charging. Second, use of antistatic additives (where permissible) to promote charge dissipation.

7.12 Health Monitor

Operation of a 24 hour body portable health monitor unit was easily upset by static discharges occurring with normal domestic activities, such as removal of clothing at night. This was a particular problem in low humidity environments. The unit was basically a small belt mounted box of electronics to which a number of sensors over the body were connected. Signals from nearby static discharges picked up on the sensor leads, acting as aerials, coupled into the circuits and upset circuit operation. Opportunities were available within the box for coupling around the circuit by resistive, capacitive and induction mechanisms. The immunity to static discharges was raised to a very acceptable level by the simple expedient of capacitively decoupling each incoming lead directly to the metallised case of the box. This diverted the fast transient flows of charge to the lumped self-capacitance of the clam-shell case and thereby avoided penetration of transient signals to the inside of the box. As more reliance is placed on microelectronic and computer control of industrial processes there needs to be greater appreciation of the risks of operational upset by static discharges.

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