

5. APPROACHES TO TACKLE STATIC PROBLEMS

5.1 General comments

The preceding sections have provided a background of theory, methods for measurements and the levels at which static is likely to cause problems in different situations. It is now time to turn to practical questions:

- how do you find out if it is static causing the problem experienced?
- is static a real risk in particular situations?
- what can be done to overcome/avoid risks?
- how do you know if remedial measures remain effective?

We start by noting the 5 Cs of static electricity:

C1: Characteristics of materials:

- chargeability
- charge decay
- capacitance loading
- resistivity
- dielectric constant
- shielding
- ability to support an incendive electrostatic discharge

C2: Coupling:

- geometry effects
- modelling
- time domain effects
- capacitance

C3: Consequences:

- electric fields
- surface voltages
- stored energy
- electrostatic forces (attraction for dust and debris and thin films)
- ignition capability (metal electrodes/dielectric surfaces)
- EOS/ESD damage risk to semiconductors
- EMC radiation/susceptibility (upset operation of electronic systems)

C4: Countermeasures:

- reduce charging
- promote charge removal
- design to overcome consequences

C5: Constructive use:

- electrostatic forces (electrostatic precipitation, photocopying, paint and crop spraying, particle alignment (e.g. flocking))

5.2 Is 'static' the cause?

The first points to consider in any practical situation are whether there are materials and activities that are likely to give rise to separated charges and what measurements can be made to examine the practical situation. In many cases inspection and experience will provide a very useful starting point. If plastic or artificial fibre materials are present, if materials are dispersed

into the air, if sizeable conducting bodies (notably people) may not be electrically well linked to earth – then there could be problems. While it may be feasible to make helpful measurements on materials away from the practical situation it is desirable where practicable, and often necessary, to make observations in the real situation. This gives opportunity for unexpected features to show themselves.

The above overview needs to lead to an assessment of the forces, potentials, quantities of charge, available electrostatic energy available in relation to the practical situation and operations. From this the significance of various electrostatic aspects can be assessed and recommendations made on actions to overcome or avoid risks and problems. To this will be added recommendations on future actions to check that the remedial actions proposed are checked to ensure they remain effective.

When considering problems with static electricity it is important to remember that electrostatics is only ever a part of the overall 'system'. Electrostatic aspects must be viewed in conjunction with many practical factors. Thinking of the 'system' is important because not only does it help assessment of the role of static but will provide the framework for considering alternative ways to tackle problems. Understanding the electrostatic aspects of problems is usually desirable but may not be necessary for achieving a solution. The 'problem' may be an electrostatic problem: but the 'solution' need not depend on electrostatics. For instance: risks of ignition of flammable atmospheres by static discharges might be tackled by avoiding static. Alternatively, risks of ignition might be removed by avoiding the occurrence of a flammable atmosphere. It is important to recognise that there may be other mechanisms of ignition, and to check for these - for example by frictional heating, impact sparks (for example steel and flint) or thermite reactions (involving aluminium or other light alloys with rusty steel).

It is important not to stop thinking of alternatives as soon as one possible cause or one solution of a problem has been identified. There may be several contributory factors and a variety of solutions. All need to be recognised and considered in the context of the 'system' - which will include personnel, engineering implementation and economics as well as technical aspects. There are however a number of general basic actions which need to be taken for reasons of safety [1,2,3].

5.3 Codes of Practice

A number of Standards relating to the control of static are listed in Section 6.6. The main Codes of Practice available relating to static electricity concern:

- the control of static risks in relation to risks of shock, mechanical handling problems and ignition of flammable gases in petrochemical and processing industries [1,3]
- the control of static risks in the handling of semiconductor devices and microelectronic assemblies [2].

The basic philosophy for the control of static in the above Codes is to provide reliable earth linkage everywhere to everything so that any static charges that arise will migrate quickly to earth and not be available for retention on isolated conductors or insulator surfaces. This means visible metal earth bonding straps for all metal plant. With plastics and naturally insulating type materials it means avoiding charge retention by for example modifying the material by additive or by surface treatment or by an alternative choice of material. Where charge retention cannot be adequately controlled by material selection then local air ionisation may provide a route for charge neutralisation by making the local atmosphere partially conductive.

It may be expected that static could be controlled by appropriate choice of associated materials according to the 'triboelectric series'. This is not a practicable or reliable approach to avoid risks or problems – but it may help reduce them. It is easy to show that PTFE rubbed on PTFE gives two highly charged surfaces!

Codes of Practice cover many common practical risk situations very well, but there are a

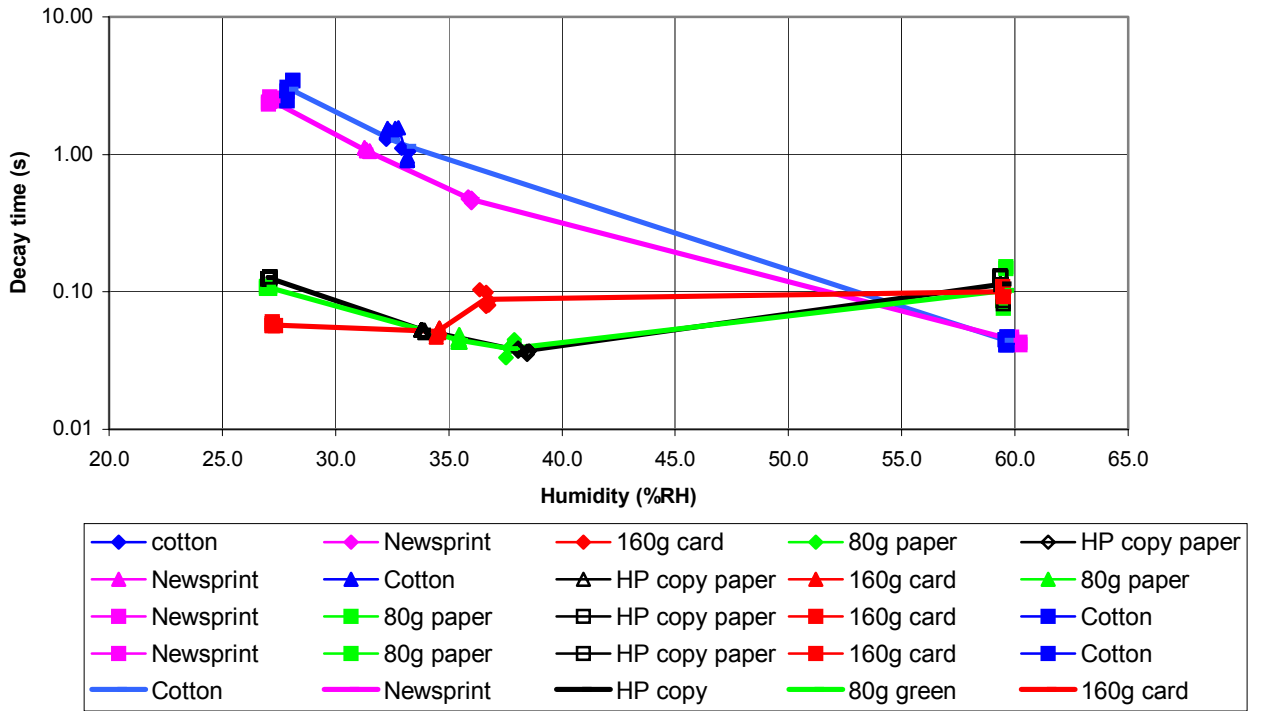
number of problems which are not covered. The following sections provide ideas of some alternative approaches worth consideration.

5.4 Characteristics of materials

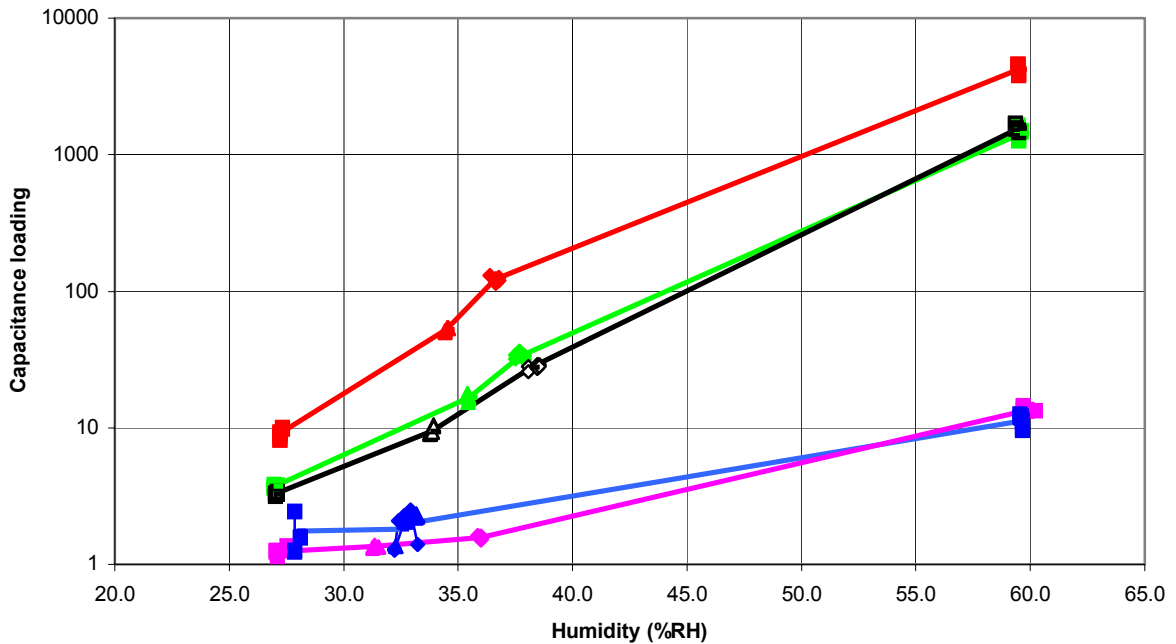
Resistivity measurements have traditionally been the way used to qualify materials where static electricity is thought likely to cause problems or presents risks. In some situations this measurement can be appropriate (e.g. flooring and footwear) when the need is to drain charge from a conductor in contact (e.g. from the body to the floor). Where problems arise from static charge retained on a material itself then a measurement of resistivity may be quite inappropriate. This is particularly true for inhomogeneous materials. Resistivity indicates the fastest route available for charge migration. The slowest route for charge migration is what is relevant for charge retention. Charge decay measurement is appropriate in such situations. However, it is important that the method of measurement used is suitable and is shown to give results that match the decay of triboelectrically generated charge [1] (see also Section 3.7). It is to be noted that Federal Test Standard 101C Method 4046 does not achieve this [2]. To avoid the occurrence of local high voltages and to limit the time they may be present requires the charge decay time to be short compared to the time of mechanical actions responsible for charge separation. Decay times below $\frac{1}{2}$ s have been suggested as suitable [3] but recent studies have indicated that decay times below $\frac{1}{4}$ are needed [4]. It is worth noting that decay time must not be too short (probably above a few ms), if the possibility of spark discharges directly to the material itself is to be avoided.

A feature of materials that can limit the influence of retained static charge is the capacitance presented to charge on the surface. If the capacitance is high then the surface voltage likely to arise from the quantities of charge transferred in practical events may be sufficiently low as not to allow risks or problems. Measurement of this capacitance effect requires measurement of the initial peak voltage generated when a measured quantity of charge is deposited on the surface of a material (see Section 3.7). The following Figures show examples of how charge decay times and capacitance loading vary with humidity in different ways for a cotton fabric and for paper. Charge decay times for 'finished' papers seem fairly constant with humidity, whereas for newsprint and for a cotton fabric they are much longer at with lower humidities. The constancy of decay times of 'finished' papers may arise because of a near balance between increasing charge mobility and increasing capacitance loading with humidity.

DECAY TIME VS HUMIDITY



CAPACITANCE LOADING VS HUMIDITY



5.5 Investigative procedures

The fieldmeter is the main instrument for investigation of electrostatic questions. These instruments can be used, as explained in Section 3, for measuring the main parameters of interest in electrostatic investigations. The following comments draw attention to a number of points to remember in studies in practical situations.

- Sources of static: A fieldmeter is useful to scan around a work area to identify materials

and operations where static charge and surfaces voltages are present. Remember to earth bond the fieldmeter. For induction probe instruments (no rotating chopper) switch on the instrument with the sensing surface well shielded from any sources of charge. A high sensitivity fieldmeter (field mill type) makes it easy to find even low levels of static at a distance. When possible sources have been identified then one can focus in to confirm identification and make quantitative measurement. Beware of influence of other surfaces nearby that may be charged or may be shielding the effects of charge. Where suspect materials are lying on another material, particularly on an earthed surface, it is helpful to lift the material to see whether it is this that is actually charged – and to try rubbing the material to see if it easily becomes charged. Do not scan too quickly when looking for sources of static as the response time of the display may not show observations reliably.

- Body voltage: A fieldmeter in an electrostatic voltmeter configuration provides a useful basis for near zero current drain measurement of voltages. The electrostatic voltmeter can be connected to the person by a trailing lead to, for example a wrist strap. The lead should have good quality insulation. Because body actions involve timescales to below a second it is wise to record observations with a time resolution better than $\frac{1}{4}s$.

- Charge decay: A simple approach to assess charge dissipation capability of powders is to slide the powder down a chute of the material likely to be relevant on to an earthed metal plate. A sensitive fieldmeter observing the pile of powder will show how strongly the powder is charged and how quickly this charge goes away. If the powder is very dusty then it is wise to shield the sensing aperture of the fieldmeter while sliding the powder. The difficulty with the method is that it may not be very quantitative for the quantity of charge generated, or the size and form of the pile of powder, etc. This is where more formal instrumentation becomes appropriate (see Section 3.7).

- Flooring: Resistivity is the appropriate way to assess flooring. The overall ability of flooring and footwear to control body voltage can be demonstrated by linking the person to a recording electrostatic voltmeter and getting the person to walk, scuff their feet, get up from a chair, etc.

- Garments: The ability of garment fabrics to dissipate static charge and so avoid problems of cling and attraction of atmospheric dust and debris is most simply assessed by charge decay measurements (see Section 3.7). With fabrics for cleanroom garments the inclusion of conductive threads may provide sufficient capacitance to surface charge to enable the material to be suitable to avoid appreciable surface voltages even though the decay time may be long [4].

- Microelectronics: The problem is often the identification of unsuitable materials – and the testing of new prospectively suitable materials. The problem is often that of proximity. If for practical convenience items arrive for assembly in ‘unsuitable’ packaging can one be sure to avoid this packaging coming close to sensitive devices and circuits. Note that devices do not become insensitive to static just because they are on a circuit board – you may have just connected the device to extensive aerials! Note also that solder resist coatings on PCBs can become charged and hold that charge! Where materials cannot be made ‘acceptable’ in themselves or extra measures seem appropriate then air ionisation is a useful additional way to control static.

5.6 System changes

The following notes suggest general ways risks and problems may be reduced or avoided by changes to the ‘system’:

- a) Change system design to avoid any significant levels of static arising on isolated conductors - for example earth bonding all metal parts of plant, ensure operators wear conductive footwear and ensure floor free of insulating layers, avoid chance of release of flammable gases and dusts, use of inert gas where flammable materials can be released (but think about

asphyxiation risks), change materials so static can leak away easily, on-chip protection against static discharges, make microelectronic systems immune to static discharges.

b) Design to accept consequences - for example explosion venting, explosion suppression, remove personnel from direct line of fire for loading reactors, avoid possible knock-on effects to prevent possible small events becoming major disasters (e.g. think through the 'What if...' possibilities)

c) Minimise static generation - avoid sliding of materials (webs, powders), avoid stalled rolls, limit speeds (processes, liquid flows), minimise use and areas of insulating material surfaces.

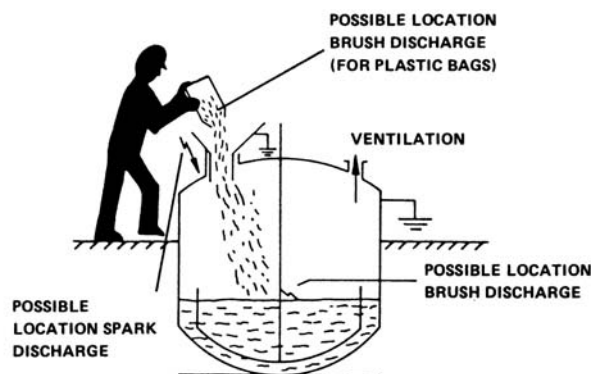
d) Enhance charge leakage - for example by choosing or modifying materials to have good charge decay characteristics. This may require use of humidity control or additives or surface treatments

e) Avoid the presence of the dust or debris that can be attracted to charged surfaces – for example, by a local supply of well filtered air

f) Train staff to increase awareness of risks and benefits of following guidelines and requirements. (See general guidance from Health and Safety Executive [12]).

5.7 Some specific examples

5.7.1 Risks at loading reactors containing flammable solvents:



- opening hatch to over-rich reactor atmosphere will ensure a region within flammable range around hatch
- stirring, or stopping of stirring, can cause generation of high voltages within reactor, on surface of liquid or on any unbonded conductors
- sliding of powders out of packaging, plastic or paper, likely to mean charged powder and charged operator and probably charged packaging. Note that the operator is optimally positioned to receive the full consequences of any explosion.
- incendive discharges can occur if highly charged packaging or charged operator touches reactor hatch opening
- if ignition and explosion occur operator is in prime target position for damage

Remedial approaches: Use of inert gas seems attractive but is not simple. Inerting may be ineffective around open hatch and sizeable quantities of inert gas may be needed if frequent hatch openings occur. There is asphyxiation risk to operators. Best to segregate operator from open hatch using indirect loading via rotary loading valve and have a separate safe route blow off vent if any ignition occurs. If open hatch must still be used then best to use paper not plastic lined sacks, to provide general fresh air movement to clear flammable atmosphere around open hatch and to ensure operator is earthed via footwear and by contact to a support guard rail which

he will naturally contact on loading into hatch opening.

5.7.2 In silos and flammable liquid storage tanks:

All debris (in particular any cans that might float in fluid systems) need to be removed before filling vessels.

Carry out dipping and gauging only via a permanently mounted earthed shield tube and use only dissipative dipping or gauging equipment. Avoid direct man lowered sampling cup into vessel - a conducting cup and/or line may collect charge and spark on touching probing aperture, an insulated person may become charged up via the support line and discharge on touching the probing aperture.

5.7.3 Transfer of charged material into vessels/containers

The receiving container must be earth bonded. If the container has an insulating lining and/or the powder may have a long charge decay time then an earthing rod should be placed into powder within the lining. This will provide a resistive path for charge leakage and opportunity for corona charge leakage if surface potentials try to rise to a high level on the powder surface.

5.7.4 FIBCs

If charged powders are collected in fabric storage vessels (e.g. FIBCs) the fabric should be dissipative and preferably have multiple conductive threads woven in. It is not yet clear why certain FIBC materials appear to avoid risks of ignition, even when they are highly charged and not bonded to earth. It is suggested that the inclusion of 'conductive' threads with quite high core resistivity may both limit the area of surface from which electrical discharges can draw charge and also limit the ability to draw charge from neighbouring areas. If metal threads are used then these MUST be reliably bonded to earth.

5.7.5 Fluids

Charge will be retained on fluids collected in vessels with insulating linings, so an earthing route must be provided by an earthing rod or plug of adequate area

5.7.6 Moving webs

Charge on moving webs arising from contact and separation from drive and handling rolls may be neutralised using passive, radioactive or active (corona) charge neutraliser bars. This only neutralises the charge locally. A better solution is to change the characteristics of the material to provide more rapid charge dissipation.

5.7.7 Flooring

Wherever flammable atmosphere may occur conductive/dissipative flooring and conductive footwear should be used to avoid charges on personnel. In many industries flooring may get covered with powders that may be insulating – so other ways of earth bonding are needed (for example an earthed rail against which the operator is likely to lean during operations).

5.7.8 Humidity

It may be possible to use humidity to enhance electrical conductivity of powder products and surfaces - but this may cause problems of adhesion, may be technically unacceptable or may not be successful if product does not adsorb moisture

5.7.9 Aircraft refuelling:

The flow of insulating liquids (for example high quality hydrocarbon fuels) through fine filters can cause strong charging. Charge can accumulate on any unbonded conductors but also

on free surface of fuel. Usual to limit maximum flow rates and use antistatic additives where feasible [3]. The rate of charge dissipation in low conductivity fluids collected in large vessels is more important than initial charge density - charge decay time needs to be short compared to filling time.

5.7.10 Carbon dioxide

The release of carbon dioxide causes strong charging when 'snow' is produced [5,6]. This can be a problem in preventative release of fire extinguishing gases [6]. Major accidents have been Bitburg and Alva Cape.

5.7.11 Aerosol cans

Aerosol cans may become charged if leakage occurs. If flammable propellant used then a risk of ignition. Lifting leaking can from earthed surface can increase risk by decreasing capacitance and increasing energy [7].

5.7.12 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 [8]. 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.

5.7.13 Clamping of coating steel sheets

Thin steel plates with a protective plastic film coating can experience clamping from the electrostatic force generated by the tribocharge created at movement between the plate surfaces. Surface voltages on the coatings may be quite low, only around 100V, but the clamping force can exceed the weight of plates because of the close proximity of the surfaces. The solution recommended is modification of the charge dissipation capabilities of the coating layer.

5.7.14 Solvent extraction of copper

Risks of ignition may arise during the kerosene based solvent extraction of copper. Risks can be avoided if the charge decay times of processing liquids are adequately short [13].

5.7.15 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 [14].

5.7.16 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.

5.7.17 Tank washing on large crude oil tankers

An example of the advantage of correlation between multiple observations is offered by studies carried out on the causes of explosions in large crude oil tankers during tank washing operations. It was known that electrostatically charged mists are generated from the interaction of the high pressure cleaning water jets with the tank walls during washing operations [9]. The anticipated risk of ignition was that slugs of wash water became electrostatically charged on leaving projections, such as the nozzles of washing machines or the edges of structural elements, and these then discharged with sparks when they reached internal structures of the tanks [10]. Shipboard studies were carried out to find out whether there was any occurrence of actual electrostatic sparks during tank washing and, if so, to identify the likely features of the washing operations responsible [10,11].

The shipboard studies involved observation during practical tank washing operations of electrostatic conditions by fieldmeter measurements and the occurrence of electrostatic sparks by radio signal monitoring. Arrangements were included for flash photography of the behaviour of the wash water within the tanks triggered by observation of coincident radio signals at two well space radio aerials within the tank space [11]. The hope here was to obtain information on the size and location of water slugs at the time of occurrence of sparks so that modelling calculations could be carried out on the discharge energies that could have been involved – and hence available as a risk. For these studies all the equipment needed to be approved for use in flammable atmospheres (even though the atmospheres in the tanks was inerted). Arrangements followed the comments in Section 3.12.

The studies showed that large numbers of sparks occurred normally during tank washing operations and that these were associated with alignments of the washing jets to give interactions with particular features of the tank structures [11]. Risks have been controlled in practice by using ‘inert gas’ – spent flue gas generated at the time of cargo discharge by the pump boilers or engines involved.

REFERENCES

[1] "*Code of Practice for Control of undesirable static electricity*"
BS 5958: Part 1:1991

[2] "*Basic specification: Protection of electrostatic sensitive devices. Part 1: General requirements*" EN 100015: 1992

[3] "*Static electricity: Technical and safety aspects*" Shell Safety Committee 1988

[4] J. N. Chubb "*Measurement of tribo and corona charging features of materials for assessment of risks from static electricity*" IEEE-IAS Meeting Phoenix, Arizona Oct 1999

[5] E. Heidelberg, K. Nabert, G. Schon Arbeitsschutz 111958 p 221

[6] G. J. Butterworth "*Electrostatic ignition hazards associated with the preventative release of fire extinguishing fluids*" Electrostatics 1979 Inst Phys Confr Series 48 p 161

- [7] "*BAMA Electrostatic Guidelines: General guidelines for the safe production, handling and disposal of aerosols with reference to electrostatic creation*" British Aerosol Manufacturers Association, Feb 1995
- [8] J. N. Chubb, J. Embury, D. Bourne, S. Southall "*Measurements for the assessment of ignition risks from static electricity*" IEE Colloquium on Electrostatic problems during materials handling, London, Feb 15, 1994
- [9] J. M. Van der Weerd "*Electrostatic charge generation during washing of tanks with water sprays, II Measurements and interpretation*" Static Electrification Conference, London, 1971 IoP p 158
- [10] J. N. Chubb "*Practical and computer assessments of ignition hazards during tank washing and during wave action in part ballasted OBO cargo tanks*" J. Electrostatics 1 1975 p 61
- [11] J. N. Chubb, G. J. Butterworth, "*Instrumentation and techniques for monitoring and assessing electrostatic ignition hazards*" 'Electrostatics 1979' Inst Phys Confr Series No 48 p 85
- [12] Health and Safety Executive Website: <http://www.hse.gov.uk>
- [13] J. N. Chubb "*A system for the advance warning of lightning*" Paper presented at the Electrostatics Society of America 'ESA 2000' meeting, Niagara Falls, June 18-21, 2000
- [14] J. N. Chubb, P. Lagos, J. Lienlaf "*Electrostatic safety during the solvent extraction of copper*". Paper at 'Electrostatics 2003' Heriot Watt University, Edinburgh, 23-27 March, 2003