3. INSTRUMENTS AND MEASUREMENTS

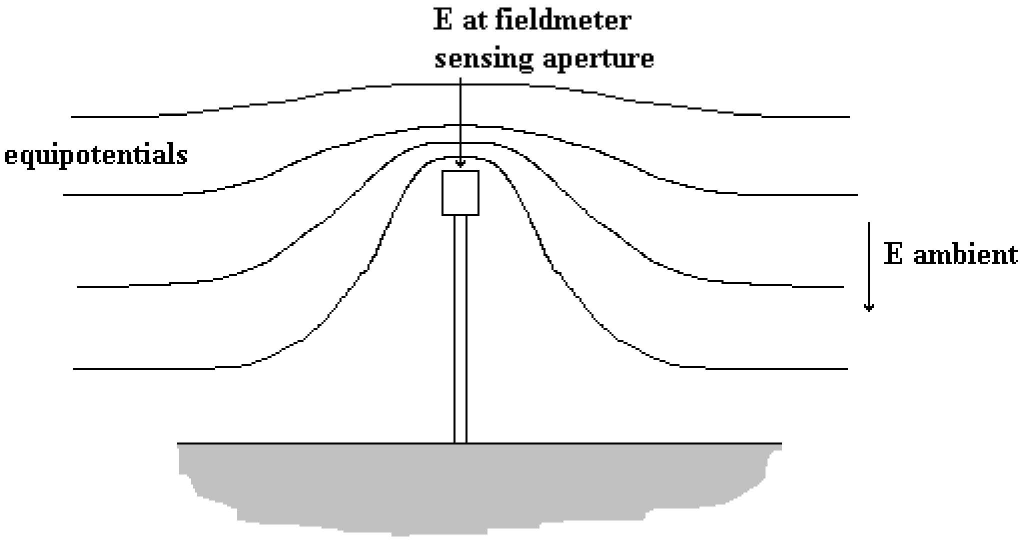
3. 4 PRACTICAL MEASUREMENTS

3.4.1 Measurements of atmospheric electric fields

The local voltage in a space charge cloud (for example of charged mist or dust) can be measured with a voltage follower probe or with an electrostatic fieldmeter acting as a potential probe [1,2].

The electric field at the sensing aperture of an earthed fieldmeter E depends on the effective diameter of the fieldmeter d and the local potential V, present before the fieldmeter was introduced as: E = f V / d The factor f is near unity. The fieldmeter needs to be several diameters away from nearby surfaces.

The ambient atmospheric electric field E_a is conveniently measured using an electrostatic fieldmeter at earth potential mounted on a pole a known distance above ground level. In this arrangement the fieldmeter is being used as a probe of the local potential at its mounting height. This mounting arrangement is simple to implement, avoids anxieties about ground level dust and debris (and insects) entering the fieldmeter sensing aperture and gives useful enhancement to the basic fieldmeter sensitivity.



The electric field at the sensing aperture of an earthed fieldmeter E depends on the local potential V, present before the fieldmeter was introduced, and the effective diameter of the fieldmeter d, as:

$$E = f V / d$$

The factor f is near unity. The fieldmeter needs to be several diameters away from nearby surfaces. This approach is very appropriate for measurement and for long term continuous monitoring of atmospheric electric fields.

For an ambient atmospheric electric field, E_a (V m^{-1}) the local voltage at a height h (m) is: $V = E_a h$. The sensitivity of a fieldmeter as a potential probe, mounted well clear of nearby surfaces, is close to $V = E_{fm} d$ – where E_{fm} is the electric field (V m^{-1}) at the fieldmeter sensing aperture responsible for the fieldmeter reading and d the effective sensing head diameter (m). Hence the ambient electric field is obtained from measurement of the electric field at the fieldmeter sensing aperture as:

$$E_a = E_{fm} d / h$$

There will be a contribution to the electric field measured dependent on the alignment of the sensing aperture relative to the ambient electric field. If for example the two field components are in directions to add, then the atmospheric field can be derived as:

$$E_a = E_{fm}\, d / (h\, (1\text{-}d/h))$$

As d/h is normally small the influence of this effect is small.

The actual sensitivity of measurements can be checked in-situ by applying a calibration voltage to the whole fieldmeter assembly. This gives the fieldmeter reading as a function of local voltage - so the local ambient atmospheric electric field is obtained knowing the mounting height of the sensing aperture.

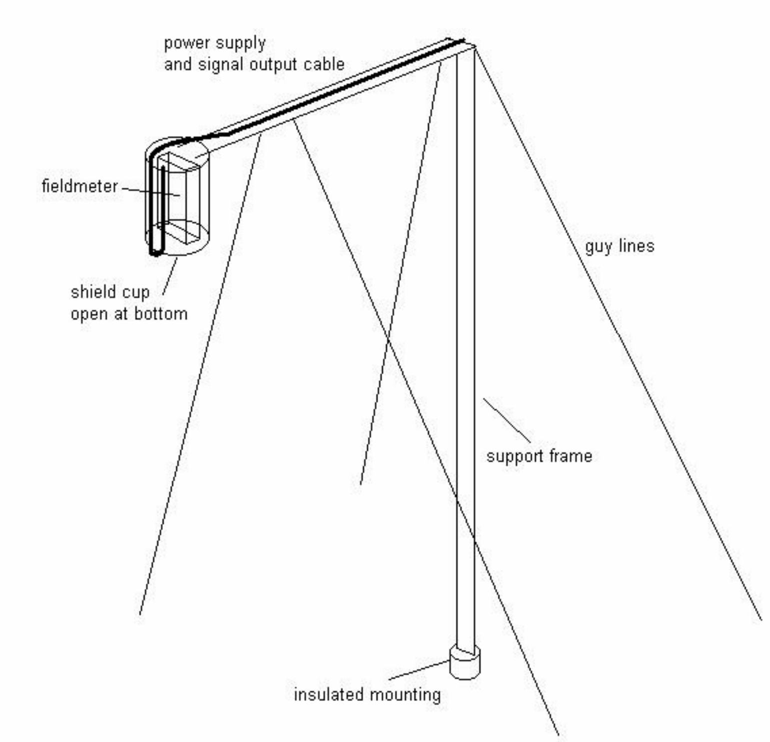
For measuring and long term monitoring atmospheric electric fields the electrostatic fieldmeter needs to be designed and constructed for reliable operation even in very wet environments and with driving rain [3,4,5]. Application of a modest level alternating potential to the fieldmeter assembly relative to earth can be used for continuous monitoring of the operational health of the observation system. This ensures confidence in observations during operation in adverse environmental conditions [5].

The relation of local ambient atmospheric electric field values to the charge, altitude and distance characteristics of thunderclouds may be modelled with Spreadsheet calculations treating the cloud charges, and their image charges below the ground plane, as dipoles.

Where the fieldmeter is mounted other than above a large plane ground area well clear of any buildings or earthy projections there will be need to 'interpret' electric field measurements in relation to the geometric arrangement of the surroundings. This can be done with computer modelling calculations - but this may be difficult and lacking conviction in complex three dimensional arrangements. One approach to tackle this problem is to normalise readings in relation to otherwise known ambient atmospheric electric field values with, for example, a clear sky situation - when the ambient field is typically around 100V m^{-1}.

The above discussion illustrates basic arrangements for measurement of atmospheric electric fields. It is directly appropriate for measurements with fieldmeter instruments that are not adversely affected by rain and have the ability to provide continuous measurements even through periods of heavy rain [4,5]. The advantages of an upward looking fieldmeter for long term continuous observations is simplicity of mounting and use of rain to keep the surfaces of the sensing region clean. In the absence of such instrumentation good quality measurements may be made using more standard fieldmeters mounted with the gallows type structure sketched below.

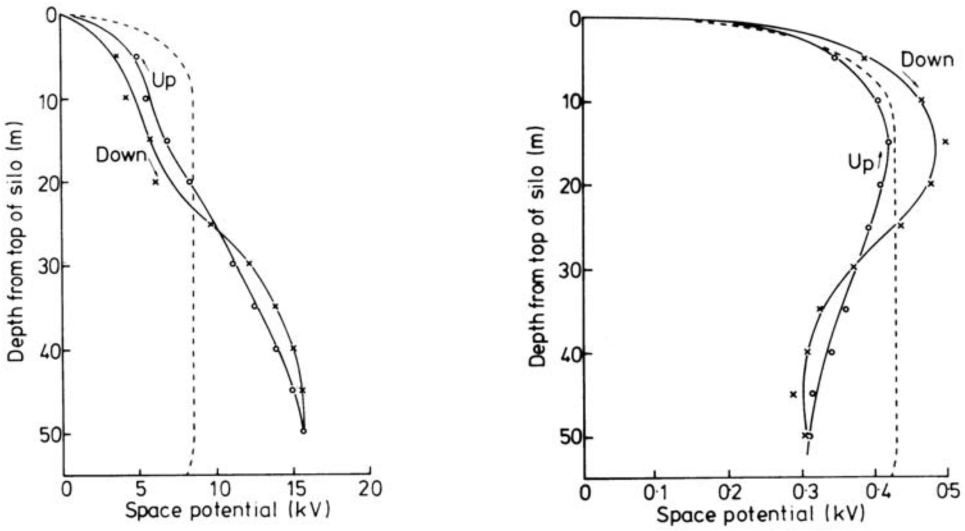
The fieldmeter sensing aperture is protected from direct impact of rain by pointing downwards. The case, circuits and connections are protected by mounting the fieldmeter up into the deep downwards facing cup. Dry air purging of the fieldmeter circuits and sensing region may be desirable. If the cables are routed down the inside of the cup, and then back over the outside, then it is wise to wrap them in a conducting shield (e.g. aluminium foil) connected to the cup and 'earth' of the fieldmeter to avoid risk of any residual charge on the cable insulation affecting readings. The mounting structure should be conducting and connected to the 'earth' terminal of the fieldmeter. It is advise to mount the support structure and any guys with insulation at their ground level ends. This allows calibration voltages to be applied to the whole assembly for checking system measurements sensitivity – as noted above.



Observation of horizontal electric field components may be made in conjunction with measurements of vertical atmospheric electric fields. This can be done using two electrostatic fieldmeters separated horizontally and at a known height above ground. Each fieldmeter acts as a probe of the local potential at its location. The difference between the two horizontally separated fieldmeters thus provides a measure of the horizontal component of electric field while the average of the two fieldmeters provides a measure of the vertical component of electric field. Horizontal electric fields will be small compared to common mode the vertical component, so it is important to operate the fieldmeters at high sensitivity. By servo controlling the average potential of the two fieldmeters to their average local potential both instruments can be operated at maximum sensitivity. However, in this situation even small differences in the effective heights of the two fieldmeters will give apparent readings of horizontal electric field. This problem can be tackled by mounting the two fieldmeters at either end of a cross arm on a mast that can be rotated on a vertical axis. True verticality of the mast axis and equal heights for the two fieldmeters can be established by making observations with mast rotation under clear sky conditions.

3.4.2 Fieldmeters as potential probes in large scale studies

Electrostatic fieldmeters are very useful as probes of potential distributions in industrial situations in just the same way a above for measuring atmospheric electric fields. This approach was used during work on the problem of explosions on very large crude oil tankers during tank washing operations [1,2]. A fieldmeter was lowered down into the cargo tank space to measure the distribution of space potential in the charge mist created by impact of the tank washing jets on the walls and surfaces of the tank structure. With modelling studies (see Section 3.4.4 below) these observations were able to be interpreted in terms of maximum space potential and mean volume space charge density. An example of potential probe observations in a large food product silo are shown below during product filling and afterwards [1].



Fieldmeter used as potential probe in food product silo:
During filling After filling

3.4.3 Large Scale Faraday Pail

The Faraday Pail can very easily be adapted for a wide variety of applications in industry. For example, measuring the charge on filtered hydrocarbon fuels. The liquid flow can be collected in a suitable size container (for instance, a 200l oil drum) that is supported on good quality insulation and shielded from its surroundings. Where practical the design comments in Section 3.2.4 should be implemented. Received nett charge may be measured either using an appropriate 'virtual earth' charge measuring amplifier unit or using a fieldmeter. The fieldmeter approach is simple and allows easy scaling of sensitivity – but needs to be used with care. The sensing aperture of the fieldmeter needs to be mounted in a stable arrangement to measure the voltage of the receiving vessel (the drum) with no insulation nearby that may affect readings. The sensitivity of the fieldmeter to the voltage of the drum should be checked if the separation distance or arrangement is not that for which the fieldmeter has been calibrated. The capacitance of the receiving vessel needs to be measured. To start, the drum needs to be 'earthed' with an earthing stick. Two preliminary observations: first, does the fieldmeter reading remain constant after earthing; second, does the fieldmeter reading remain constant after some charge has been added to the vessel (for example by finger contact while the feet are scuffed on the floor). These observations check the stability of the system and the quality of the insulation. Meaningful measurement can now be made. Two points requiring care: first, it is wise not to let the vessel voltage get too high as this will come to affect the validity of readings. If the sensitivity is too high then a good quality high voltage capacitor can be connected from the vessel to earth to reduce sensitivity. Second, if measurements are being made in atmospheres that may be flammable then it will be best to use a piece of wood connected to earth as the earthing stick. The reason is that this will avoid risk of sparking when the charge vessel is connected to earth by dissipating the accumulated charge slowly.

3.4.4 Measurements on static discharges

The quantity of charge transferred in electrostatic discharges to charged plastic surfaces, involving for example brush type discharges, may be useful in assessing the risk of ignition of flammable gases [6]. Care needs to be taken in measuring charge transfer and current flows in electrostatic discharges – as noted in Section 3.2.8. It is necessary that the electrode to which measurements are made is shielded against pre-discharge charge induction fields (as noted in Section 3.2.8) [7]. For reliable current measurements the electrode and its cable connection to the measuring oscilloscope need to be considered as a transmission line [8]. An oscilloscope with at least 500MHz single shot bandwidth is needed. Charge transfer measurements are much easier and can be made with a virtual earth charge measurement circuit.

3.4.5 Radio detection of spark discharges

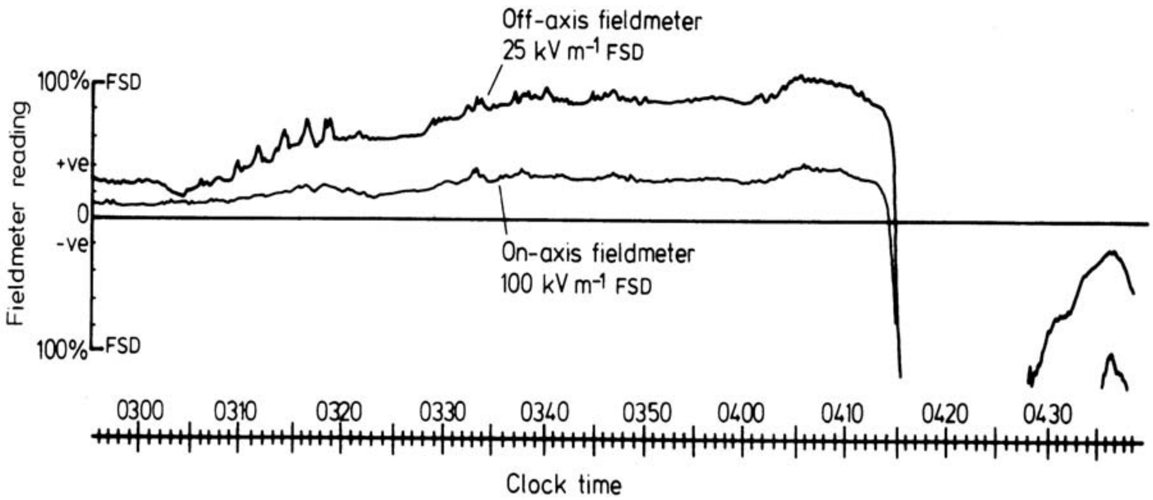
Radio observations can provide indication of the occurrence of 'spark' type electrostatic discharges [9,10] - with good segregation against corona discharges [9]. They can thus be used to investigate the time of occurrence of events that, if sufficiently energetic, could present a risk of ignition or damage [11]. No indication is provided of the discharge energy involved. Recent work in the microelectronics industry has shown that the physical position of low energy spark discharges can be located with good precision (within about 100mm) in 3 dimensions on the basis of precision timing of radio transient signal reception with at least 4 aerials [12,13].

3.4.6 Industrial Measurements

Studies of risks and problems involving measurement in practical plant to be planned with care and consideration of plant operational requirements and need to be agreed with plant management and safety personnel. It will be wise to suggest making the plant insurers aware of on-site studies - and the benefits likely to accrue. Indemnity cover needs to be arranged for any external staff or consultants.

Careful planning is also needed to ensure that observations can be interpreted to provide information which will improve the safety or efficiency of plant operation. Great care needs to be taken to obey safety requirements. Where flammable atmospheres may be present only BASEEFA Certified instrumentation and equipment shall be used - unless a formal dispensation is appropriate and is arranged. Note needs to be taken of existing Codes of Practice and Standards as may be applicable and useful [14,15,16,17].

It is very helpful to make recordings (for example paper chart or computer recording) of observations and where feasible to include observations of relevant plant operating parameters and time. Studies need to be made over extended periods of operation and if possible should include likely 'worst case' conditions and/or materials. The following diagram relates to studies in a large food product silo [1].



Fieldmeter observations during 'normal' filling of food product silo showing sudden large excursion of space potential (100kV m^{-1} is about equal to 11kV of local space potential)

Where electrostatic fieldmeters are used to observe electrostatic conditions in industrial or practical situations, arrangements need to be made to ensure that instrument operation will not be adversely affected by features of the working environment. This may involve ability to withstand high humidity, water mist, water spray and droplets (e.g. rain), dust and fibres and larger contaminant particles that may be conducting, highly insulating and/or sticky! Such environmental problems can be handled by suitable designs of instrumentation - for example large gaps between surfaces and long surface tracking distances on insulation in fieldmeter sensing regions [3,4]. Care in mounting position and attitude in combination with air or gas purging will also be helpful. It is wise to arrange to be able to check the fieldmeter zero reading from time to time - particularly where highly insulating and charged particles are likely to be present. For critical and extended duration studies it is wise to consider continuously monitoring operational health of instrumentation so confidence in observations can be demonstrated [5].

3.4.7 Modelling

In studies on practical plant it is often not feasible to make measurements where one would prefer to make them. Modelling, physical, analytic [18] or computer modelling [19,20,21] provides a way to relate observations at places which are accessible to electric field values at other places in a system. Computer modelling can handle quite complex structural arrangements, and in two and three dimensions [1,19,20,21]. However, it would be very unwise to base interpretation of conditions of a complex situation on electrostatic observations at any single location. Modelling may well involve some assumptions about voltages on surfaces and/or the uniformity of space charge and/or the fraction of volumes filled. It is wise therefore to use multipoint fieldmeter observations and/or explore the variation of voltage through some part of the volume to check the basis of the modelling [1,2].

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