2.2. Target values and safety margins

IEC 60079-32-1 [1] indicates that to avoid incendive discharges from an insulating liquid surface its potential must be less than 25 kV. Given the likely slurry movement in reality, compared with the inevitable flat surface which would be used for modelling, as well as some other uncertainties, it was somewhat arbitrarily decided to aim for an order of magnitude margin of safety. In other words, the target maximum surface potential as determined by modelling would be 2.5 kV.

To avoid spontaneous discharges across a liquid surface (as opposed to discharges initiated by objects approaching the surface) the maximum electric field must not exceed the breakdown strength of the atmosphere in the vessel head space. Taking the breakdown strength to be that of air under normal atmospheric conditions ($3x10^6$ V.m^{-1}) and applying the larger but no less arbitrary safety margin of two orders of magnitude (mainly allowing for the numerically higher values), a target maximum electric field of $3x10^4$ V.m^{-1} was specified.

2.3. Initial Modelling

A sketch of the high shear blender vessel and a simplified version which might be used for modelling, where only the potentials and fields at the liquid surface are of interest, are shown in Figure 1. Essentially, the simplified version sets the bottom cone of the model vessel approximately at the position of the top of the blender.
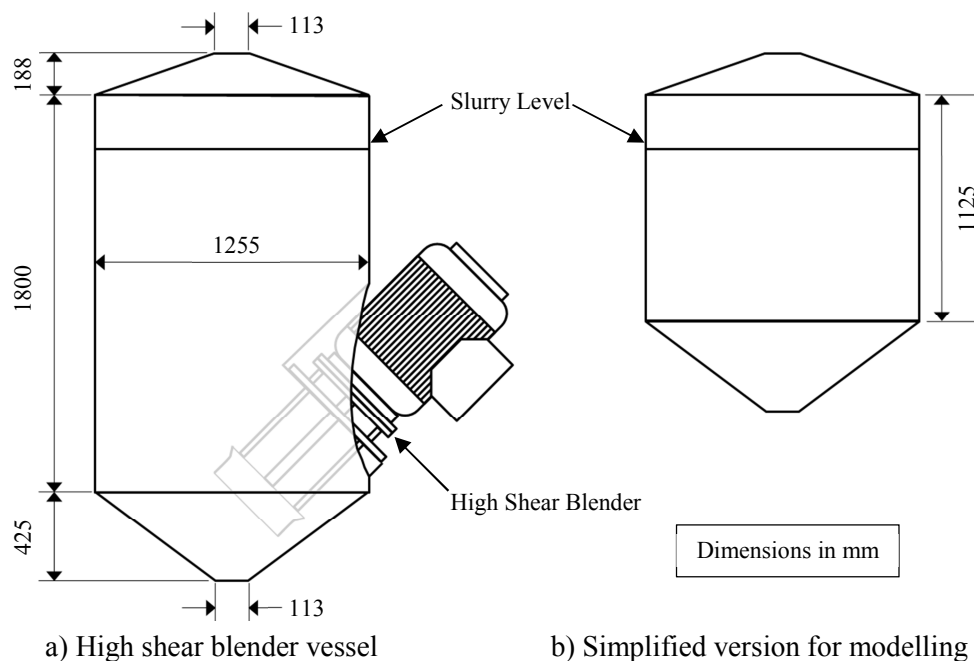

a) High shear blender vessel   b) Simplified version for modelling

Figure 1. Sketch showing model dimensions.

The first modelling trials used both of the geometries shown in Figure 1, as well as a charge density in the slurry of $1x10^{-4}$ C.m^{-3}. This value is towards to top end of the $5x10^{-6}$ to $4x10^{-4}$ C.m^{-3} range given in IEC/TS 60079-32-1 for pumped flow in pipes, thereby making some allowance for the expected high charging due to particulates and high shear.

The results showed similar values for electric fields and potentials between the two geometries (better than 10%), such that later trials used only the easier to model simplified version. However, at about $1x10^6$ V.m^{-1} the maximum electric field was very much higher than the target value and, at 340 kV, the maximum potential was well over the safe limit even without applying a safety margin.

3. The detailed assessment

3.1. Measured and modelled fields and potentials for laboratory scale equipment

Laboratory scale trials were carried out using low concentration model slurries and a commercial slurry. The latter was the commercial slurry known to have the lowest conductivity. The laboratory scale blender had a nominal 2 litre capacity with a normal stirrer and a high shear blender. It had a bottom valve through which slurry samples were dropped into a Faraday Pail to allow direct charge to mass ratio measurement. A field meter (Simco Model FMX-003) was used to monitor the electric field above the liquid. Figure 2 shows the blender geometry and the potential distributions determined by the computer model on two planes through the field meter. Table 1 shows a comparison of results.
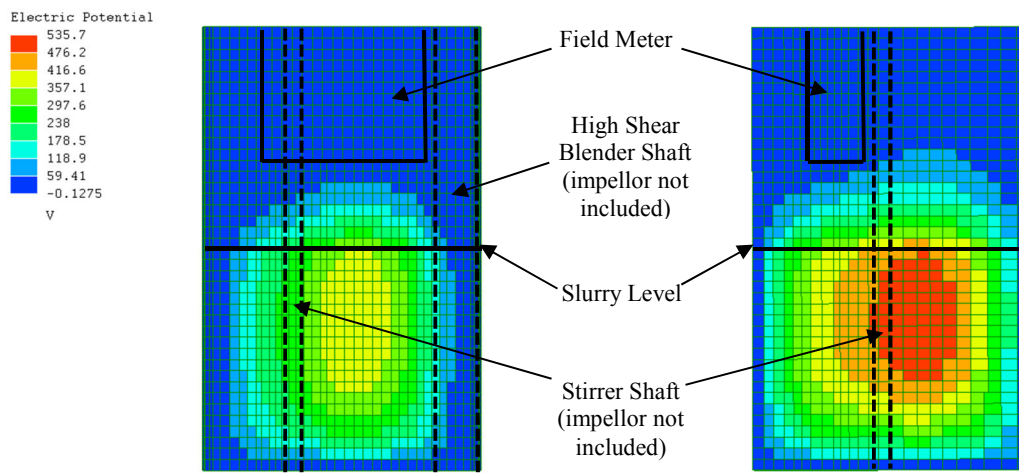

Figure 2. Potential distributions on perpendicular planes through field meter in laboratory blender.

Table 1. Experimental and computer model results for laboratory scale blender.

Formulation	Experimental			Computer Model	
	Slurry Charge:Mass Ratio (nC.kg^{-1})	Measured Field* (kV.m^{-1})	Slurry Surface Potential* (kV)	Field (at meter) (kV.m^{-1})	Slurry Surface Potential (kV)
Model Formulation 1	41	10	0.4	6.6	0.4
Model Formulation 2	820	180	7.2	161	11
	1200	260	10	252	17
Model Formulation 3	6	2	0.08	0.6	0.04

*Measure field calculated from displayed surface potential. Surface potential adjusted for measuring distance.

The good agreement between experimentally determined and modelled values provided additional verification for the computer model and supported the slurry charge-to-mass ratio measurements.

3.2. Estimation of maximum commercial slurry charge to mass ratio

The least conducting commercial slurry tested in the laboratory scale blender was still much more conducting than the model slurries of Table 1. Also, the much higher solids concentration compared with the model slurries meant samples could not be taken for direct charge to mass ratio measurements. However, field meter measurements were taken. In fact, the field was too low to register a sensible reading, but that alone was enough to indicate the electric field at the field meter must have been <400 V.m^{-1}. With confidence from the previous comparisons, running the model with values selected by trial and error showed the charge to mass ratio must have been <1.3×10^{-9} C.kg^{-1}.

It is well known that charge generation increases with specific power of the blender [1]. The laboratory scale blender provided specific power of 75 W.kg^{-1}, compared with 15 W.kg^{-1} for the full

scale blender. Hence, using the above determined maximum charge to mass ratio for modelling the full scale blender fields and potentials would be erring on the side of safety.

3.3. Final modelling results for the full scale blender

Final modelling of the full scale blender used a charge to mass ratio of 1.3×10^{-9} C.kg^{-1} (determined above), together with the simplified geometry model referred to in Section 2.3. Graphical and numerical results are shown in Figure 3 and immediately afterwards, respectively.
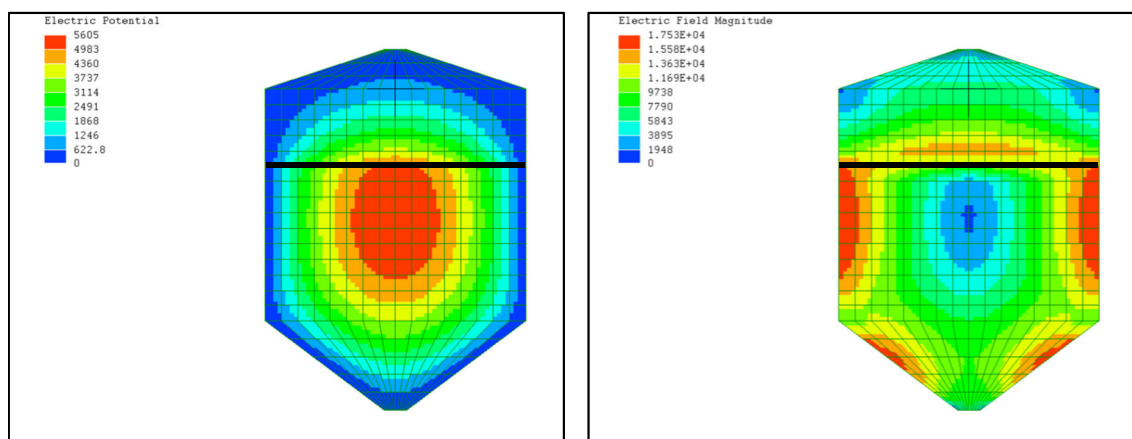

Figure 3. Final graphical results of modelling the full scale blender.

From the results shown graphically in Figure 3 the following values were obtained:
- Maximum potential at the slurry surface: 5.2×10^3 V
- Maximum electric field at the slurry surface: 1.6×10^4 V.m^{-1}

The maximum electric field is below the selected target value and, although the surface potential is not as low as its target value, it is well below the 25 kV cited in IEC/TS 60079-32-1.

4. Conclusions

By combining computer modelling with experimental measurements as described it was concluded that incendive electrostatic discharges in the full scale high shear blender vessel are so unlikely that no additional protective measures (such as inerting the vessel headspace) would be required.

Inevitably this conclusion came with a number of limitations based on assumptions made along the way. Set out as recommendations these were: all other ignition sources must be properly assessed and addressed; no fixed or moveable items should protrude into the vessel headspace; reduced batch sizes must not be permitted if the blender specific power exceeds 50% (arbitrary margin) of the laboratory scale blender power, and; a new assessment must be undertaken for new formulations of lower conductivity than the current worst case commercial slurry.

Overall, an approach for combining computer modelling of electric fields and potentials in process plant with experimental measurements has been successfully demonstrated and used for a particular situation. However, it is considered this general approach could represent a useful starting point for undertaking many similar assessments for a wide range of other process equipment.

References
[1]   IEC/TS 60079-32-1 2013 Explosive atmosphere Part 32-1 Electrostatic hazards, guidance
[2]   Glor M and Pey A 2013 *J. Electrostatics: Electrostatics 2013, Budapest* **71** pp362-367
[3]   Britton L G 1999 *Avoiding Static Ignition Hazards in Chemical Operations* (New York: AIChE/CCPS)