

Report on

**Tests performed on 6-7th April to Determine the
Electrostatic Safety of a Non-conductive Pipe System**

Report No. R0972/GLH/JMS/UVP dated 19th April 2010



G L Hearn B.Sc C.Eng M.I.E.E – Director, Wolfson Electrostatics Ltd.



Dr J M Smallwood BSc MIET MInstP CEng CPhys, – Director Electrostatic Solutions Ltd.



Dr. Ing U von Pidoll – Convener, IEC TC31 JWG29
Physikalisch-Technische Bundesanstalt
Zertifizierungsstelle, Zertifizierungssektor Explosionsschutz



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1. Summary

A series of tests have been performed by Wolfson Electrostatics aimed at quantifying the electrostatic safety margin associated with non-conductive plastic pipe systems for transfer of fuels in filling stations – in this case the pipe system used was UPP. The tests were performed at a test facility at Cookson & Zinn in the United Kingdom and were witnessed by visitors from the Peoples' Republic of China, representing the fuel retailing regulatory authority as follows:

Han Jun- SEI, Vice-chief Engineer, Professor Senior Engineer
韩钧-中国石化工程建设公司，专业副总工程师，教授级高级工程师

Zhang Jianmin – SEI, Deputy Chief Electrical Engineer, Senior Engineer
张建民-中国石化工程建设公司，电气副总工程师，高级工程师

Zhaopeng Ni – Tianjin Fire Research Institute, Research Fellow,
Director, Department Fire Code
倪照鹏-公安部天津消防研究所，研究员

Xiao Yiqing – Beijing Municipal Institute of Labour Protection,
Engineer
肖义庆-北京市劳动保护科学研究所，工程师

Yang Wenfen - Beijing Municipal Institute of Labour Protection,
Professor
杨文芬-北京市劳动保护科学研究所，研究员

Xu Wenzhong - Building Design and Research Institute of the
General Logistics Department of PLA, Senior Engineer.
许文忠-中国人民解放军总后勤部建筑设计研究院，高级工程师

The visitors witnessed all test runs and were encouraged to actively participate where appropriate.

In addition to Wolfson Electrostatics, additional technical expertise and supervision were applied throughout the test programme by Dr. Jeremy Smallwood of Electrostatic Solutions Ltd. [1] and Dr. Ulrich von Pidoll of PTB [2]. Further technical input was provided by Jamie Thompson of APEA [3] and Phil Lambeth of BP Global Fuels Technology [4].

During this programme of tests, every effort was made to obtain data under the simulated realistic worst-case conditions existing at a fuel filling station. Key parameters including fuel flow velocity and electrical conductivity were monitored.

Details of the test set-up, methodology and results are given in the appropriate sections of this report below.

2. Background

2.1 The use of plastic pipe for fuels

The use of electrically insulating synthetic materials, such as plastics, for fuel pipelines and other fuel handling components is now widespread.

In the case of buried pipelines in filling station forecourts, the use of these materials offers superior corrosion resistance and increased longevity over metal. This in turn reduces the risk of pollution due to fuel leakage. It is well reported that the flow of fuel under certain conditions in both metal and plastic pipes can produce measurable levels of electrostatic charge on the fuel.

Pipe systems in modern filling stations generally contain both plastic pipe lengths and metal components such as valves and couplings on which electrostatic charge can accumulate. Non-conductive pipework properly installed with grounded metal fittings and capped electrofusion coupler terminals should not create electrostatic ignition hazards. This is reflected in the draft International Standard IEC TR60079-32 [5] which recognizes and allows non-conductive pipe to be used.

Several million meters of non-conductive pipe (approximately 250,000 sites) have been installed over the last 40 years and are in operation at petrol filling stations in more than 140 countries. Considering an average of one filling operation per week per each underground tank gives an estimate exceeding 50 million filling operations every year through non-conductive piping.

2.2 Static electricity

There are five general conditions necessary for an electrostatic ignition hazard to be present:

1. Sensitive flammable atmosphere
2. Generation of electrostatic charge
3. Accumulation of charge
4. Electrostatic discharge (ESD)
5. Sufficient discharge energy for ignition

If all of the above conditions exist, an ignition hazard will be present, if any of the conditions are removed, the hazard is removed.

Petroleum spirit (gasoline) vapour has a flashpoint of around -43C and is flammable within the range of about 1-6% by volume with air. At most times within a pipe system and storage tank, there is insufficient oxygen to support combustion - ie the atmosphere is over-rich. During tanker delivery, a flammable atmosphere may be established just inside or around the end of the fill pipe. This of course applies equally to metal and plastic systems.

Biofuels containing alcohol may have a wider flammable range than that of petrol [6]. Diesel which has a flashpoint in excess of 60C will not produce a flammable atmosphere under normal conditions and is not considered at risk from static electricity at any time during delivery.

During fuel delivery it has been estimated that typically around 7000 litres is transferred in 10-12 minutes. This corresponds to a moderate velocity in the pipe of around 1.5 metres per second. During fuel delivery at normal rates, turbulent flow occurs creating charge separation. Any filters, valves and elbows will generally increase the amount of charge, due to greater interfacial charge separation, higher fuel velocities and increased turbulence.

The electrostatic charge that is generated in fuel being pumped along pipes arises from the presence in parts per million (or billion) of ions in the fuel. Consequently high-purity fuel will not charge strongly. Similarly a high ionic content (characterised by electrical conductivity in excess of around 150 picosiemen per metre) will result in rapid recombination of ions and charge relaxation producing little or no net charging.

The conductivity of market-place petrol can vary from 5-500 pS.m⁻¹ and experiments have shown that the highest charge generation occurs at a conductivity of 5-50 pS.m⁻¹[7]. Biofuels with at least 10% alcohol have an electrical conductivity several orders of magnitude higher than traditional fuels and are unlikely to generate hazardous levels of static electricity due to flow [8].

With plastic systems, electrostatic charge can accumulate on the pipe wall and associated ungrounded metallic components, such as the heating coils in electro-fusion couplings (EFC's), metal valves and other metal fittings. This represents the principal difference between plastic piping systems and earthed metal systems from an electrostatic point of view.

Totally buried insulating plastic pipes will not create dangerous discharges inside or outside of the pipe. In chambers and fill boxes, small sections of the pipe are not buried. The larger metal components present in a fill box may have enough capacitance, to produce incendive sparks when charged by induction of fuel flowing through the pipe. For this reason, such objects in chambers and fill boxes should be grounded. In addition, the electrical connections of electro-fusion couplers should be either grounded or discharges prevented by use of tightly closed plastic caps.

For an ignition hazard to exist, an electrostatic discharge (ESD) is required. From a correctly installed non-conductive pipe system in which conductive metal parts (such as EFCs) are either grounded or prevented from being a source of electrostatic discharge (e.g. by tight caps on the EFC terminals), the only type of ESD possible is a brush discharge.

For a brush discharge to constitute an ignition source, a number of extreme conditions are required which are not expected under normal fuel flow conditions. An electrostatic discharge will only occur where an intense electric field is established (in air about $3000\text{kV}\cdot\text{m}^{-1}$). When fuel flows through a buried pipe the charge built up on the inside wall creates a field through the wall of the pipe to the surrounding ground. There is no significant potential gradient within or along the pipe. It follows therefore that an ESD cannot occur in this region unless sufficient field strength is established through the pipe wall (HDPE has a breakdown strength of around $100\text{kV}/\text{mm}$ [9]). Consequently it is difficult to see where such a discharge would originate and terminate in a non-conductive pipe.

The main area of investigation in the tests described in this report is the tanker hose connection point in the fill box and where the outer surface of the pipe is exposed. This is because it is postulated that air may enter the pipe as the tanker hose is disconnected. In these areas it is agreed that conductive items must be grounded. Again however any charge build up on the inside of the pipe is unlikely to create a potential gradient within the pipe except where the pipe terminates on a grounded metal coupling.

With regard to brush discharges generally, work undertaken at the Shanghai Maritime University [10] indicates that on a plastic surface a potential of at least 20kV is required to ignite hydrogen gas in its most sensitive concentration (hydrogen has a much lower ignition energy than petrol (0.02mJ compared with 0.24mJ for petrol). This level of potential has not been observed in non-conductive systems under normal operating conditions. Furthermore, work undertaken on electrically insulating sheets by PTB [11] indicates that surface potentials in excess of -25kV are required to ignite propane gas which has an MIE close to petrol of 0.25mJ.

Previous tests that Wolfson have undertaken in the past with low conductivity fuels in non-conductive pipes at flow velocity up to $2.8\text{ m}\cdot\text{s}^{-1}$ produced a maximum potential of around -8kV [12].

3. Scope of tests (Test regime)

It was considered important that the tests performed here accurately encompass realistic worst case conditions existing at filling stations. It was considered therefore that the layout of the test facility should closely represent a typical forecourt but also be able to simulate extreme conditions.

From published work it is now widely recognised that the principle parameters influencing the level of electrostatic activity generated during fuel flow are (a) the nature and electrical conductivity of the fuel and (b) the flow velocity and level of turbulence. Consequently, the

choice of test fuels and the design of the test facility were crucial in order to achieve meaningful conclusions. These parameters are discussed in more detail later in this report.

In addition, the coexistence of a flammable atmosphere and electrostatic discharge necessary for ignition is postulated only at the input of the circuit where the plastic pipe terminates at the grounded metal connection at the tanker fill point. For this reason the electrostatic measurements were concentrated at this point. However, measurements were also undertaken at the end of the pipe circuit and at various points around the circuit where the buried pipe was exposed.

Criteria for electrostatic ignition hazard in this investigation would be (a) the presence of electrostatic potentials of several tens of kilovolts together with (b) the detection of electrostatic discharges.

3.1 Choice of test fuels

Two test fuels were chosen for these trials: Fuel C which is a 'pure' form of gasoline comprising roughly 50/50% by volume of Iso-octane and Toluene [13] and White Spirit, a light oil similar to aviation fuel [14]. Based on previous work, both of these fuels are known to produce relatively high levels of charging [12,15].

During the course of the tests, the conductivity of both fuels was regularly monitored using a Wolfson Electrostatics Model L40 precision liquid conductivity meter [16]. The Fuel C was in the range 37-47 pS.m⁻¹ with the White Spirit 13-15 pS.m⁻¹. This meant that both test fuels were in the optimum range for highest charge generation.

The storage tanks at the test facility incorporated approximately 1500 litres of Fuel C and 1600 litres of White spirit.

3.2 Fuel flow velocity and turbulence

It was agreed that the fuel flow velocity in the test rig should equate to or just exceed the maximum achieved in practice. In order to determine this value, the average speed measured from over 2000 field data points recorded at BP offset filling lines was analysed and found to be 1.54 m.s⁻¹ with a standard deviation 0.27 m.s⁻¹. The highest speed measured was 2.3 m.s⁻¹. This speed range is well covered by the experimental test facility.

Figure 1 below shows typical fuel delivery flow rates from a road tanker in terms of flow rate in l.min⁻¹ and velocity in m.s⁻¹ in 110mm pipe [17]. Figure 2 gives a histogram of maximum flow velocity data from 2000 operations.

BP - Malpas
Flow rate in Offset Fill

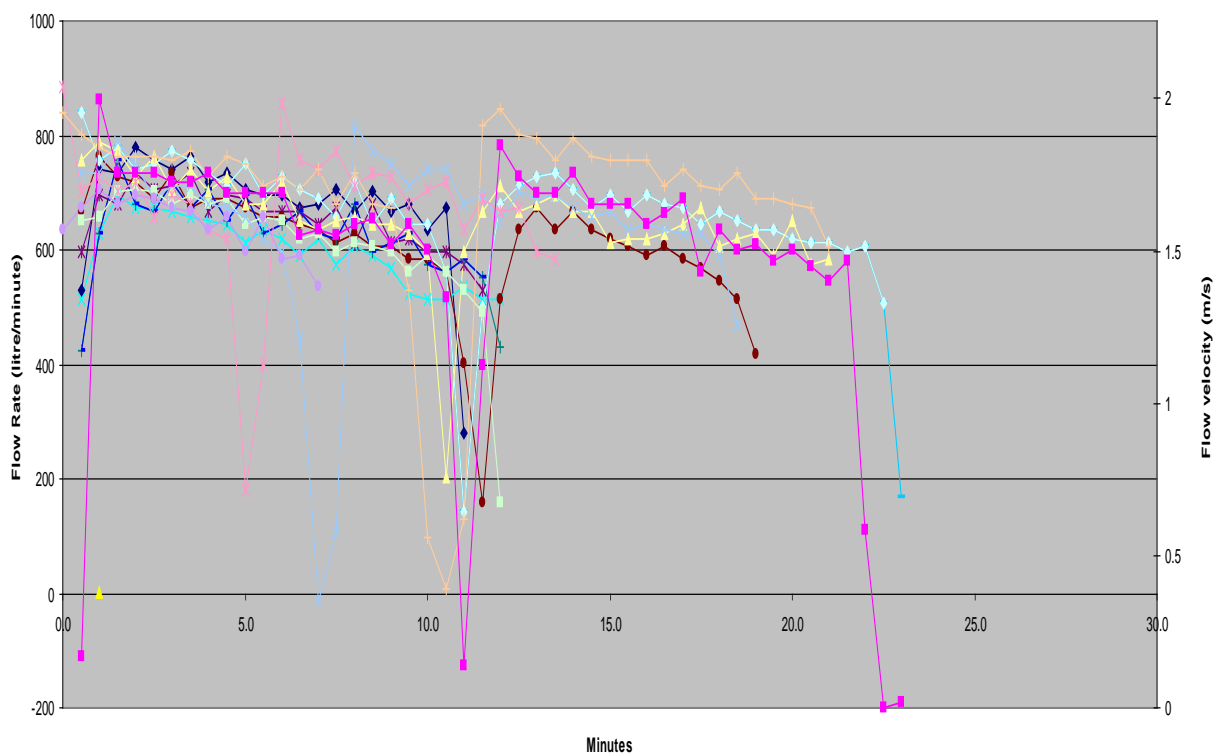


Figure 1. Fuel flow graphs from BP Malpas during tanker delivery showing flow and velocity data with respect to time.

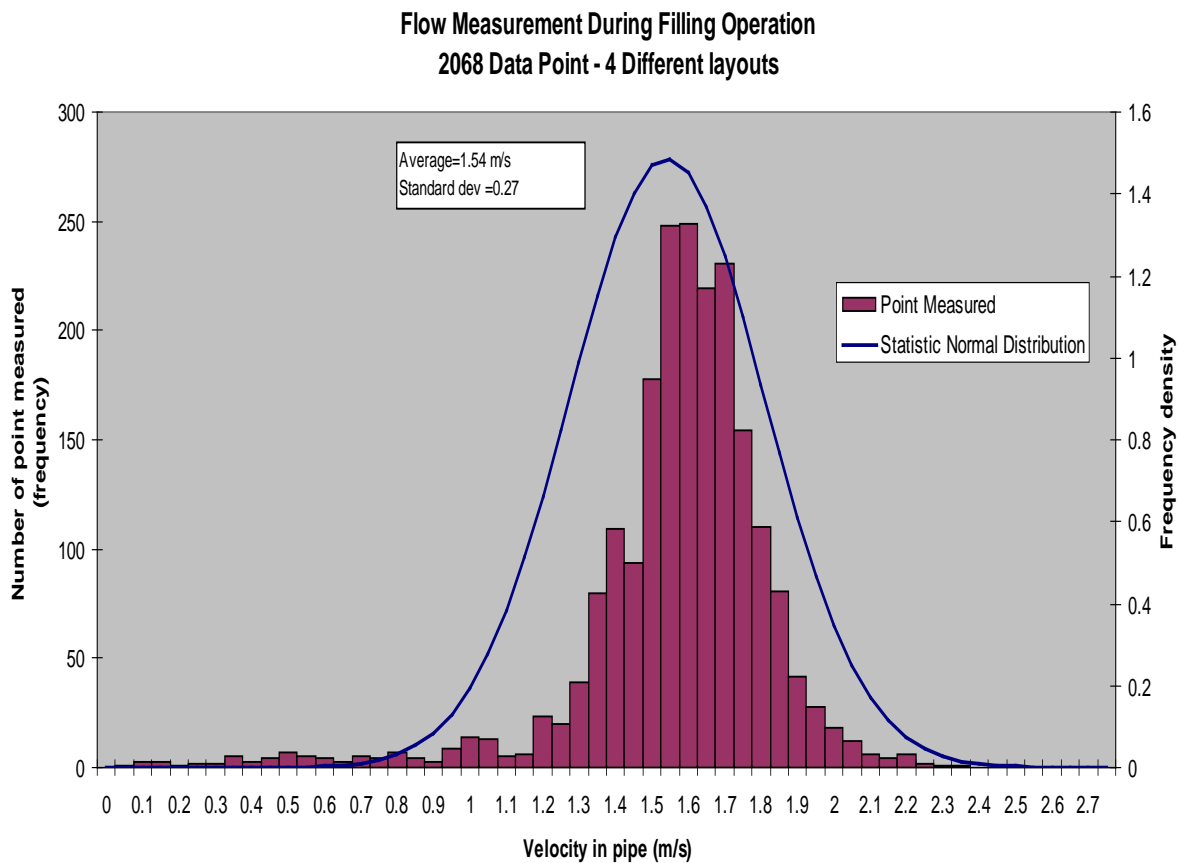


Figure 2. Fuel velocity data with respect to time obtained from 150 operations.

3.3 Instrument calibration

The electrostatic instrumentation used in these tests was calibrated in the Wolfson Electrostatics laboratories at Southampton University prior to the tests at Cookson & Zinn.

A JCI 140 electrostatic field meter [18] positioned 60mm away from the pipe was calibrated to read potential on the inside of the pipe. This was done in the laboratory by applying a conductive lining to the inner wall of the pipe and raising it to a known voltage using a high voltage power supply. Part of this calibration procedure is shown in Figure 3(a).

For any given charge generation, the electrostatic potential developed on ungrounded electro-fusion couplers and pipe will depend on its capacitance to ground. An exposed EFC will have a significantly lower capacitance than one that is buried. This effect was investigated in the laboratory by comparing EFC's in free space positioned 200mm above a ground plane with similar couplers wrapped in a grounded conductor (simulating burial as shown in Figure 3(b)). An increase in capacitance by a factor of around 6-7X is observed when the EFC is buried. Conversely therefore, electrostatic potential measured on exposed EFC's would be expected to be reduced by a similar factor once the coupler was buried.

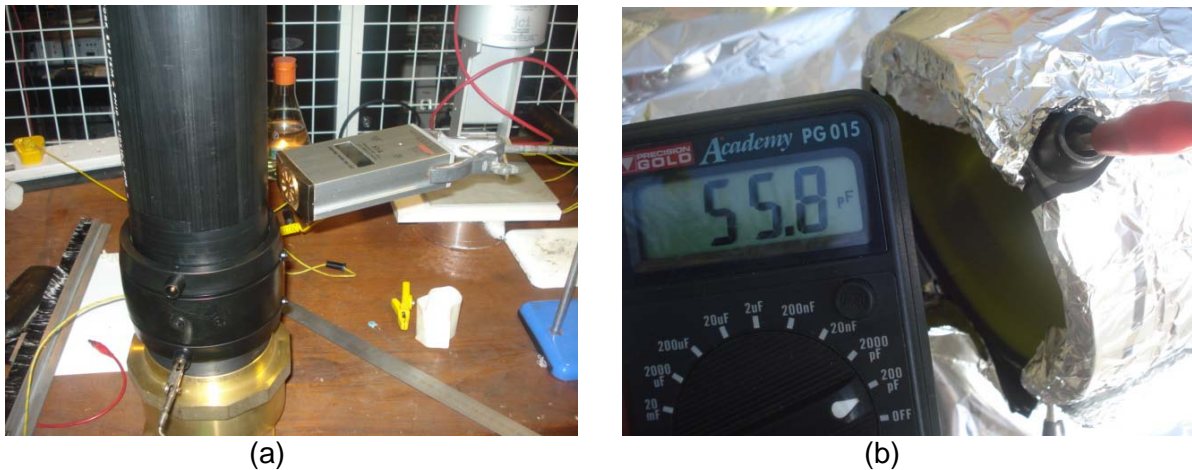


Figure 3. (a) Calibration of electrostatic field meter to measure potential on the inside surface of the pipe. (b) Comparing the capacitance of buried and unburied EFC's. The buried coupler is simulated by wrapping in grounded aluminium foil.

4. Experimental test facility

4.1 Description of the test facility

The experimental test rig is shown in Figures 4-6 below and schematically in Appendix A and B at the end of this report. The principle features of the test facility are as follows:

1. Two pipe circuits; 63mm and 110mm running roughly in parallel with buried and exposed sections and incorporating a series of straight and elbow electro-fusion couplers.
2. Two clean stainless steel 1.5m³ fuel tanks for storage of Fuel C and White Spirit test fuels connected to the pipe circuit by a stainless steel manifold.
3. Diaphragm pumps (two in parallel) placed at the end of the pipe runs to draw fuel from the storage tanks through the pipe circuit.
4. Open test chambers at the input and output points of the pipe circuit containing, valves and couplings and enabling electrostatic measurements to be undertaken at these key points.
5. A length of proprietary tanker hose joining the manifold to the input of the pipe circuit to exactly simulate fuel delivery.
6. Flow meter incorporated in the manifold to give continuous flow readings together with total fuel transferred.
7. JCI140 electrostatic field meter monitoring the potential in the pipe at the fuel input and JCI148 monitoring the electrostatic potential on the last electro-fusion coupler coil (see Figure 5).
8. Continuous output signals from electrostatic instrumentation monitored on data recorders. This would show the presence of electrostatic discharges at high potentials.
9. Small electrodes fitted to exposed electro-fusion couplers to enable the electrostatic potential to be easily measured at these points (see Figure 6).
10. Sampling point in the manifold to enable measurement of liquid conductivity.

4.2 Test run procedure

A total of six test runs were performed each lasting around 12-15 minutes. The run time was chosen to correspond to a typical delivery from an individual road tanker compartment. During the test run the fuel was continuously pumped around the test circuit and for each run the following parameters were recorded:

- Ambient temperature and relative humidity.
- Fuel type (Fuel C or White Spirit)
- Fuel conductivity (before and after the test run)
- Pipe diameter
- Fuel flow rate, total fuel transferred and total run time
- Flow velocity in pipe (calculated)
- Electrostatic potentials at the input and output of the pipe circuit (continuously monitored – see Figure 5)
- Electrostatic potentials at exposed EFC's and pipe (intermittent spot measurements)
- Presence of electrostatic brush or spark discharges characterised by a rapid collapse of potential.

Throughout the test runs, continuous interaction was encouraged between the experts and the visitors (see Figure 7).

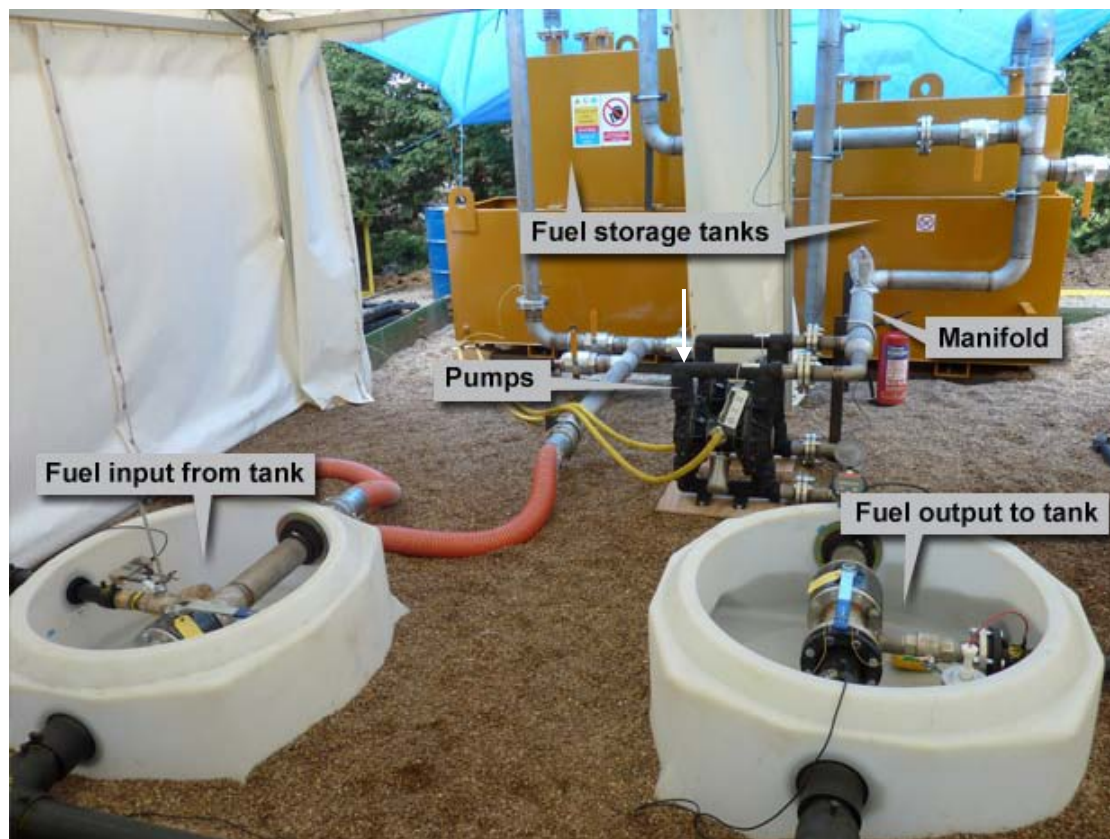


Figure 4. Photograph of test circuit showing fuel tanks, pumps, input and output connections to and from pipes and buried pipe sections.

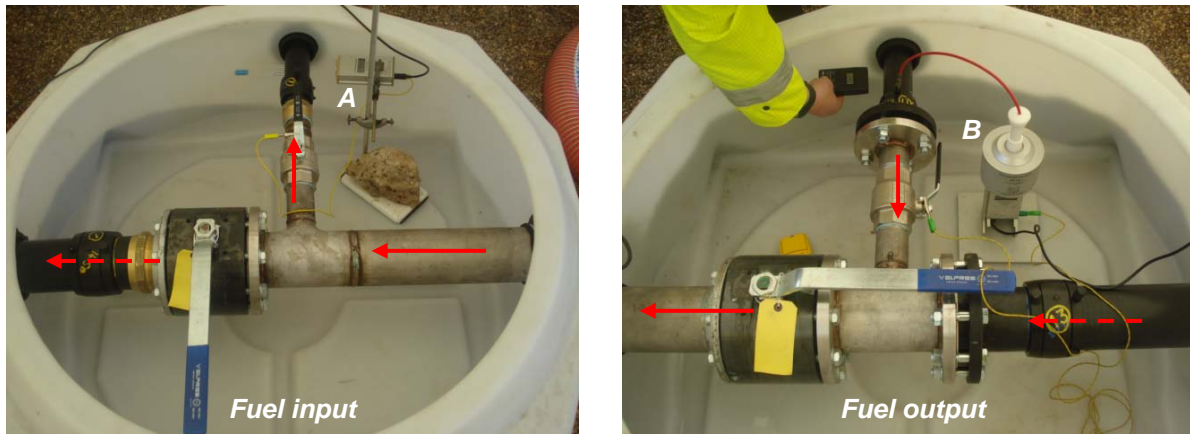


Figure 5. Detail of the electrostatic measurements at the input (A) and output (B) of the test circuit. In these photographs the fuel is set to go around the 63mm pipe circuit and the flow direction is shown by the red arrows. The JCI140 electrostatic field meter (A) is monitoring the potential in the pipe at the fuel input. The JCI148 (B) is monitoring the electrostatic potential on the last electro-fusion coupler coil.



Figure 6. Electro-fusion couplers partly buried and exposed. A small metal electrode (arrowed) is attached to the metal coil within the coupler to enable the electrostatic potential to be easily measured.



Figure 7. Demonstration of measurement of electrostatic potential by Dr. Von Pidoll (left). Discussion and interaction between experts and visitors (right).

5. Test results

The results from the six runs are summarised in Table 1 below. Runs 1 and 2 were with Fuel C in the 110mm pipe, runs 3 and 4 were Fuel C in the 63mm pipe and runs 5 and 6 were with White Spirit in the 63mm pipe. Flow velocities were in the range 1.8 to 2.3 m.s⁻¹. The maximum voltage recorded in each run at the input and output of the pipe circuit is shown in bold in the bottom two rows of the table.

run	number	1	2	3	4	5	6	
fuel type		fuel C	fuel C	fuel C	fuel C	w spirit	w spirit	
pipe		110	110	63	63	63	63	mmOD
flow rate		907	935	827	274	218	274	l/min
flow velocity [1]		2.1	2.1	1.9	2.3	1.8	2.3	m/s
total fuel		12700	14068	3290	3291	3434	3146	litres
run time		14.00	15.03	13.53	12.00	15.47	11.30	min.sec
fuel cond.	start of run	47	43	41	37	14.1	14.1	pS/m
	end of run	43	41	37	33	14.1	13.6	pS/m
Temp.		13	13	15	15	39.5	13	deg C
humidity		55	57	42	42	76	69	%RH
max. volts	input pipe	-1.1	+0.13	-3.97	-4.68	-1.42	-0.87	kV
max. volts	output EFC	-0.7	-0.86	-1.54	-2.19	-0.78	-0.48	kV

[1] approximate value

Table 1. Data from the six test runs performed with Fuel C and White Spirit.

Figures 7 and 8 below give an example of how the electrostatic potentials develop as a function of time during a test run. Figure 7 refers to run 4 and Figure 8 refers to run 5. In each case, the potential steadily increases from zero (or near zero) in the first few minutes of flow. It then then appears to stabilise for the remainder of the run. Test run 4 gave the highest readings of electrostatic potential.

The spot measurements on the exposed electrofusion couplers also gave the highest reading of potential during run 4. This was at the first elbow connector at the beginning of the 63mm pipe circuit. Here around -10kV was observed on a 4.6pF exposed EFC. In practice this section of pipe and coupler would be buried which would increase the capacitance from 4.6 to about 30pF thus probably suppressing the voltage to around 1.5 kilovolts.

No electrostatic discharges (ESD's) were detected at any stage during any of the test runs.

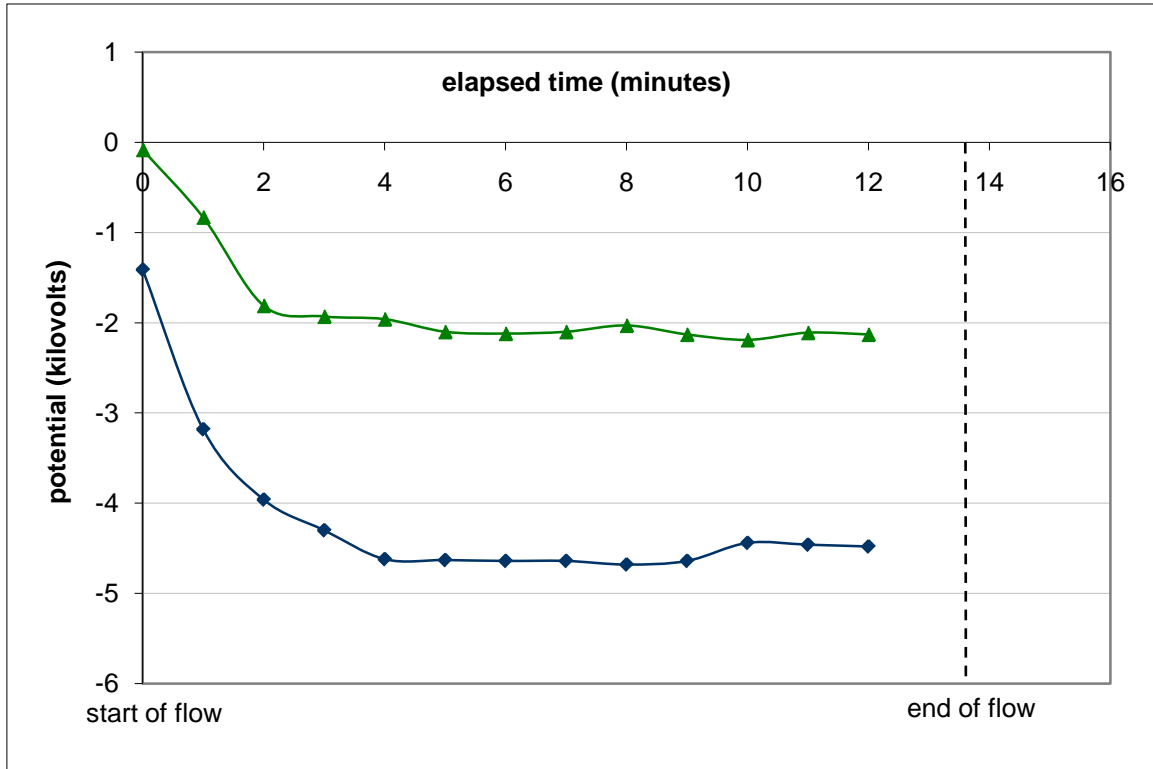


Figure 7. Electrostatic potential developed on input pipe (green trace) and output electrofusion coupler (blue trace) during run 4 – Fuel C at 2.3 m.s^{-1} in 63mm pipe.

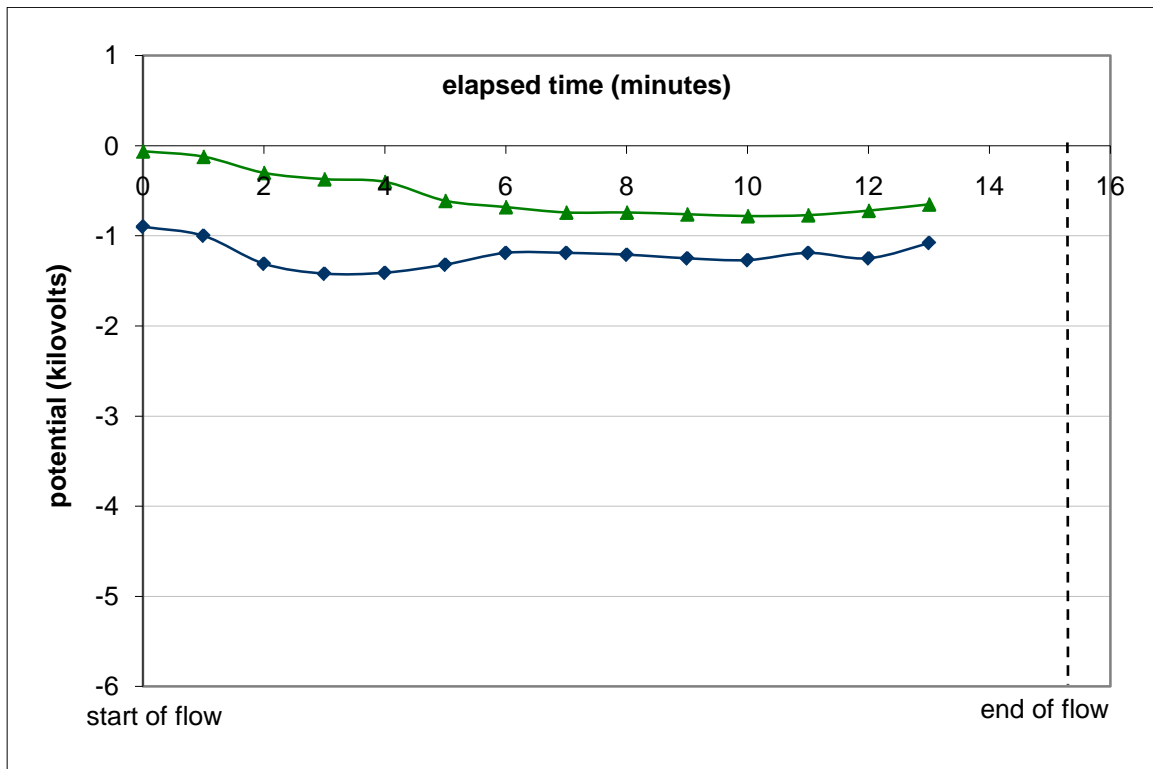


Figure 8. Electrostatic potential developed on input pipe (green trace) and output electrofusion coupler (blue trace) during run 5 – White Spirit at 1.8 m.s^{-1} in 63mm pipe.

6. Summary of results and conclusions

The tests performed using the Experimental test facility described in this report have been designed to simulate practical worst case conditions existing at filling station forecourts. In particular, highly charging fuels have been chosen exhibiting electrical conductivity values within the range reported for optimum charge generation. Furthermore, care has been taken to use flow velocities equivalent to the maximum reported levels and to avoid artificial conditions in the fuel delivery system which could give rise to unrepresentative results (for example an artificial condition would be incorporating a pump at the input of the pipe circuit rather than at the output).

The data obtained for Fuel C in terms of the profile of charge generation during the test run (Figures 7 & 8) and the maximum electrostatic potentials attained show reasonable agreement with earlier work and therefore give confidence in the results. With White Spirit, there is no previous data so it is not possible to draw comparison. However, the level of charging was generally lower than with Fuel C.

The maximum electrostatic potentials recorded during these tests will not give rise to incendive brush discharges as they are well below the 25kV threshold and therefore do not represent a hazard. Furthermore, there appears to be a wide margin of safety between the levels of static electricity generated in these tests and those necessary to create an ignition hazard. This in turn helps to explain the continued safety record of non-conductive pipe currently installed and operational throughout the world.

This leads to the main conclusion that there is enough safety margin for the safe use of UPP pipework when used according to IEC TR 60079-32 DC:2010.

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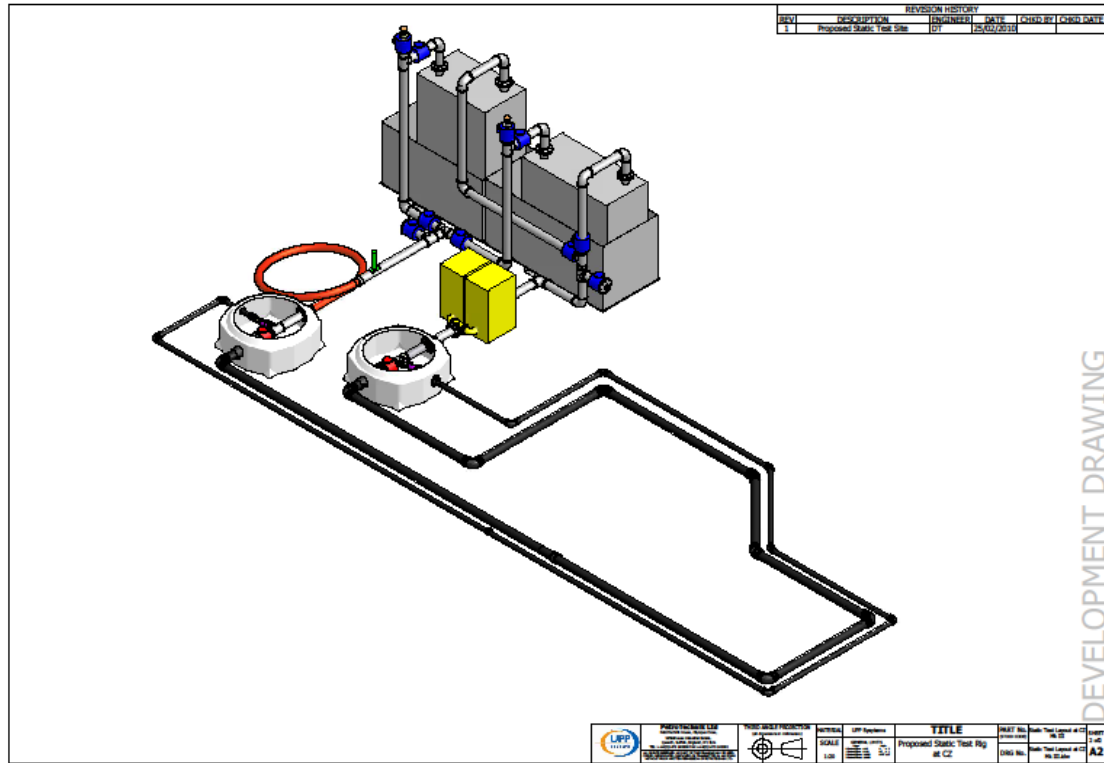
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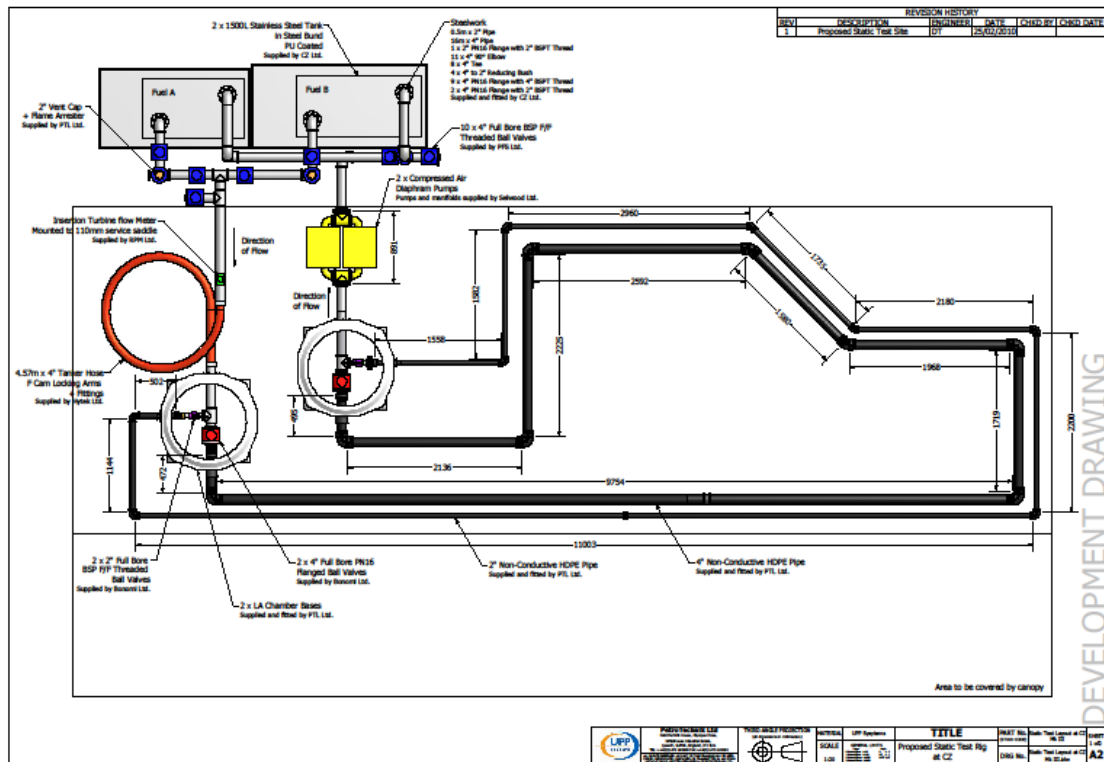
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Tests performed on 6-7th April to Determine the Electrostatic Safety of a Non-conductive Pipe System
 Report No R1086/GLH dated 19th April 2010

Appendix A. Experimental test facility – layout



DEVELOPMENT DRAWING



DEVELOPMENT DRAWING