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# Electrostatic ignition hazards arising from fuel flow in plastic pipelines

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**Abstract**

The use of electrically insulating synthetic materials, such as plastics, for fuel pipelines and other fuel handling components is now becoming widespread. In the case of buried or underground pipelines in filling station forecourts the use of these materials offers superior corrosion resistance and increased longevity. 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 metal pipes can produce significant levels of electrostatic charge on the fuel. Little work, however, has been undertaken on plastic pipe where charge can accumulate at the fuel/pipe wall interface.

This paper reports on tests performed on a full-scale, high-density, polyethylene pipework system. During the tests, an iso-octane/toluene fuel mix of controlled and known electrical conductivity was transferred through the system at varying flow rates. Both buried and free-standing pipeline configurations were simulated. A number of test runs were performed yielding considerable data relating to the resultant electrostatic activity including electrostatic potential, the nature and location of electrostatic discharges and the discharge energy. The influence of components such as in-line valves and couplings, which have a metallic component, are also evaluated. The extensive data resulting from this study are presented graphically. The paper concludes with an analytical section and draws important conclusions with regard to the parameters influencing the degree of ignition hazard present. 

*Keywords:* Electrostatic; Potential; Charge; Ignition; Fuel; Plastic pipelines

## 1. Generation of electrostatic charge

Studies by Bright (1977–1978), Gibson (1971), Hughes (1980) and Klinkenberg (1967), have shown that electrostatic charge is generated in fuel being pumped along pipes. The charging process arises from the presence in parts per million (or billion) of ions in the fuel. Feleci (1984) determined that positive or negative ions selectively attach themselves to any interfacial surface in contact with the fuel, such as the inner wall of the pipe, due to selective chemical adsorption (and possibly ionic injection from the pipe wall). In addition, with plastic pipes, the charge concentration on the inner wall surface can be altered by the dissociation into ions of surface chemical species (Ottewill, 1975). As a consequence, the inside surface of the pipe acquires a unipolar charge and ions of the opposite polarity in the fuel are attracted to it. A charged layer then extends from the wall into the fuel of a thickness that increases with decreasing fuel conductivity, the net charge in the pipe being zero when the fuel is at rest.

When the fuel flows, the ions in the boundary layer tend to be carried along, while the opposite charge on the wall dissipates to earth at a rate depending primarily on the pipe material's conductivity. The amount of unipolar charge being carried by the fuel depends upon differences between the positive and negative ions, in their diffusion rates to the pipe wall and their adsorption rates onto the wall. These properties in turn depend on the fuel's conductivity and flow characteristics, together with the wall's dimensions, conductivity, chemistry and surface roughness (Gibbings & Hignett, 1968; Gibson & Lloyd, 1970; Koszman & Gavis, 1962). The relative contributions to the total charge of the ionic diffusion and adsorption rates at different piping locations and for different flow conditions may alter, leading to changes in both the magnitude and sign. Any filters, valves and elbows will generally increase the amount of charge, due

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to greater interfacial charge separation, higher fuel velocities and increased turbulence. Similarly, the presence of free water in the fuel can also increase the charge concentration, again due to the charge separation arising from the large interfacial area of the emulsified mixtures.

The electrostatic behaviour of fuels in earthed metal pipework is reasonably well understood. In contrast, the charge levels developed in plastic pipes may depend markedly on the inner wall chemistry, and usually cannot be predicted. In such pipes, the amount of charge carried by diesel, petrol and other electrically insulating fuels (of conductivity less than 200 pS $m^{-1}$) may actually decrease with flow time if the inner wall resistance to earth is large. This is because a counter-charge and potential accumulate on the inner wall that opposes further charge separation.

With plastic pipe systems, as with metal pipework, the primary source of charge generation is due to the flow of fuel through the pipe, as discussed above. With metal systems the charge on the metalwork will normally be conducted safely to earth. 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, 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.

In addition to the electrostatic charging mechanisms associated with fuel flow, there is also the possibility of electrostatic charge generation by friction with the external pipe wall and other components of the system, such as the walls of plastic chambers and sumps. In such cases, the charge generation mechanism could be frictional contact with clothing.

## 2. Ignition hazard

Petroleum spirit vapour is flammable within the range of about 1–6% by volume with air. The ignition energy varies significantly over this flammable range and has a minimum value of 0.25 mJ corresponding to a concentration roughly midway between the upper and lower flammable limits. At or near this concentration, vapour ignitions may occur as the result of sparks from ungrounded metal or electrostatic brush discharges from charged plastic.

Lewis and von Elbe (1987) found that the ignition hazard associated with a spark discharge is primarily dependent upon its energy content and the physical spark gap length. If the spark length is less than 2 mm only a fraction of the thermal energy of the discharge is released into the atmosphere (the rest is absorbed by the discharging surfaces). Since the breakdown strength of air is approximately $3\times10^6$ V $m^{-1}$, a spark gap of 2 mm has a breakdown voltage of around 6 kV. Spark discharges, therefore, which are lower than the ignition energy of the flammable media present *or* are the result of electrostatic potentials significantly below 6 kV, do not pose an ignition hazard. In gas ignition tests, Glor (1981) recorded the highest reported brush discharge energy from a plastic surface of around 3.6 mJ. Brush discharges have only been observed to create an ignition hazard with hydrocarbons when they occur from a negatively charged surface (Lovstrand, 1981). Furthermore, in order to obtain a brush discharge it is necessary to first generate a surface potential of around $-20$ kV (Britton, 1999).

## 3. Investigation

Some initial observations and measurements were performed on a system already installed at a filling station forecourt. All commercial plastic pipe systems for fuel are similar in construction. The pipe itself is extruded polyethylene (PE) available in various diameters between 32 and 160 mm OD and has a wall thickness of 6–10 mm depending on diameter. On a forecourt, although the pipe is buried, access can be gained at three points: the road-tanker refuelling point, underground fuel storage tank manifold sump and pump manifold box. The pump manifold box is shown in Fig. 1.

During the investigation, the following potential ignition sources were considered: electrostatic brush discharges from the pipe wall and the plastic walls of the manifold chamber and spark discharges from isolated metal components including electro-fusion coils, valve bodies, metal entry-boot rings (where the pipes enter the chamber) and ‘Jubilee’ clips. Electrical capacitance measurements on the metal components yielded the values shown in Table 1.

In order to investigate electrostatic potentials

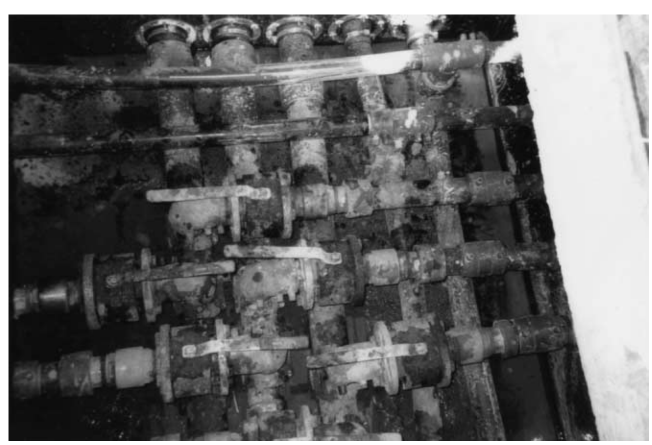

Fig. 1. Underground pump manifold box clearly showing valves, metal-ringed entry boots (at top of photograph) and electro-fusion couplings (green cylindrical objects most clearly seen on the pipes to the right).

Table 1
Capacitance of electrically isolated metal components in manifold box

| Item | Capacitance |
|---|---|
| 1-1/2″ electrofusion coupling | 4.8–11.0 pF |
| 2″ electrofusion coupling | 3.9–7.4 pF |
| 3″ electrofusion coupling | 13–31 pF |
| Valves on 2″ line | 23–24 pF |
| Metl rings in entry bood | 25–44 pF |
| ‘Jubliee’ clips | 25 pF |

developed on the various elements of a PE pipeline system due to fuel flow, a test pipeline was constructed using commercial polyamide lined PE pipe. The test set-up enabled electrostatic measurements to be undertaken at various points during the flow of low conductivity fuel, pumped at high velocity using a pneumatic diaphragm pump. Details of the test system are given in Fig. 2. The system under test comprised two legs, one of 63 mm diameter pipe and the other of 90 mm (the most common for petrol), coupled together with a valve. It also included a number of electro-fusion couplings — straight, 45 and 90° elbows. In order to simulate burial of the pipe, in some tests certain sections were covered with grounded aluminium foil. These sections are also indicated in Fig. 2. Both the valve and electro-fusion couplings were left ungrounded in order to mimic the situation that occurs in practice. Preliminary measurements of the capacitance of these components indicated that they were similar to the capacitance values observed at the forecourt.

Six-hundred litres of refined iso-octane and toluene (50:50 mixture) was purchased for the trials. The electrical conductivity of the fuel was measured at the depot prior to delivery and at the test site yielding a value of around 4.0 pS $m^{-1}$. Prior to performing the fuel flow test runs, 200 l of the low conductivity fuel was used to purge and clean items such as the pump, flexible hoses and fittings. A pump was chosen for these trials which had the capability of delivering a fuel flow rate of the maximum to be expected in forecourts (in order to obtain practical worst-case electrostatic charging).

Fig. 3 shows a section of the pipe system under test, including part of the 90 mm leg covered with grounded aluminium foil to simulate burial. The valve can be seen in the foreground of this photograph connected to an electrostatic voltmeter. The voltmeter, in turn, is connected to a computer to continually monitor the electrostatic potential developed.

A total of 22 test runs were undertaken, each run involving the transfer of around 200 l of fuel in 35–60 s, with the main controlled variables being flow direction and fuel conductivity. Runs were performed at a maximum pumping rate of 200–340 l $min^{-1}$. This corresponded to a velocity of 1.6–2.8 m $s^{-1}$ through the narrow bore pipe. The fuel conductivity was measured at the start and on completion of each run. Fuel conductivity was incrementally increased from 80 to 500 pS $m^{-1}$ over the last six runs by adding a proprietary anti-static agent (conductivity improver). In addition to monitoring the fuel flow rates and conductivity, measurements were performed to determine the electrostatic potential on the pipe wall, the electro-fusion coup-

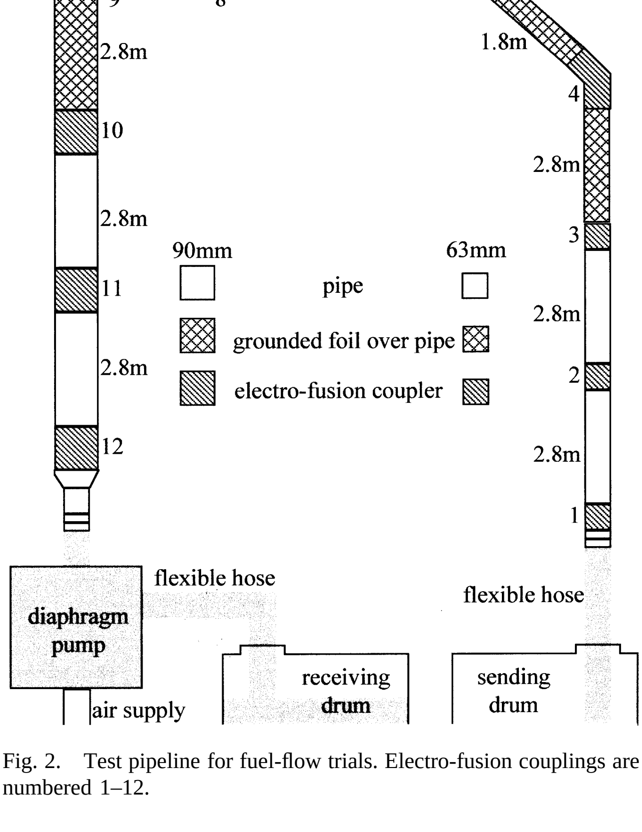


Fig. 2. Test pipeline for fuel-flow trials. Electro-fusion couplings are numbered 1–12.

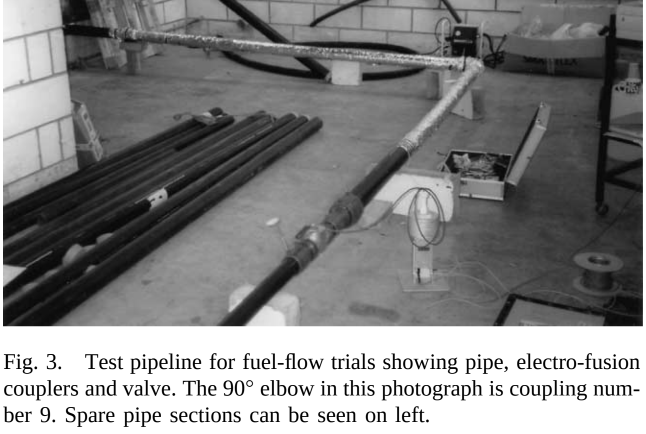

Fig. 3. Test pipeline for fuel-flow trials showing pipe, electro-fusion couplers and valve. The 90° elbow in this photograph is coupling number 9. Spare pipe sections can be seen on left.

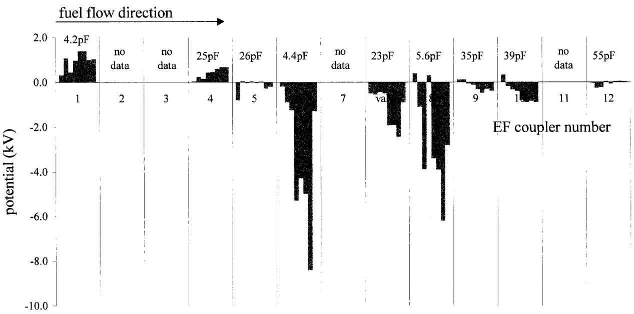


Fig. 4. Electrostatic potentials developed on electro-fusion couplings and valves over the first nine test runs.

lings and the valve during and after each run. Relative humidity and temperature were recorded at 35–47% and 10–18°C throughout.

For all test runs the diaphragm pump was situated downstream of the pipeline and residual charge on the fuel was allowed to dissipate prior to each run. This meant that the electrostatic charge measured on the pipe and fittings was due to fuel flow through the pipe rather than the action of the pump.

Fig. 4 shows potentials monitored over the first nine runs on each of the 12 electro-fusion couplings and the valve in the form of a bar chart. The chart indicates the fuel flow direction and the capacitance of the coupling heater coils and the valve. Couplings 2, 3, 7, and 11 were not instrumented and therefore yielded no data. Each bar on the chart represents a test run. As expected, those couplings with a relatively high capacitance due to foil covering exhibited the lowest potentials, the highest potentials being recorded on uncovered electro-fusion couplings nos. 6 (4.4 pF) and 8 (5.6 pF). During these runs, it was observed that the fuel conductivity increased from 4.0 to 64 pS $m^{-1}$ presumably due to contaminants.

Fig. 5 shows the electrostatic potential on the valve during and immediately after fuel flow. The electrostatic potential developed quickly at the beginning of the run, but then began to level to a maximum (although this maximum was not reached during the test run). This effect was presumably due to the inner pipe wall becoming saturated with charge. On completion of the run and cessation of fuel flow, a significant degree of charge relaxation was observed with virtually all of the generated electrostatic charge being dissipated within 90 s.

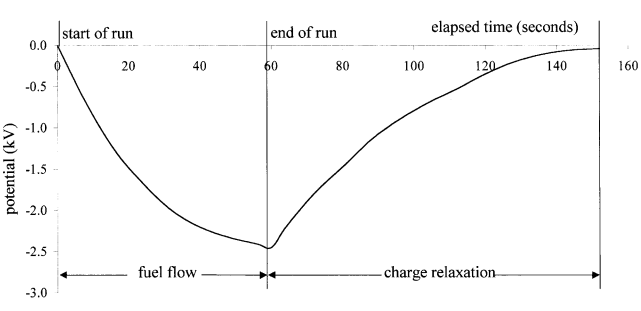


Fig. 5. Electrostatic potential developed on valve body during and after fuel flow.

Fig. 6 incorporates data from all the test runs and shows how the electrostatic potential on the valve and the first electro-fusion coupler varied as a function of the fuel conductivity. It can be seen quite clearly from this graph that the maximum potentials were observed at a fuel conductivity value of around 50 pS $m^{-1}$. Increasing the fuel conductivity to values exceeding 200 pS $m^{-1}$ generally resulted in lower levels of potential.

## 4. Summary of results and conclusions

The fuel flow tests described in this paper are representative. The pipe lengths used in the experiments were similar in terms of length and layout to those in a forecourt. The fuel velocity of 2.8 m $s^{-1}$ represents a practical worst-case since typical flow rates in a forecourt are in the range of 40–50 l $min^{-1}$ per nozzle and four or five nozzles could be delivering fuel simultaneously through the same piping. Conductivity in the range 4.0–500 pS $m^{-1}$ is realistic for forecourt petrol (Von Pidoll, Kramer, & Bothe, 1997).

The maximum electrostatic potential observed during fuel flow was −8.4 kV on an electro-fusion coupler of capacitance 4.4 pF. In terms of electrostatic discharge energy this equates to 0.16 mJ. This is below (but close to) the minimum ignition energy of 0.25 mJ for petroleum spirit vapour. Maximum potentials were observed with fuel of conductivity around 50 pS $m^{-1}$. Based on these results the fuel conductivity needs to be greater than 200 pS $m^{-1}$ in order to minimise electrostatic charge generation in plastic pipe systems.

The electrostatic potentials developed on the walls of the piping during fuel flow were all significantly below the −20 kV threshold for brush discharges to occur. Corresponding electric field strengths through the pipe wall were at least two orders of magnitude lower than the

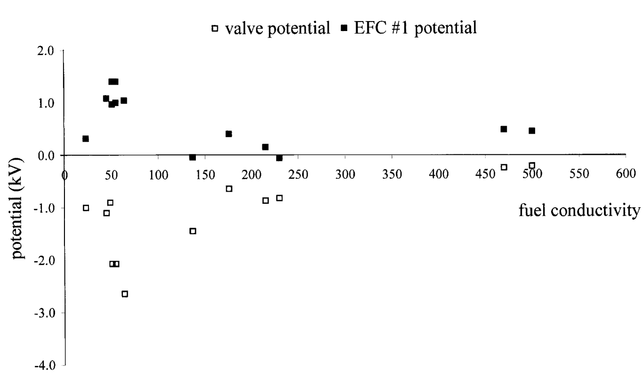


Fig. 6. Maximum electrostatic potentials on valve and coupling no. 1 as a function of fuel conductivity. Each point on the graph corresponds to a test run.

electrical breakdown strength of polyethylene (Chen & Davies, 2000). There is, therefore, no danger of electrical breakdown through the pipe wall under these conditions. The potentials measured on valves and couplers in test runs where a grounded-foil covering was used were similar to those for uncovered pipe.

Fuel flowing at high velocity for longer than the test run duration may result in slightly higher potentials (from Fig. 5). Furthermore, different pipeline configurations may produce slightly different potentials. In these cases, the minimum ignition energy of the fuel may be reached by a coupler or valve. Should this occur it would only exist for a short period of time as charge relaxation occurs immediately fuel stops flowing. It may be advisable, however, for personnel not to enter a sump or any other underground chamber during or immediately after fuel flow if a flammable vapour concentration is present.

When there are no personnel present in or around a plastic chamber the only mechanism of electrostatic charge generation is the flow of fuel. There is no significant risk of electrostatic ignition due to fuel flow in these cases provided that electrical sparks cannot occur from charged metal components. These components are primarily metal valve bodies and electro-fusion couplings. In order to avoid the generation of sparks these items should either be grounded or positioned away from other metal components such that spark-over cannot occur within the chamber. This will not apply to buried electro-fusion couplings.

When a person enters a chamber, charge may be generated on the person's clothing and body and also on the plastic walls of the chamber by friction due to the person's movement. The greatest degree of electrostatic ignition hazard is perceived as a spark originating from the ungrounded body of a person working within the chamber. This conclusion applies to personnel working in these environments generally and is not restricted to plastic pipelines. In these cases the appropriate precautions as indicated in the International Standards should be applied.

From the results obtained from this study, it is concluded that under all practical conditions, the plastic pipe system and their associated elements (valves, electro-fusion couplers, etc.) are unlikely to constitute an increased electrostatic ignition hazard over existing metal systems due to fuel flow.

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