Electrostatic hazards with underground plastic pipes at petrol stations

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Abstract. The paper analyses some ignition incidents that have been reported with insulating, (non-conductive) underground plastic pipes in retail petrol stations. The occurrence of the incidents is compared with voltage measurements, observations of the typical spread of streaming currents recorded in gasoline handling and theoretical estimates of the voltages on the pipes. The comparisons suggest that neither incendive sparks from unbonded conductors nor incendive brush discharges from insulating pipe surfaces can be ruled out although both are expected to be rare. The hazards can be prevented by using pipes with earthed conductive or dissipative inner linings.

1. Introduction
Fuel arrives at petrol stations by truck and is transferred through buried pipes to underground storage tanks. From the tanks it is transferred through more buried pipes to the familiar “petrol pump” dispensers that fill customer vehicles. The buried pipes are increasingly being made of plastic (HDPE) to avoid corrosion. The plastic pipes may be either completely insulating (“non-conductive” type) or they may have a dissipative inner lining (“conductive” type). Connections to the pipes are made either above ground or in chambers (“fill boxes”) or sumps let into the ground. With the non-conductive type of pipe there has been a small number of electrostatic ignitions (flash fires) either inside connection chambers or inside the pipes themselves.

This paper lists some reported electrostatic ignition incidents with non-conductive pipes and evaluates the possible ignition mechanisms by considering laboratory measurements of pipe voltage [1,2], observations of the typical spread of charging currents in hydrocarbon distribution systems [3] and new theoretical estimates of the voltages that result from liquid flow.

2. Incidents involving non-conductive plastic pipe systems at filling stations
Although a risk of escalation or injury is clearly present, the incidents have not usually been serious. Therefore, reporting may be somewhat haphazard and the list below is unlikely to be comprehensive. Nevertheless, there are relatively few incidents and, given the large number of vehicle fills that occurs globally at petrol stations, it is clear that the incident frequency is very low:
1) Hungary, 1998-2000: At least 5 fires in fill boxes at 4 sites. Unbonded conductors and exposed external pipe surfaces in the fill boxes.
2) UK, 2001: One minor ignition in a fill box when replacing the metal cap on an unbonded end-fitting after filling a tank. Unbonded end fittings and exposed external pipe surface in the fill box.
3) Sweden, 2002: 4 ignitions inside pipes immediately after disconnecting filling hoses. Pipes completely buried with no exposed external surfaces and no unbonded conductors. Discharges thought to have occurred from the inner surface of pipe.

4) Hungary 2005/2006: 6 fires in fill boxes. Unbonded welding sockets and exposed external pipe surfaces in the fill boxes. Flame arrestors on pipe ends. Discharges from isolated welding sockets suspected. Flame arrestors may have increased charging levels.

5) Australia, 2007: One fire when a newly fitted pipe was used before it was buried (backfilled).

6) Ireland, 2009: One fire, repeated audible and occasional visible discharges in a fill box. Unbonded and unplugged welding sockets and exposed external pipe surface in the fill box. Audible discharges reported to continue despite earthing all conductors although, subsequently, welding sockets neither capped nor earthed. Discharges eliminated by changing to conductive pipes.

3. Voltage measurements in non-conductive plastic pipe systems
Hearn [1] measured the voltages created by a 50:50 toluene/isooctane mixture in a laboratory mock-up of the piping that feeds the dispensers from the tanks. Some pipe sections were covered in conductive foil to represent burial whilst others were left exposed. The highest recorded voltage was -8.4 kV and Hearn concluded that this voltage was too low for hazards unless isolated conductors were present.

Other measurements [2] using E5 gasoline, alkylate gasoline and white spirit in long lengths of exposed plastic pipe have given voltages up to 90 kV. These would be hazardous even without isolated conductors. It is important to understand how these results differ from Hearn’s.

4. Variations in streaming current and other factors
When performing laboratory voltage measurements to assess risk, the test conditions should either replicate the practical worst-case or allow it to be estimated. For fuel charging, the ideal procedure is to measure streaming current in the field, identify the maximum and then use laboratory tests with enhanced charging (e.g. charge injectors or filters [3]) to show that the current needed for incendive discharges is greater than the field-trial maximum. This approach is expensive and it is common to dispense with field trials and enhanced charging and simply do laboratory voltage measurements with representative liquids. This simplified procedure tends to underestimate the highest voltage that could occur but was adopted in [1] and [2]. We now examine the likely degree of underestimation.

Figure 1 shows a typical gasoline streaming current distribution obtained by field measurement. The highest current is about three times the mode and the cumulative distribution shows that a randomly chosen sample has a 70% chance of giving less than half the maximum current. Gasoline is not unique in this respect: an even wider distribution of charging has previously been reported for diesel [3]. Typically the highest current is two to five times the mode and a randomly chosen sample is likely to give close to the mode current.

With a test liquid synthesised from pure hydrocarbon components, charging would generally be expected to be lower than in a real gasoline because the extra processing needed to isolate the pure components tends to remove the polar impurities that give rise to charging. Thus the streaming current of a synthesised test liquid is likely to be lower than that of a worst-case gasoline by more than the above factor of two to five.

A voltage measurement may also deviate from the worst case in other respects. The resistances of dissipation paths through both the liquid and the pipe walls increase at low temperature and humidity.
and no relevant measurements have been reported under these conditions. Also, voltages increase with time and in [1], the flow time was limited by the available fuel volume (recirculation was used in [2]).

5. Voltage calculations
We have done steady-state voltage calculations for exposed pipe lengths based on the Carruthers and Marsh expression [5] in order to identify the factors that promote high voltage. They show that the voltage on the exposed ends is proportional to the exposed length and to the square of the flow speed. Consequently, test rigs designed to assess operational risks must use the longest realistic lengths of exposed pipe (not always done) and the highest practical flow speeds (usually done).

We have also used an adapted form of equation (3) of reference [6] to calculate the time-dependent voltages that occur in a typical buried pipe (15 m long, 90 mm ID, 0.75 m exposed at each end, flow speed 2.8 m/s, streaming current 100 nA, flow duration 15 min). The streaming current approximately matches the maximum in the data referred to in [2] and is expected to be typical rather than worst-case. The worst-case current is probably higher by a factor in the range discussed above. The flow time is typical of the time taken to fill an underground tank at a petrol station from a delivery truck.

Figure 2 shows the calculated voltage on the pipe at the end of flow versus distance along the pipe for different fuel conductivities. As the conductivity increases, potentials at the upstream end rise whilst those at the downstream end decline. A maximum voltage is reached at the upstream end when the conductivity is about 35 pS/m. Further increases in conductivity cause the voltage to fall at both ends because of increasing dissipation through the liquid column.

The calculated maximum voltage on the exposed upstream end of the pipe considerably exceeds the lowest suggested threshold voltage for the occurrence of brush discharges that can ignite hydrocarbons (25 kV [7]) even though the assumed streaming current is not worst-case. Around the upstream end, a flammable atmosphere could occur either inside the pipe after disconnection of the delivery hose or, for pipes terminating in an enclosed chamber, outside the pipe due to spillage or vapour leaks.

Examination of the transient solutions shows that the maximum voltage at 15 min was approximately double that at 1 min (the duration of Hearn’s tests [1]) and was still rising. Maximum voltages would have been higher if more fuel was delivered.

6. Discussion of hazards
Hearn [1] used a realistic pipe configuration but did not ensure that streaming currents, test-duration or dissipation conditions were worst-case. Consequently, his measured voltages are likely to be several times lower than the worst-case. When this is allowed for, his data suggest that brush discharges from

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1 The charging parameters suggested for hazard assessment in NFPA 77 [4] give a worst-case streaming current of 1.6 μA. This exceeds the currents estimated from [2] by rather more than our suggested uncertainty level. This is expected as the NFPA correlation represents a universal worst-case
insulating surfaces and sparks from unbonded conductors are both credible ignition sources. The KPS tests [2] confirm this but, as they used very long lengths of exposed pipe, the results are not directly relevant to the short exposed sections that exist in real site layouts. They do, however, demonstrate the need to ensure that pipes are properly buried to avoid incidents like Case 5).

Experimental measurements, incident investigations and calculations all confirm that voltages on exposed pipe ends in fill boxes can be high enough for incendive sparks from unbonded conductive objects. Regrettably, both incident investigations and site installation photographs (even from sites that have not had incidents) reveal multiple instances of welding sockets that are both uncapped and unbonded and of unbonded metal components such as flanges, end-couplings and hose clips.

The investigators of Case 4) linked that set of incidents to discharges from unbonded, uncapped welding sockets. Tests revealed a breakdown voltage of 20 kV for a similarly-located welding socket. The gaps between conductive items in a fill box are such that other unbonded items would typically have similar, or greater, breakdown voltages except for incidents, like that in Case 2), in which a manual activity such as replacing an end cap was involved. The occurrence of occasional incidents where breakdown voltages are high supports the view that worst-case voltages in the field can be considerably higher than those measured by Hearn [1]. In some of the incidents thought to involve welding sockets (e.g. Case 6), the gaps between the socket and the nearest earthed object were larger than in Case 4) and the breakdown voltage would be expected to have been higher. This supports the suggestion, arising from our voltage calculations, that voltages on exposed ends may also exceed the threshold of 25 kV [7] for incendive brush discharges from insulating surfaces. Therefore hazards from this mechanism cannot be ruled out. In addition, Case 3) shows that incendive discharges can be drawn from the inner surface of even a fully-buried pipe with no unbonded conductors.

The high voltages and associated ignition hazards that occasionally arise with non-conductive pipes can be prevented by using earthed conductive (dissipative-lined) plastic pipes. With this approach, it is important to ensure that all linings are earthed in order to avoid the creation of an isolated conductor.

7. Conclusions

1. Ignitions associated with non-conductive plastic pipes at petrol stations are rare. Most appear to be associated with sparks from isolated conductors but ignitions caused by incendive brush discharges from insulating pipe surfaces cannot be ruled out.

2. The voltage data in Reference [1] underestimate the worst-case, in-service voltage on non-conductive service-station pipes because testing did not establish the worst-case streaming current, dissipation conditions or flow time. However, the data probably does represent typical behaviour and suggests that ignitions will be rare provided conductive items are earthed.

3. The voltage test data in Reference [2], overestimates normal in-service voltages because unrealistically long unearthed sections of pipe were tested but they show the voltages that could arise on an unburied non-conductive pipe.

4. Voltages can be minimised by keeping exposed (unburied) pipe lengths as short as possible.

5. The electrostatic ignition risks arising with non-conductive plastic pipes can be avoided by using earthed conductive plastic pipes. If this approach is adopted, it is important to ensure that all linings are earthed in order to avoid the creation of an isolated conductor.

References

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