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Electrostatic ignition hazards in motor cars – occurrence, detection and avoidance

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This paper deals with ignition hazards for gasoline and hot diesel fuel vapours in and around tank systems of modern motor cars due to unwanted electrostatic discharges. The first section gives a summary of some recent car fires probably caused by electrostatic discharges. Various influences such as insulated conductive parts in the flammable zone around the tank inlet and charging of persons contributed to these incidents. The second section shows examples of good and poor management of electrostatic ignition hazards in motor cars of today. These examples include safety measures recommended for insulated conductors, personal charging, plastic tank systems and fuel lines, plastic parts in the vicinity of the tank opening, electrical equipment in the tank system and vehicles with high diesel reflux temperature. The third section describes test strategies and measuring techniques for determining ignition hazards due to static electricity.

1 Introduction

In recent years electrostatic discharges have increased in importance as an ignition source. The reason for this is quite simple: plastic materials are increasingly used instead of metal. While metal cannot be charged by rubbing and metal also discharges objects being in contact with it this is not the case for insulating plastic materials. As a consequence electrostatic hazards that did not occur in the past may occur in modern vehicles containing a greater number of plastic parts.

To make a comprehensive statement on present-day knowledge on electrostatic ignition hazards in motor cars this paper is divided into three sections. In the first section a compilation of some car fires during refuelling probably caused by static electricity is given. The second part will give examples of good and poor electrostatic ignition hazards management. These examples have been taken from modern cars. The third section of this paper will present test strategies and measuring techniques for determining ignition hazards due to static electricity.

2 Some ignitions of fuel vapours caused by static electricity

Since 1992 ignitions of gasoline/air-mixtures at public filling stations have regularly occurred during the refuelling of motor cars. Some of these ignitions resulted in the cars catching fire. These incidents typically occurred in form of multiple fires of specific car types at a specific fuel dispenser. The circumstances usually led to the conclusion that static electricity is the most probable ignition source [1]. Since 1992 more than 50 of such ignitions have occurred in Germany. Worldwide the number of fires reported is of the order of a fair hundred [2].

Lately the most prominent example has been the release of a new minicar in England. 500 new models had already been delivered when the manufacturer stopped the production on 3rd September 2001 after two fires had occurred during the first refuelling of the new model in England. According to the German newspaper "Handelsblatt" [3], it was found that the conductive but insulated fuel hose inside the car got so highly charged by the flowing fuel that sparkover took place. As this sparkover happened in the area of explosive fuel vapours an ignition of these vapours could result. For this reason the cars were called back and an earth cable between fuel hose and car body was installed. This modification solved the problem. The ignition hazard arose because the minicar had been tested in countries with gas recovery systems only. England is, however, a country without gas recovery system. As a consequence, more fuel vapours were set free during refuelling creating an explosive atmosphere in the sparkover region.

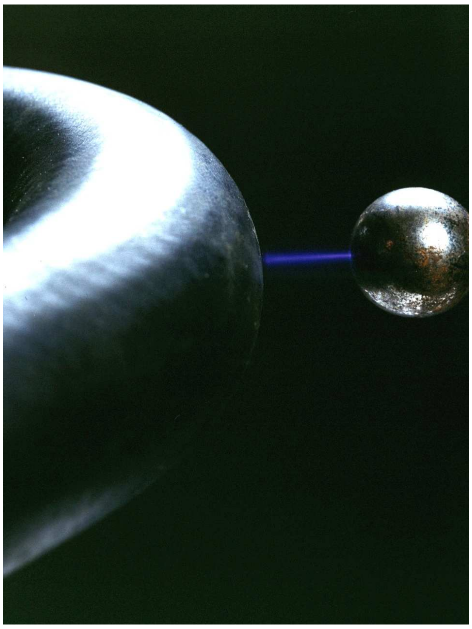

Fig. 1: Sparkover of an insulated conductive fuel hose to an earthed electrode due to charges created by the flowing fuel

In the last few years, only a few fires during refuelling occurred in Germany. In contrast to the incidents before, they were almost exclusively produced by women getting charged. The German magazine "Der Spiegel" [4], therefore, produced the headline: "Frauen tanken riskanter" (Women refuel more riskily). According to [4], the reason for this phenomenon is quite simple: Women usually do not like the smell of gasoline and often are more sensitive to cold than men. For this reason they frequently leave the filling nozzle during refuelling to go back inside the car. They then get charged when leaving the car seat and may produce a spark in the vicinity of escaping fuel vapours when touching the earthed filling nozzle.

From April 2001 to June 2002, eight fires occurred at Japanese filling stations when the driver opened the tank cap without having touched the refuelling nozzle or any other earthed part. In every case, the relative humidity was less than 50%, and some drivers reported an electric shock when the fire broke out. For this reason, electrostatic discharge is the most probable ignition source. As some of the accidents were recorded on video these pictures were later shown on television and in newspapers resulting in an upset of the Japanese population. In the sequel all Japanese car manufacturers decided in June 2002 to use earthed dissipative tank caps in all their cars as soon as possible [5].

Fig.2: Pictures of a recorded refuelling fire in Japan [4]

Nevertheless, this measure would not help prevent the fires occurring when getting inside the car after the start of the refuelling process. On 23rd September 2002 the American Petroleum Institute and the Petroleum Equipment Institute of America therefore jointly published a press release [6] urging all car manufacturers to use only earthed dissipative tank caps in their cars and additionally print a precise warning hint in the users' manual or close to the filling cap that getting in the car interior during refuelling is dangerous and may lead to fire. This is the minimum safety measure for avoiding personal charging during the refuelling process if the seat material used is not antistatic.

3 Positive and negative examples of avoiding electrostatic ignition hazards in motor cars

3.1 Insulated metal parts

Filling stations distribute high quantities of flammable liquids. For this reason electrostatic hazards are to be strictly avoided, especially in zones 1 and 0. However, main areas of the filling station are not classified as explosive although there is an explosion risk. These are e.g. the dissipative forecourt areas where the cars and road tankers are parking. The reason for that is that cars and road tankers are not explosion protected.

To guarantee a certain electrostatic safety level at filling stations, the current rules on electrostatics [7-8] demand two independent leakage paths for the cars to be filled up or the road tankers to be emptied. The first is the conductive hose between dispenser and filling nozzle. The resistance between the two ends of the filling hose may not be higher than $10^6\ \Omega$. This earth path dissipates only charges from the car if there is

+ a conductive path between the filling nozzle and the car body.

However, a few cars do not have such a connection. Typical examples of a missing connection include

- an unearthed metal ring fastener
- no metal ring fastener
- an earthed metal ring fastener which does not come into contact with the filling nozzle during refuelling (normally the weight of the filling nozzle ensures an adequately safe contact).

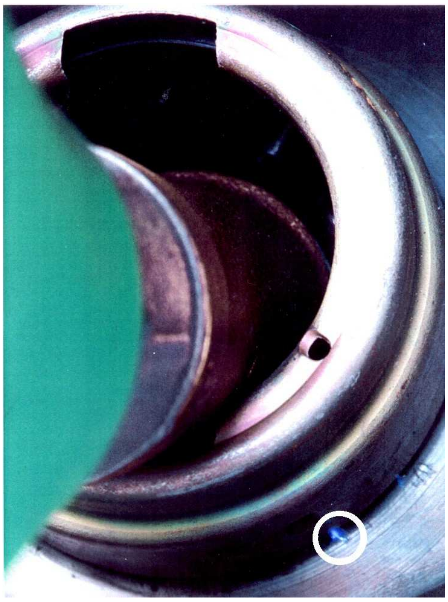

Fig.3: Sparkover from the earthed metal ring fastener to the conductive rubber seal which is in contact to the insulated charged car body.

For this reason, a second independent earth path is necessary to prevent electrostatic hazards. This second path is from the car body via the tyres to the dissipative forecourt area. As a consequence, the tyres are to have a sufficiently low leakage resistance. This is the case for the old tyres filled with soot, but not for some silica tyres produced around 1993. However, after the tyre manufacturers have realised this recommendation, silica filled tyres as are now available are usually sufficiently dissipative. Due to the conductive dirt on our streets (salt, minerals and soot), the tyres of 1993, if still in use, now usually are sufficiently dissipative. The second earth path requires a forecourt area with a leakage resistance of less than 10^8 Ω. This requirement is fulfilled in Germany but not worldwide. A few cars exist which do not have this second path due to

– insulated axles (resistance between car body and tyre rim greater than 10^8 Ω) due to rubber damping elements for noise reduction.

Some cars contain insulated metal parts in the region of the tank inlet tube. This is not forbidden but against the recommendations of electrostatic rules and standards [6-8]. Typical examples of insulated conductive parts are:

– metal ring fastener for the filler cap (unless electrically connected to the car body)
– metal filler cap (if screwed to an insulated plastic inlet tube)
– unearthed conductive pipes or hoses
– metal tank lid (if insulated mounted on a plastic hinge).

3.2 Personal charging

German requirements no longer provide insulating forecourt areas, and also the number of insulating tyres has decreased considerably resulting in a much smaller number of incidents than in the first half of the nineties. Today, personal charging seems to be the greatest hazard when filling up a car [2,4-6]. Such hazards arise when a refuelling person leaves the filling nozzle arrested during filling up to return inside the car to take his/her credit card. He/she then might get charged and approach charged to the earthed filling nozzle again. Alternatively, a person may start the refuelling process while another person continues it. In February 1996 the PTB has advised the German car manufacturers to pay attention to this problem [1].

It is well known that a transferred charge Q of 60 nC is sufficient to ignite gasoline vapours under optimized conditions [7-9]. When experimentally reproducing situations leading to an ignition, 120 nC or more was usually found. The seats today used in cars can be divided into three groups:

+ the charge Q on a raising person is always less than 60 nC even under worst case conditions (leather seats, antistatic fabrics, fabrics for computer workplace seats)
o Q is between 60 nC and 120 nC under most conditions (typical standard seat material)
– Q is greater than 120 nC under most conditions (strongly chargeable fabrics or artificial leather seat material leading to electric shocks when touching earthed metal parts).

Charges of less than 60 nC are recommended although seats with values of less than 120 nC would be a progress as regards safety and unwanted electric shocks. If highly chargeable seat materials are used, a warning hint is necessary as an absolute minimum safety measure.

3.3 Electrostatic hazards attributed to the tank system

3.3.1 Tanks made of nonconductive PE plastics

Frequently, tanks of Polyethylene, mostly with a fluorinated inside wall, are used. This type of tank is considered to be safe if there is no explosive atmosphere inside and outside the tank [1, 7-9]. If

+ the first filling process is carefully executed at a reduced flow rate, and
+ the sink for spilled fuel at the tank inlet is not open but connected to a hose to separate the spilled fuel from the outside of the tank inlet tube (or there is no sink at all) and
+ the tank inlet tube is separated from the fuel vapours by laying it in a hollow space which may be open at its bottom side,

the risk of explosive diesel or gasoline atmosphere is minimized to an acceptable limit.

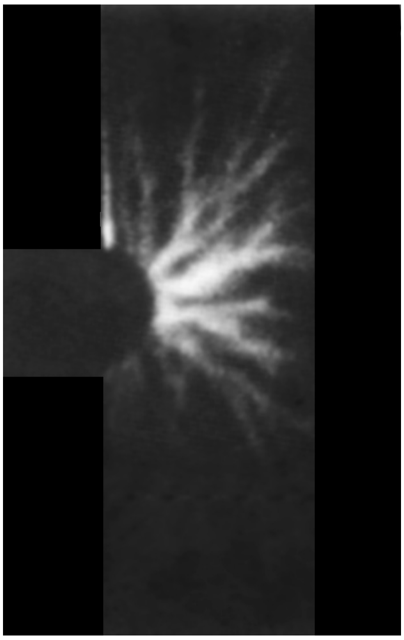

Fig.4: Discharge from outside a plastic inlet tube to an approaching ball electrode due to charge creation by flowing fuel.

3.3.2 Tanks made of nonconductive PE plastics with an earthed wire inside

This type of tank is considered to be safer during the first filling process than PE tanks without earth wire. It is also much less critical with respect to explosive atmosphere inside and outside the tank tube [1, 7-9].

3.3.3 Metal tank systems

Earthed metal tank systems need no special safety measures as regards electrostatic hazards [1, 7-9].

3.3.4 Fuel pipes and hoses

When fuel flows in a pipe or hose, charge separation occurs between the fuel and the internal surface of the pipe producing electrostatic charges of opposite polarity on the liquid and the inner pipe wall. The extent to which the charges are retained depend on the liquid, the pipe material and the flow velocity. Highly charged insulated pipe surfaces could even lead to electric breakthrough and puncture of the pipe wall. Such a wall puncture will lead to fuel leakage which is hazardous and harmful to the environment. Low breakthrough voltages are acceptable only in the case of very short pipes in combination with flow velocities lower than 1 m/s.

– Some car manufacturers use fuel pipes with a breakthrough voltage of only 3 kV.
+ Some car manufacturers use metal fuel pipes or plastic pipes with a sufficiently high breakthrough voltage.

Fig.5: Electrical breakthrough of a plastic fuel line to a metal clamp at 3 kV

3.3.5 Electrical equipment in the tank system

Usually, the electrical equipment in the tank system (fuel gauge sensor, fuel pump etc.) need not have a type of protection for explosive atmospheres because gasoline vapours are always too fat and diesel vapours always too lean for ignition. If, however, diesel vapour temperatures higher than 60°C are produced in the region of such devices, additional measures are necessary (see chapter 3.3.6).

3.3.6 Hazards due to high diesel reflux temperatures

No ignition has been reported for diesel tank systems up to now. As the flash point of German diesel is slightly higher than 55°C, there is no explosive atmosphere present at normal temperatures. Fig.6 shows the lower and upper explosion limit of a typical German diesel and its vapour pressure as a function of temperature. Note that diesel fuels in other climatic zones may have a somewhat different vapour pressure. For temperatures lower than 60°C the vapour pressure of German diesel is outside the explosive range which is situated between upper and lower explosion limit. For temperatures around 70 °C, however, a stoichiometric mixture of diesel/air is created, which can be easily ignited by sparks. The ignition energy of this mixture lies around 0,25 mJ. The most incendive mixture lies somewhat above the stoichiometric value and has an ignition energy of about 0,20 mJ.

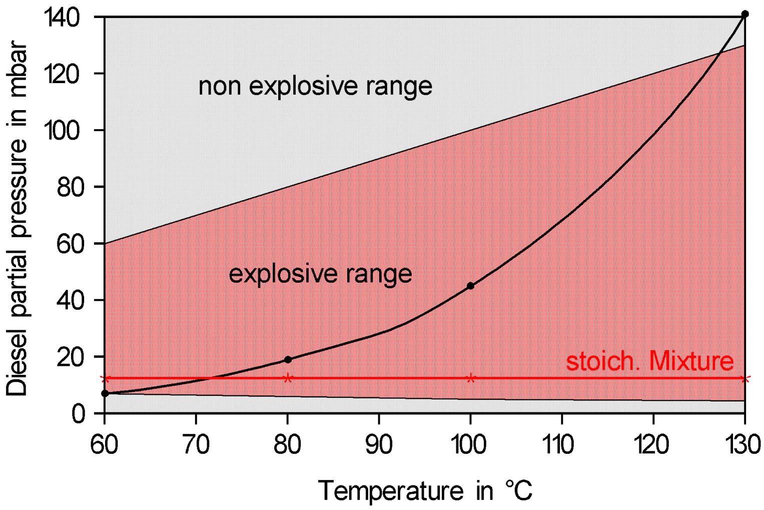

Fig.6: Vapour pressure and explosion range for German diesel as a function of temperature (data from [10])

As modern diesel engines produce diesel reflux temperatures of up to 130°C, there is a great chance that electrostatic discharges or sparks produced by electric devices in diesel tank systems become incendive if they meet with diesel vapours of more than 60°C. Ignition of diesel vapours in the fuel tank may be hazardous because it may lead to an explosion of the total fuel tank. For this reason, such a scenario must be safely prevented. Fortunately, some car manufacturers have become aware of this problem and take the following or comparable precautions:

+ use of encapsulated or intrinsic safety electric fuel gauges, and
+ arrangement of metal meshes acting as flame arrestor in front of the electric fuel pump, and
+ test experimentally that the tank system withstands an inner diesel fuel explosion (due to the limited amount of incendive diesel vapours inside the tank this is the case in many tank systems), or
+ use of coolers to cool down the diesel reflux temperature below 70°C even under worst case conditions.

These measures are not necessary for gasoline fuel tank systems because the gasoline vapour pressure is always above the explosion range even in gas recovery systems at very low temperatures [11].

3.3.7 Ignition hazards due to chargeable plastic surfaces

Although insulated conductors contribute to most of the ignitions of explosive atmosphere caused by static electricity, discharges from highly charged insulating plastic surfaces must not be neglected. Typical plastic surfaces in the region of explosive fuel vapours include the filler cap, the tank lid, the tank trough and plastic fenders or other body parts made of plastic. The car manufacturer shall either

+ use a dissipative plastic material, or
+ test experimentally that no ignition hazards exist (see section 4). Due to the earthed metal car body in their vicinity, insulated plastic surfaces show only little tendency to produce incendive discharges.

4 Methods to investigate electrostatic charging

There are four methods for evaluating ignition hazards due to static electricity:

- Measurement of the surface resistance of the plastic material and comparison with values from rules and standards [7-9,12]. Usually, electrodes of conductive rubber stripes are used for this purpose (100 mm length, 10 mm distance, 2 kg pressure, 100 V test voltage). Increasing test voltage usually decreases the surface resistance, but more than 1000 V must not be applied. A so called “teraohm meter” or “insulation tester” is needed (e.g. [13]). More details can be found elsewhere [7-8].
- If the material is not sufficiently conductive, the ignition hazard may be derived from the projected surface area of the evaluated plastic material by comparing it with values from rules and standards [7-9,12].
- Some antistatic materials have a high surface resistance so that the incendivity of possible discharges under worst case conditions has to be determined. It is rather simple to determine the incendivity of a discharge from a maximally charged surface (metal or plastic) by means of a coulombmeter (e.g. [14]) and compare it with threshold values from standards [7-9]. It is important only to really apply worst case conditions in this experiment (e.g. dry climate). Alternatively, this experiment can also be made in an explosive atmosphere produced by specific test gases. In the case of multiple discharges, e.g. from fabrics and high voltage electrodes, the oscilloscopic

transferred charge method must be used. More details of these methods can be found elsewhere [9, 15].

- Measurement of the electrostatic potential in kV of e.g. a fuel line with flowing fuel by means of a small electric field mill (e.g. [16]) and comparison with the known breakthrough voltage of the line. As the electric field to be determined is usually distorted, a reference experiment with a metal line of the same dimensions at a known potential is usually necessary to calibrate the field mill. It is important that worst case conditions (e.g. max. chargeable fuel, max. flow velocity) prevail. We use a special hydrocarbon mixture [17] as a test fuel because it is the strongest charge generating liquid we have found up to now and there are only little differences between different product charges. This product does not smell and has a flashpoint above 55°C too.

With these four methods all problems posed by the investigation of electrostatic hazards should be covered.

5 Conclusions

The ECE Directive No. 34 [18] requires in its paragraph 5.1.9 that "The fuel tank and the filler neck shall be designed and installed in the vehicles in such a way to avoid any accumulation of static electricity charges on their entire surface. If necessary, they shall be discharged into the metallic structure of the chassis or any major metallic mass by means of a good conductor."

This requirement seems to be too restrictive. For this reason, this paper gives in chapter 3 and 4 some good and well-tried examples taken from commercially available motor vehicles to demonstrate how to avoid electrostatic ignition hazards. The conclusion from these examples is that it is not necessary to avoid any static electricity charges but sufficient to avoid any hazardous charges in any region of explosive vapours. For this reason this ECE paragraph is under discussion in the UN version [19] of the ECE Directive.

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