MVFRI RESEARCH SUMMARY
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Fire Safety in Motor Vehicles with High Voltage Electrical Systems

Based on contracts with:
Underwriters Laboratories
Chilworth Technology
Southwest Research Institute

Major auto manufacturers have been considering electrical systems that operate on 36-volt DC architectures, transitioning from the 12-volt systems (14 volts when charging) typically used today. The 36-volt architecture charges at 42 volts, with possible voltage peaks as high as 58 volts. Another trend is toward "mild hybrids," where the engine is shut off when stopped in traffic, while other systems, such as the air conditioning, continue to operate. This technology is commonly referred to as an integrated starter generator and can provide approximately a 10% fuel economy improvement in city driving. The research under this project explored fire safety issues associated with higher voltage electrical systems applied to automotive use.

Even at 14-volts, there are fires caused by shorts and other malfunctions in the electrical systems. As was shown in the data analysis research conducted by MVFRI [Digges 2008; Kildare 2006; Bahouth 2005], most fires occur in frontal impacts and initiate within the engine compartment. Since batteries are typically mounted in that region of the vehicle and most of the underhood fluids are flammable (including the engine coolant), there is reason to suspect that the battery may contribute to many underhood fires. Batteries contain a great deal of energy (~ 3 million Joules for an 85 Ampere-hour battery). A short can dissipate hundreds of Watts, and can ignite surrounding flammable materials. A crushed battery can create either external or internal shorts and begin a heat release that can ignite the plastic battery case, and then spread to other underhood materials.

If a circuit is broken with a 14-volt circuit, some sparking may occur, but not a sustained arc. With a 42-volt system there is likely to be a sustained arc when a circuit opens or there is a short to ground. This arc has tremendous power associated with it. It can easily produce 1000 Watts of power. The temperature of the plasma can be 6000 C. This level of power can ignite most materials and can burn holes in sheet steel. MVFRI initiated research with Underwriters' Laboratories (UL) to develop test procedures for controlling high voltage DC arcing . However, the initial studies were unsuccessful and funding for the research was abandoned by MVFRI but continued by UL (Wagner, 2007)

There is also another phenomenon called "Carbon Tracking" which can be present at 14 volts, but will be more common at 42 volts. It is caused by an electric field across an "insulator." "Insulators" can conduct small amounts of electricity and gradually convert the hydrocarbons in the plastic to carbon - which is a good conductor. After considerable time (i.e. 10-15 years of a vehicle lifetime), this deposit of carbon can grow until it is capable of conducting a large amount of current. Shortly after the current builds up, the material will effectively short and cause an arc, and the material can ignite.

This process is accelerated by having conducting liquids or solids on the surface of the conductor. Oil, dirt, grime and moisture, which are readily available in the engine compartment, can get on the plastic electrical components and speed-up the process. Road salt (and battery acid released in a crash) are also conductors which can exacerbate the situation. 42-volt systems (with associated voltage margins) will be more susceptible to this phenomenon.

CARBON TRACKING.

MVFRI and USCAR jointly funded research on DC carbon tracking of plastic materials used as connectors and insulators. [Wagner, 2003, Wagner, 2004] This effort developed a DC test procedure and evaluated 24 candidate plastic materials. A wide range of performance was exhibited by these materials. Twelve tests were highly instrumented and provided some insight into the physics of the carbon tracking phenomenon [Stephenson, 2005].

An electrolyte, 5% NaCl, was used to accelerate the test and also to simulate road salt used in winter. By varying the conductivity of the electrolyte, UL studied the effect of conductivity on the tracking resistance of various materials. The insulator materials were tested by exposing them to drops of the electrolyte while exposed to voltages ranging from 12 to 150 volts. The goal was to resist electrical conduction after exposure to 55 drops. When tested at 60 volts, five of the materials allowed conduction before the goal of 55 drops was achieved. Two of the materials caught fire after exposure to 18 and 21 drops of electrolyte. One material failed to meet the 55 drop goal at 42 volts. [Wagner, 2003 Table 5].
The electrical conductivity of common underhood fluids was also measured to see if they might induce carbon tracking [Dey, 2004]. It was found that the electrical conductivity of these fluids was too low to be a concern.

ELECTRICAL CONDUCTIVITY MEASUREMENTS OF ENGINE COMPARTMENT FLUIDS

As automobiles incorporate higher voltage there is the possibility of causing fires due to the phenomenon of Carbon Tracking. Tracking occurs when a normally insulating plastic is exposed to contamination and a current begins to flow between a potential difference.

In frontal crashes, engine compartment fluids, including gasoline, can be splashed onto electrical components. We wanted to know if any of these fluids were conductive enough to cause Carbon Tracking of polymers.

MVFRI contracted with Chilworth Technology to make electrical conductivity measurements of 12 engine compartment fluids [Dey, 2004].

Conductivity is measured in units of Siemens per meter (S/m). However, given the magnitude of the Siemen, conductivity is commonly reported in picosiemens per meter (pS/m). [1 pS = 1×10^{-12}S] Conductivity measurements for 12 engine compartment fluids are shown in Table 1.

Chilworth Technology, Inc., performed liquid conductivity testing in accordance with British Standard 5958, Code of Practice for the Control of Undesirable Static Electricity - Part 1 (1991) and ASTM D2624, Standard Test Method for Electrical Conductivity of Aviation And Distillate Fuels. The method involves the use a liquid conductivity cell. The cell consists of a pair of concentric cylindrical electrodes. The liquid sample to be tested is poured into the annular space between the electrodes and a known voltage is applied. The current through the cell is measured and the conductivity is calculated from the measured current, applied voltage, and cell constant which corrects for the cell geometry.

The test system is checked (validated) before, during, and after testing by measuring the conductivity of heptane (certified grade) -- a known insulating liquid. When the liquid sample is conductive a BM-10 megohmmeter is used to measure the resistance.

Table 1: Results of conductivity measurements for engine compartment fluids

Sample	**Conductivity Average [pS/m]**	**Rating**
Quaker State SAE 5W30 Motor Oil	4.7×10^4	Conductive
Mobil 1 SAE 5W30 Synthetic Motor Oil	3.6×10^4	Conductive
Valvoline SynPower Power Steering Fluid	73	Non-conductive
Quaker State Dextron III/Mercon Automatic Transmission Fluid	7.1×10^3	Medium-conductive
Prestone DOT3 Brake Fluid	2.5×10^8	Conductive
Prestone Ethylene Glycol 100% Anti-freeze	3.1×10^7	Conductive
Sierra Propylene Glycol 100% Anti-freeze	4.1×10^7	Conductive
All Weather Windshield Washing Fluid	9.3×10^7	Conductive
Regular Unleaded Gasoline	3.3×10^2	Medium-conductive
Diesel Fuel	3.3×10^2	Medium-conductive
Prestone Anti-freeze Mix Ethylene Glycol 50% / 50% H_2O	8.9×10^7	Conductive
Sierra Anti-freeze Mixture Propylene Glycol 100%/50% H_2O	6.5×10^7	Conductive

The results from Table 1 show that the most electrically conductive underhood fluid is brake fluid at 2.5×10^8 pS/m. This is about 3 orders of magnitude less conductive than that necessary to cause a Carbon Tracking concern. Thus it is concluded that the underhood fluids do not constitute a fire risk from Carbon Tracking. Of course, many of the fluids are flammable and can contribute to underhood fires.

BATTERY ABUSE TESTING.

Since batteries are typically mounted in the underhood region of the vehicle, and most of the under-hood fluids are flammable (including the engine coolant and windshield washer fluid), there is reason to suspect that the battery may contribute to many underhood fires. Batteries contain a great deal of energy (~ 3 million Joules for an 85 Ampere-hour battery). A short can dissipate hundreds of Watts, and can ignite surrounding flammable materials. A crushed battery can create either external or internal shorts and begin a heat release that can ignite the plastic battery case, and then spread to other under-hood materials.

MVFRI contracted with SwRI for abuse testing of 36-volt batteries and comparable 12-volt batteries.. The batteries were tested using several of the test procedures in SAE Standard J 2464 “Electric Vehicle Battery Abuse Testing,” The tests included penetration, crush, radiant heat, and short circuit tests. Results showed no significant energy releases or flaming from the 36 volt batteries tested. The author concluded that the results showed no increased risk of the 36V batteries over the 12V batteries with regard to the abuse testing performed.

REFERENCES

Bahouth, J., and Kuznetsov, A., “Automotive Fire Safety Research”, January, 2005.Prepared for Motor Vehicle Fire Research Institute by George Washington University, www.mvfri.org

Digges, K., “Fire Occurrence in Frontal Crashes Based on NASS/CDS”, SAE Paper 2008-01-0256, April, 2008. Available at www.sae.org

Dey, W., “Conductivity Measurements for New Engine Compartment Fluids,” Prepared for Motor Vehicle Fire Research Institute, by Chilworth Technologies, Inc, April 2004. www.mvfri.org

Kildare, S., and Digges, K., “Analysis of Fire Occurrence in Automotive Crashes Using NASS CDS Data (1995-2004)” Prepared for Motor Vehicle Fire Research Institute by George Washington University, October .2006. www.mvfri.org

Stephenson, R., “Physics of DC Carbon Tracking of Plastic Materials,” Fire and Materials Conference, San Francisco, California, Jan. 2005. www.mvfri.org

Wagner, R., Stimitz, J., “Properties of Plastic Materials for Use in Automotive Applications: Study of Arc Track Properties of Plastic Materials when Subjected to DC Voltages Ranging from 12 V DC - 150 V DC; Prepared for Motor Vehicle Fire Research Institute and USCAR by Underwriters Laboratories, December 15, 2003. www.mvfri.org

Wagner, R., Stimitz, J., “Properties of Plastic Materials for Use in Automotive Applications: Study of Arc Track Properties of Plastic Materials when Subjected to DC Voltages Ranging from 12 V DC -150 V DC; Addendum Report; Prepared for Motor Vehicle Fire Research Institute and USCAR by Underwriters Laboratories, Oct. 2004. www.mvfri.org

Wagner, R., “Development of a DC High-Current Arc Ignition Tester”, SAE 2007-01-1042, April 2007. Available at www.sae.org

Weyandt, N., “Comparative Abuse Testing of 36V and 12V Battery Designs in General accordance with SAE J2464, Prepared for Motor Vehicle Fire Research Institute by Southwest Research Institute Report 01.06939.01,002, May 2005. www.mvfri.org

Weyandt, N., “Comparative Abuse Testing of 36V and 12V Battery Designs” SAE 2006-01-1274, April, 2006. Available at www.sae.org