MVFRI RESEARCH SUMMARY
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Fire and Toxicity Properties of Underhood Fluids and Plastics

Based on contracts with:
Southwest Research Institute,
FM Global,
Galaxy Scientific and TRACE Technologies,
Biokinetics and Associates, Ltd.

Considerable MVFRI research has focused on understanding the factors that may contribute to the cause of under-hood fires. The crash factors that are associated with underhood fires have been analyzed and the results are reported in a separate research summary. Burn tests of vehicles with underhood fires are also summarized elsewhere. The research summarized here deals with the fire and toxicity properties of under-hood fluids and plastics. It also examines alternative ways of measuring these properties.

FIRE AND TOXICITY PROPERTIES OF UNDERHOOD PLASTICS

Combustible materials produce smoke atmospheres that are toxic, contributing to physical incapacitation, loss of motor coordination, faulty judgment, disorientation, restricted vision, and panic, all of which inhibit or prevent egress from a burning vehicle. In partnership with NHTSA, MVFRI has funded a research program to investigate the toxicity of the smoke that evolved from the combustion of materials from exterior vehicle components, specifically those that may be located under the hood of a vehicle in the engine compartment.

The MVFRI toxicity research was in conjunction with an ongoing research program conducted for NHTSA by Southwest Research Institute [Battipaglia 2003]. The NHTSA research compared fire properties of automotive materials commonly used in the engine compartment. Southwest Research Institute (SwRI) selected 18 exterior automotive parts, approximately nine each from two vehicles. The primary objectives of the NHTSA project focused on an engine compartment fire scenario and were:

1. To identify or develop a small-scale test methodology to rate automotive materials consistent with actual fire performance in vehicle burns; and
2. To establish levels of performance for this test methodology that would significantly alter the fire outcome in terms of injury or survivability.

Work performed for the MVFRI dealt with the toxicity of the smoke evolved from those materials during combustion. A combined report that summarized the research was provided by SwRI [Battipaglia 2003]

From a literature review, the Cone Calorimeter (ASTM E 1354) was identified as the most suitable test apparatus. Heat fluxes in the range of 20 to 50 kW/m^2 were found to be representative of thermal exposure conditions in motor vehicle fires that originate in the engine compartment. The literature survey also included a detailed review of recent full-scale vehicle burns in support of the analysis to meet the second objective of the NHTSA project. It was postulated from this review that engine fires become a threat to occupants trapped in the passenger compartment when a critical fire power of approximately 400 kW is reached.

For the experimental part of the NHTSA project, 18 exterior automotive parts (outside the passenger compartment) were selected from a passenger van and a sports coupe. The vehicles were previously tested in full-scale by Factory Mutual (FM) as part of a previous research program funded by General Motors Corporation (GM) [Tewarson, Vol. I, II, III, 2005]. Three types of measurements were made in the NHTSA project:

1. Micro-scale tests were performed using modulated differential scanning calorimetry (MDSC) to determine thermal-physical properties of the materials.
2. Small-scale fire tests were conducted in the Cone Calorimeter (ASTM E 1354) at 20, 35, and 50 kW/m2 to obtain ignition, heat release and smoke production data over a range of exposure conditions. The materials were also tested in general accordance with the Federal Motor Vehicle Safety Standard (FMVSS) 302. Exterior materials do not have to meet the FMVSS 302 requirements, but the test data were obtained to serve as a baseline. Additional Cone Calorimeter tests were also obtained on a subset of the components that were coated with a metallic, reflective film.
3. Intermediate-scale calorimeter or ICAL (ASTM E 1623) tests were performed at the same heat fluxes as in the Cone Calorimeter to obtain heat release rate and smoke production rate data for six of the 18 components.

The MVFRI project involved additional measurements of toxic gases in the duct for most of the Cone Calorimeter tests. Concentrations of CO, CO2, HCl , HCN, and NOx were measured continuously during each test with a Fourier Transform Infrared (FTIR) spectrometer. The concentration measurements were used to calculate yields, i.e. the total mass of each toxic gas generated during flaming combustion divided by the mass loss of the fuel over the same period. CO yields obtained in this study are comparable in magnitude, but consistently lower than values reported in the literature for the same generic classes of materials. This can be explained by the fact that the literature values were obtained in the Fire Propagation Apparatus (ASTM E 2058) under reduced ventilation conditions compared to the Cone Calorimeter. The use of the measured yields to calculate a fractional effective dose in real engine fires was also reviewed.

Three materials were selected from the set of 18 for an evaluation in two commonly used toxicity test procedures. The Airbus ABD 0031 procedure is based on the National Bureau of Standards (NBS – now National Institute of Standards and Technology (NIST)) smoke chamber (ASTM E 662) and involves supplemental gas analysis. The International Maritime Organization (IMO) smoke and toxicity test procedure is detailed in Part 2 of Annex 1 to the FTP code and is based on a modified version of the NBS smoke chamber as described in ISO standard 5659 Part 2. Both procedures specify acceptance criteria that include limiting concentrations of CO, HCl, HCN, NOx, and a few additional gases. The three materials that were selected had the lowest, median, and highest peak CO concentrations in the Cone Calorimeter tests of all the materials that were tested. The material with low peak CO concentration was a PVC and exceeded the limits for HCI in the IMO and Airbus tests. The material with median CO in the Cone Calorimeter failed the IMO test, and the material with high CO in the Cone Calorimeter marginally met the IMO and Airbus requirements. It can be concluded from these tests that the CO concentrations in the Cone Calorimeter are not consistent with those in box-type toxicity tests. This can be explained by the fact that plenty of excess air is continuously supplied in the Cone Calorimeter, while the atmosphere in the IMO and Airbus smoke chambers typically becomes vitiated during a test.

The MVFRI contract with FM Global provided for summaries of vehicle burn tests and materials testing methods for fire properties [Tewerson, October 2005 Vol. II and III]. The occupant compartment survival times based on heat and toxicity based on vehicle fire tests were summarized [Tewerson, October 2005 Vol.I and Tewarson, SAE 1555, April 2005]. Further details on this project along with final reports may be obtained through the MVFRI website.

Under a separate contract funded by MVFRI, personnel from the Fire Safety Branch of the FAA and Galaxy Scientific Corp. performed flammability evaluations of 18 automotive plastics using a microcalorimeter at TRACE Technologies LLC [Lyon 2005; Lyon 2006]. The flammability of the underhood plastics tested was similar to the flammability of plastics from the passenger compartment. When compared to plastics used in the interior of aircraft cabins, the automotive plastics were several times more flammable. There was considerable variation in the flammability of plastics used under the hood. Two parameters used to measure flammability were the heat release capacity (HRC) and the total heat release (HR).

The heat release capacity (HRC) is the ratio of the specific heat release rate to the surface heating rate. The HRC is a flammability parameter that is a good predictor of fire performance and flame resistance. High values indicate higher flammability. Testing of 13 plastics used in aircraft passenger cabins produced an average value of 98 J/g-K. Plastics used in aircraft overhead compartments have an average HRC of 216 J/g-K.

The total heat release (HR) is obtained by dividing the maximum value of the specific heat release rate by the heating rate in the test. The HCR and HR values for typical automotive plastics are summarized in Table 1. A comparative ranking of materials based on the heat release capacity as measured by the microcalorimeter test method is shown graphically in Figure 1 [Lyon 2005; Lyon 2006].

Table 1. Heat release capacity and heat release for typical underhood automotive plastics

Component Tested	**HRC J/g-K**	**HR kJ/g**
Brake Fluid Reservoir	1298	45.3
Resonator Intake Tube	1293	43.9
Battery Cover - black	1280	43.0
Front Wheel Well Liner	1250	45.3
Battery Cover -transparent	1106	42.9
Resonator Top	966	35.2
Radiator In/Out Tank	514	22.5
Engine Cooling Fan	400	18.6
Power Steering Reservoir	397	19.4
Hood Liner Face	101	7.9
Hood Insulator	96	5.2

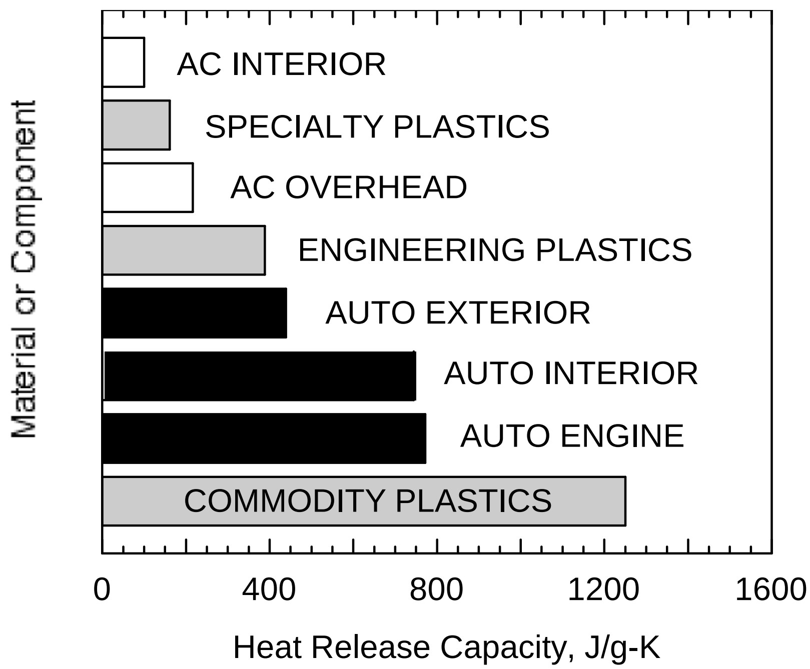

Figure 1 - Flammability of plastic materials and components ranked by heat release capacity (AC means aircraft)

Another indicator of material flammability is the heat release rate (HRR). The heat release rate (HRR) of a material in flaming combustion is a primary indicator of its hazard in a fire. The HRR is usually expressed in terms of a surface energy balance for steady flaming combustion. It is one of the measurements obtained from a cone calorimeter test.

Biokinetics measured the HRR for twenty different underhood liners to examine the extent that these materials might mitigate or aggravate the containment of an underhood fire [Fournier, August 2005; Fournier, 2006]. The results showed the materials had HRR ranging from 3.2 to 314 kW/m^2 (A difference of about a factor of 100). The time to ignition for the plastics ranged from no ignition to 3 minutes.

FIRE AND TOXICITY PROPERTIES OF UNDER-HOOD FLUIDS

MVFRI funded a research contract with FM Global to summarize the results of the $10 million automotive fire safety research conducted under the GM/DOT Settlement Agreement. Tewarson has summarized the fire resistance measurements of fluids that are commonly found in the engine compartment [Tewarson, October 2005, Vol. III and Tewarson, SAE 1560, April 2005]. The fire resistance properties were measured during the earlier contract General Motors under the GM/DOT Settlement Agreement. The flash point and hot surface ignition temperatures are summarized in Table 2.

The $\mathbf{T_{flash}}$ variable is the minimum temperature at which a fluid gives off sufficient vapors to form an ignitable mixture in an open cup. The $\mathbf{T_{hot}}$ variable is the minimum temperature of a hot surface to cause ignition of a fluid spilled on the surface. This variable requires a test that was developed by General Motors and applied during the Settlement research [Tewarson, SAE 1560, April 2005].

Table 2. Average flash and hot surface ignition temperature of underhood fluids

Fluid	T_{flash} (°C)	T_{hot} (°C)
Motor Oil (Petrolium)	134	310
Motor Oil (Synthetic)	160	324
Gear Lubrication Fluid	154	325
Power Steering Fluid	188	312
Automatic Transmission Fluid	163	304
Brake Fluid	123	287
Antifreeze	116	506
Engine Coolants	110	518
Windshield Washing Fluids	32	

FIRE RESISTANCE OF UNDERHOOD LINERS

Research was conducted by Biokinetics and Associates to investigate the use of fire safety technologies in 2003 model year vehicles. That survey identified the use of underhood insulation as a potential fire preventative feature [Fournier 2005; Fournier 2006]. It was speculated that heat from an underhood fire would melt the mounting hardware supporting the underhood insulation, allowing it to descend onto the engine and reduce the oxygen supplied to the fire. Another scenario was that these insulation materials might act to delay the time that the fire burns through the upper surface of the engine compartment. Such a delay could act to extend the survivability time of the occupant compartment.

In this project, the flammability of the underhood liner materials was tested to determine the degree to which they may be able to retard underhood fires [Fournier 2005]. An SAE paper also summarized this research [Fournier 2006].

The research included a visual inspection of 89 vehicles from the North American market. The presence of underhood insulation was found in 74 instances. In those instances, however, the fire retardant properties of the insulating materials could not be ascertained by visual inspection alone.

Twenty vehicles were selected for further testing of the fire properties of underhood materials in the fleet. The 20 vehicles represented a convenience sample of various manufacturers and classes of SUVs, passenger cars, minivans and pickup trucks. Coupons cut from the insulating liners were tested to assess their fire retarding properties with a cone calorimeter according to the test procedures of ASTM E 1354-03. The mounting hardware used to affix the liners to the under side of the hood was also tested to determine if their materials would melt or distort sufficiently to allow the insulating materials to fall.

The cone calorimeter test subjected a 10 cm x 10 cm material coupon to a constant radiant heat flux of 35 kW/m^2 for 20 minutes. From the materials behavior under the heat load the ignitability, heat release rates, mass loss rates, effective heat of combustion and visible smoke development of materials were determined and documented. Of the 20 insulating underhood liners tested, 5 did not ignite. An additional 7 insulation samples that did ignite exhibited a short time to flameout with comparatively low peak heat release rates. These samples with the inclusion of the non igniting samples show the most potential for retarding an engine fire. There was a wide range of weight loss and heat release rates among the group of samples tested. Several of the insulation materials would have contributed fuel to an underhood fire rather than acting to retard it.

The cone calorimeter testing indicated that the application of a metal foil to the engine facing side of an underhood insulting liner can significantly enhance the fire resistance of an insulating material by preventing ignition.

If an underhood insulation liner is to smother a fire the mounting clips affixing it to the hood must disengage from the hood under high heat conditions of an engine compartment fire. The mounting clips for the underhood insulation from the twenty different vehicles tested disengage from the supporting structure at temperatures ranging from 133 °C to 268 °C. The results seemed to indicate that the design of the mounting clips may have an influence on the deformation pattern and the temperature required for the insulating sample to disengage.

Given that fire resistant underhood insulating liners were identified amongst the small sample of vehicles examined, the possibility of the liners acting to retard engine compartment fire is plausible . However, the effectiveness of such a system can not be determined strictly from the component tests that were performed. Several of the underhood insulation materials in current use would contribute fuel to an underhood fire.

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