VEHICLE FLUID FLAMMABILITY TESTS

BY BILL HAGERTY AND STEVE PERANTEAU, ESCONDIDO, CALIFORNIA— Throughout the vehicle repair and fire investigation communities, there has been considerable discussion and disagreement about which under-hood fluids will ignite and under what conditions. During one such discussion, a service manager of a California Chevrolet dealership stated, "transmission fluid will not start a fire".

However, real world experience from well over 750 vehicle fire investigations and attendance at 23 fire schools have shown that nearly all fluids found in engine compartments today will start a fire under the right conditions. Engine fluids can leak for days, weeks, or months and not ignite. That's quite possible. Garage floors of the world are covered with fluids that have leaked from engines and transmissions and have never caught fire.

On the other hand, there have been thousands of actual automotive fires where an engine compartment fluid was the material first ignited. Vehicle manufacturers have assisted in documenting some of them. For example, on July 13, 1998, following numerous reports of their vehicles sustaining engine compartment fires, Land Rover North America issued Safety Recall 98V149 which states in part: "Land Rover has determined that certain under-hood hose and tubing components can fail (primarily coolant hoses). The unintended release of fluids such as engine coolant, windshield washer fluid, and automatic transmission fluid can, under certain circumstances, lead to conditions which can cause a vehicle fire[1]."

As a result of this recall, Land Rover made a series of "no cost to the vehicle owner" modifications to eliminate such fluid releases. They essentially replaced all of the coolant hoses in 20,000 Land Rover vehicles. It stands to reason that they would not have issued a recall and installed upgrades at a cost of millions of dollars if coolant fires had not been occurring in large numbers. So here was a major manufacturer of motor vehicles confirming the flammability of certain fluids found in engine compartments.

Investigators' analyses and conclusions have often been complicated by a lack of information and total misinformation about the flammability of the various fluids found under the hoods of motor vehicles. NFPA 921 also introduces some uncertainty regarding this issue by stating that "Flash point is of little or no significance when a fuel is released in spray form. Ignition on hot external surfaces may require temperatures of 200ºC (360ºF) above published ignition temperatures[2]."

Training and personal experience have brought about an awareness that nearly all vehicle fluids can cause fires under the right conditions. Under test conditions described below, we were able to validate this hypothesis.

Test Procedure

The tests were conducted using new household-type plastic spray bottles to simulate escaping liquid spraying from the pinholes or small cracks in the fluid systems that are the source of most fluid leaks. These tests were not specifically designed to precisely replicate a leaking hose or fitting, but to answer the question of whether the fluids found in a typical engine compartment would ignite on a representative hot surface. The pressures and temperatures of the fluids would be significantly higher under actual engine operating conditions.

The tested fluids included No. 2 diesel fuel, 89 octane unleaded gasoline, automatic transmission fluid, conventional and synthetic motor oils, brake fluid, power steering fluid, standard green and pink long-life ethylene glycol coolants (both full strength and 50/50), and R134a refrigerant, as well as the various compressor lubricating oils used with R134a. Fire-related properties of representative fluids are provided in the Material Safety Data Sheet.

Because hot exhaust components are the primary heat source in engine compartments, a four-inch diameter piece of steel exhaust tubing was preheated with a welding torch for each fluid tested. This simulated engine exhaust system operating temperatures, which can be as low as 600-700°F and as high as 1,000-1,200°F for a vehicle that is heavily loaded, climbing a steep grade, or towing a trailer. Temperatures of the heated pipe were monitored during the tests with a Raytek infrared remote sensor and a Craftsman multimeter with a thermocouple attached to the heated exhaust tubing. Each fluid was then sprayed onto the preheated tubing.

The 1,000-1,200°F exhaust system temperature was selected after a review of numerous Society of Automotive Engineers papers, including *"Catalytic Converter Thermal Environment Measurement under Dynamometer Simulated Roadloads[3]," "Numerical Study on Skin Temperature and Heat Loss of Vehicle Exhaust Systems[4],"* and *"Heat Insulation Methods for Manifold Mounted Converters[5]."* Although there is some variation in the temperatures measured by the authors of those reference papers, thermocouples attached to the exhaust system/catalytic converter measured temperatures ranging from a low of 689°F under no load and no throttle to 1,533°F under 100% throttle on a 4% simulated road grade.

This scientific research was consistent with the authors' personal experience using a Raytek Raynger.

MATERIAL SAFETY DATA SHEET INFORMATION FOR TYPICAL ENGINE COMPARTMENT FLUIDS

FLUID TESTED	MSDS SOURCE(S)	FLASHPOINT (ASTM METHOD[1])	AUTO-IGNITION TEMPERATURE	PERCENT FLAMMABILITY LIMITS[2]
#2 DIESEL FUEL	TESORO PETROLEUM CONOCO PHILLIPS	100-199F 38-93C (D56)	350-625F 177-329C	0.3-10.0
UNLEADED GASOLINE	TESORO PETROLEUM CONOCO PHILLIPS	-45F -43C (D56)	495-833F 257-444C	1.3-7.6
AUTOMATIC TRANSMISSION FLUID	CITGO	302-383F 450-195C (D93)	410-417F 210-214C[3]	1-7
MOTOR OIL (conventional)	EXXON MOBIL	428F 220C (D92)	500-700F 260-371C[3]	0.9-7.0
MOTOR OIL (synthetic)	EXXON MOBIL	428F 220C (D92)	500-700F 260-371C[3]	0.9-7.0
BRAKE FLUID	ASHLAND (VALVOLINE)	>250F/121C (D93)	>419F/215C	NO DATA
POWER STEERING FLUID	SHELL EXXON MOBIL	345F 174C (D92)	500-700F 260-371C[4]	0.9-7.0
COOLANT (ethylene glycol)	OLD WORLD INDUSTRIES (PEAK)	247F 119C (D3278)	748F 398C	3.2-15.3
COOLANT-DexCool (ethylene glycol)	TEXACO	260F 127C (D93)	752F 400C	3.2-15.3
COOLANT (propylene glycol)[5]	SHAMROCK CHICAGO (PRESTONE)	230F 110C (D1310)	700F 370C	2.4-17.4
R134a REFRIGERANT	DUPONT	NONE	>1350F/743C	NONE
COMPRESSOR OIL (PAG)	TECHNICAL CHEMICAL (CASTROL)	482-500F 250-260C (D92)	NO DATA	NO DATA
COMPRESSOR OIL (ESTER)	TECHNICAL CHEMICAL (CASTROL)	>450F/232C (D92)	NO DATA	NO DATA
WINDSHIELD WASHER FLUID (methanol)[5]	PITT PENN OIL CO.	108F 42C (D56)	730-878F 388-470 C	6-36

1. Refers to the laboratory test method used to determine the flash point.
2. Flammability limits are related to the initial temperatureof the fuel. higher temperatures result in wider flammability limits.
3. *NFPA 921, Guide for Fire and Explosion Investigations*, 2004 Edition.
4.*Kirk's Fire Investigation*, 5th Edition 2002
5. NOT TESTED. Data provided for comparison purposes

Test Results

The first fluid tested was brake fluid, specifically DOT 3, used in both ABS and non-ABS systems. Spraying the brake fluid on the tubing heated to 1,000°F caused instant flame.

For our next test, the most controversial "burn-or-not-burn" fluid, coolant—specifically ethylene glycol—was used. The standard green variant is found in many engine cooling systems, but since 1996 General Motors has installed a long-life pink coolant. The primary component of the pink colored coolant is also ethylene glycol.

Other manufacturers have also transitioned to long-life coolants of different colors, generally orange and yellow. The different colors usually signify the use of different corrosion inhibiting additives, however the primary component continues to be ethylene glycol. Several "environmentally-friendly" coolants, notably Prestone LowTox and Old World Industries' Sierra, are also available, but market data indicate their use is not widespread. These products utilize propylene glycol as the primary component in place of ethylene glycol due to its reduced toxicity to animals. The properties of propylene glycol suggest that it is more easily ignited than ethylene glycol. (See Material Safety Data Sheet) Therefore this fluid was not tested.

When sprayed onto the steel tubing heated to 1,000°F (a temperature that can occur quite readily in an engine compartment), both the green and pink coolant flashed into flame. This occurred not only at full strength, but also when mixed 50/50 with water, the ratio specified for most vehicle cooling systems. The diluted coolant burns because water evaporates faster than ethylene glycol. Once the water has evaporated, the remaining ethylene glycol ignites.

Next tested was automatic transmission fluid. In the early 1990s General Motors experienced numerous fires in its full-sized trucks. Fires usually did not occur in normal usage, but under heavy loads, such as pulling trailers up hills, some transmissions expelled their fluid out onto hot exhaust components and caused fires. As a result, General Motors mailed new dipsticks to owners of these trucks. The new dipsticks had a plastic locking device designed to prevent the internal transmission fluid pressure from ejecting fluid up the dipstick tube and onto the right hand exhaust manifold directly below. Flammability of automatic transmission fluid was demonstrated in the tests by spraying transmission fluid onto the steel tubing, heated to approximately 1,000 °F. The transmission fluid immediately flashed.

The fourth fluid flammability test was conducted using power steering fluid. A power steering pump can generate internal pressures that exceed 300 psi, creating tremendous potential for a vaporized spray. If a comparatively very low pressure spray of fluid from our test bottle caused a fire, fluid from a leaking power steering hose can also start a fire. Power steering fluid sprayed onto the hot exhaust tubing preheated to 1,000 °F flashed immediately.

Motor oil was the next test fluid. Conventional and synthetic oils were individually tested. Both oils ignited easily on the 1,000°F tubing.

The synthetic engine oil appeared to create a bigger flame than the same volume of petroleum-based oil.

R134a air conditioning refrigerant, which replaced R12 (a Freon-based fluid) in the early 1990s, was tested next. It was determined that undiluted R134a (both in gaseous form and liquid form) would not ignite on the test surface heated to 1,100°F.

All vehicle manufacturers require the addition of compressor lubricating oil to R134a refrigerant in order to lubricate the air conditioning compressor bearings. There are four common viscosities of compressor lubricant oil. Domestic manufacturers generally specify higher viscosity oils while foreign manufacturers usually specify a lower viscosity. The least viscous, PAG 46 (PAG = polyalkylene glycol) ignited at 800°F, while PAG 100 and 150 both ignited at about 900°F. Ester oil, which is used in the conversion of older R12 systems to R134a (due to its compatibility with the mineral oil in that refrigerant), did not flash until approximately 1,100°F.

Finally, two engine fuels were tested: No 2 diesel fuel and 89 octane unleaded California gasoline. The diesel fuel ignited on the heated tubing at a temperature between 950 and 1,000°F.

We have left the controversial subject of gasoline igniting on a hot surface for last. The 2004 edition of *NFPA 921* (paragraph 25.4.3.2) states: "Typically, gasoline will not be ignited by a hot surface, but requires an arc, spark or open flame for ignition." However, the same paragraph continues: "While ignition of gasoline vapor on a hot surface is difficult to reproduce, such ignitions should not be dismissed out of hand."

Lee Cole's *Investigation of Motor Vehicle Fires*[6] *and Kirk's Fire investigation*[7] also discuss the issue of gasoline igniting on a hot surface.

There are Material Safety Data Sheets available on unleaded gasolines that give various auto-ignition temperatures from 495°F to 830°F. The tests that we performed repetitively confirmed that unleaded 89 octane fuel will flash on a heated surface with a temperature of approximately 1,100°F.

The only common under hood fluid not tested was windshield washer fluid. This fluid typically consists of 33-45 percent methanol and 55-67 percent water. The evaporation rate of methanol is approximately 16 times that of water. As a result, the methanol in leaking windshield washer fluid is likely to evaporate before the water does, leaving no methanol to ignite. Because methanol burns with a colorless flame, the practical difficulty in determining whether the methanol ignited was also a factor in omitting this fluid from the test.

One final note: These test fluids were conducted at an ambient temperature between 75 and 80°F. In a real under-hood environment all of these fluids exist at temperatures of at least 200°F. Thus any leaking fluid in effect has a "head start" because of the much higher operating temperature.

Perhaps the most important consideration in reaching a decision as to what was the first fuel ignited in a vehicle fire is found in the balance of paragraph 25.4.3.2 in the 2004 edition of *NFPA 921*. It states: "the ignition of liquids by hot surfaces is influenced and determined by many factors, not just ignition temperature. These factors include ventilation, liquid flash point, liquid boiling point, liquid vapor pressure, liquid vaporization rate, misting of liquid, hot surface roughness, and residence time of the liquid on the surface".

Hopefully, the attached photographs of each of the vehicle fluids flashing on a heated piece of exhaust tubing will be helpful to those in the fire investigation community. It should also help to convince others who still harbor doubts that all the fluids described above can ignite on a hot surface under the right conditions. ●

References
1. Land Rover North America, Safety Recall 98V149
2. NFPA 921, Guide for Fire and Explosion Investigations, 2004 Edition
3. Catalytic Converter Thermal Environment Measurement under Dynamometer Simulated Roadloads, SAE Paper 2000-01-216
4. Numerical Study on Skin Temperature and Heat Loss of Vehicle Exhaust System, SAE Paper 2005-01-1622
5. Heat Insulation Methods for manifold Mounted Converters, SAE Paper 2000-01-215
6. Cole, Lee S., Investigation of Motor Vehicle Fires, Fourth Edition, Lee Books, San Anselmo, California, 2001
7. DeHaan, John D., Kirk's Fire Investigation, Fifth Edition, Prentice Hall, Upper Saddle River, New Jersey, 2002

ABOUT THE AUTHORS——

William (Bill) Hagerty has investigated more than 2,150 vehicle product liability cases, including more than 750 vehicle fires. He is Daubert court-qualified to testify in both state and U.S. federal courts as to the cause and origin of fires and has been retained numerous times as an expert witness in vehicle cases. Mr. Hagerty is a NAFI Certified Fire and Explosion Investigator, a Certified Vehicle Fire Investigator, and a Licensed Private Investigator in the State of California (required in the California to determine the cause of fires).

After retiring as a U.S. Navy Commander, Bill owned and operated a successful retail auto repair facility in Southern California. He began investigating vehicle fires under the direct training of Lee Cole. Bill actively assists in teaching courses in vehicle fires for Lee Cole and Associates. He also has acquired vehicle knowledge as an amateur race car road racer competing in Sports Car Club of America (SCCA) races since 1977.

G. S. (Steve) Peranteau left his 19-year position with the Naval Air Systems Command to join Bill in the fire investigation area. During his tenure with the Navy, Steve was the in-service reliability and maintainability engineering division head, overseeing F/A-18 Hornet and E-2 Hawkeye maintenance programs. He also holds a Federal Aviation Administration Airframe & Powerplant mechanic license.

Steve has already assisted with over 225 product liability investigations, including 120 vehicle fires, and is a NAFI Certified Fire and Explosion Investigator. He also assisted in conducting the vehicle fluid flammability tests described above. Steve is presently acquiring vehicle fire training and experience that will lead to his certification as a CVFI.

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