

# Hot Surface Ignition and Fire Propagation Characteristics of R134a and R1234yf Refrigerants

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## ABSTRACT

This paper summarizes hot surface ignition characteristics of R134a and R1234yf automotive air conditioning fluids on typical under-hood automotive surfaces that possess sufficient heat to ignite flammable or combustible fluids. It further investigates the effect, if any, that these two different fluids may have on the propagation of a fire in two identically equipped vehicles under similar test conditions. This testing, in part, is in response to the United States Environmental Protection Agency's proposal which seeks comments concerning the proposed replacement of the current R134a air conditioning refrigerant with R1234yf.

R134a is currently regarded as the global choice for automotive air conditioning systems however the EPA classifies it as an ozone depleting substance (ODS) and is tasked with proposing and reviewing alternatives that do not contribute to stratospheric ozone depletion. R1234yf refrigerant is classified as a non-ozone depleting gas by the EPA and has been proposed as an acceptable alternative to R134a through the authority of the Clean Air Act and the Significant New Alternatives Policy (SNAP) program. The SNAP program sets forth criteria for the implementation of R1234yf refrigerant and has indicated that the proposed alternative refrigerant does not have to be risk free to be found acceptable for use. European Union (EU) countries have developed Directive 2006/40/EC that mandates a 100-year CO<sub>2</sub> Global Warming Potential (GWP) of less than 150. R134a is nearly 10 times this level with a rating of 1430 GWP. R1234yf has a GWP rating of 4.0 or approximately 0.3% of the current R134a refrigerant [1].

Hot surface ignition testing of R134a and R1234yf mixtures with PAG 46 oil were evaluated in the first part of this paper. Typical under-hood automotive surfaces at maximum operating temperatures were established, along with a functional AC system to evaluate the ignition characteristics of the refrigerant and lubricant mixtures. Tightly controlled test parameters and conditions were utilized to minimize test to test variation. The results obtained in this testing were compared to the published auto ignition properties of the refrigerants and other automotive fluids. The second part of this paper assesses the potential effects that the changing from R134a to R1234yf may have on fire propagation in a motor vehicle.

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## INTRODUCTION

Modern vehicle designs consist of a variety of different fluids and materials located throughout the vehicle, some of which are classified as flammable or combustible as defined by National Fire Protection Association Standard (NFPA) 921. Many of these fluids or materials are chosen because of the benefits they provide relative to safety, environmental, weight, and durability performance characteristics. In the unlikely event of a vehicle fire, some of these materials or

fluids may contribute to the initiation and/or the propagation of fire within a vehicle. R134a and R1234yf refrigerants do not provide adequate lubrication for moving parts within the AC system and require PAG oil to be dispersed within the refrigerant. Pure R134a is classified as non-flammable [2] however when it is mixed with the compressor oil, the mixture may ignite in the presence of a competent ignition source. R1234yf has been classified by Honeywell as a flammable gas [3] and also requires the same type of compressor oil as R134a for automotive use. Modern vehicles

that include R134a refrigerant and compressor oil have been deemed safe and do not represent an unreasonable risk to automotive safety.

Automotive manufacturers as well as the National Highway Traffic Safety Administration have promulgated standards that are intended to apply objective measures of vehicle safety as it relates to fires in motor vehicles. Federal Motor Vehicle Safety Standard (FMVSS) 301 specifies fuel spillage rates after a vehicle is subjected to impacts from the front, side, and rear as well as a post-test static roll procedure [4]. This standard does not apply to other fluids typically contained within motor vehicles. Additionally, burn rates of combustible materials within the passenger compartment of motor vehicles are regulated by FMVSS 302, Flammability of Interior Materials [5]. These standards state that their purpose is to reduce the death and injuries to motor vehicle occupants caused by vehicle fires.

Applying a burn rate standard similar to the FMVSS 302 standard at a vehicle level may prove impractical due to a number of considerations which include significant variations in overall vehicle design, mass, and architecture as well as variations of potential fuel loads from vehicle to vehicle. Any or all of these variables would most likely change the way a fire progresses through a vehicle. Other real world considerations such as the area of the fire's origin, wind and weather, or even vehicle orientation or condition at the time of the fire will also alter the rate of fire progression in a vehicle. This paper does not attempt to develop or specify an acceptable or reasonably safe rate of fire progression in a vehicle (similar to FMVSS 302). The intent is to compare the ignition and fire propagation characteristics of the two refrigerants in an identically equipped vehicle in order to provide an objective comparison in the rate of fire propagation between the two.

## HOT SURFACE IGNITION TEST INTRODUCTION

The published auto ignition temperature (AIT) values for typical automotive fluids under various test conditions are widely discussed and reviewed with a number of technical papers and industry standards, including; LaPointe, Adams, Washington [6], Arndt, Stevens, Arndt [7], Santrock, Kononen [8], Colwell [9]. Research conducted in these papers reflects a wide variation of published auto ignition temperatures of these fluids based on test conditions. The AIT is defined by NFPA 921 as, "The lowest temperature at which a combustible material ignites in air without a spark or flame". The upper and lower flammability limits (UFL and LFL respectively) are defined by NFPA 921 as, "The upper or lower concentration limit at a specified temperature and pressure of a flammable gas or vapor of an ignitable liquid and air, expressed as a percentage of fuel by volume that can be ignited [10]. Above the UFL, the mixture is too rich and below the LFL the mixture is too lean to support combustion. At a standard temperature of 21 °C (70° F), the LFL is 6.2%

and UFL is 12.3% for the R1234yf refrigerant [3]. Higher and lower temperatures can alter these percentages. Since R134a is nonflammable, these limits for ULF and LFL do not exist (see [Table A](#) for a comparison of other common under hood fluids).

**Table A. Typical Under Hood Fluids Properties, Honeywell MSDS [2, 3, 11, 12], NFPA 921, 2008 Edition [10]**

| FLUID                      | LFL (%) | UFL% | Auto Ignition Temperature (°F) |
|----------------------------|---------|------|--------------------------------|
| R134a <sub>2</sub>         | NA      | NA   | >1369                          |
| R1234yf <sub>3</sub>       | 6.2     | 12.3 | 761                            |
| R152a <sub>11</sub>        | 3.7     | 18.0 | 851                            |
| R32 <sub>12</sub>          | 12.7    | 33.4 | >1369                          |
| Gasoline <sub>10</sub>     | 1.4     | 7.6  | 495 - 536                      |
| Washer Fluid <sub>10</sub> | 6.0     | 36.0 | 867 - 903                      |
| Diesel Fuel <sub>10</sub>  | 0.4     | 7.0  | 489 - 500                      |
| Trans Fluid <sub>10</sub>  | 1.0     | 7.0  | 626 - 716                      |
| P/Steering <sub>10</sub>   | 0.9     | 7.0  | 680 - 720                      |
| Brake Fluid <sub>10</sub>  | NA      | NA   | 210 - 550                      |
| Motor Oil <sub>10</sub>    | 1.0     | 7.0  | 644 - 680                      |

## HOT SURFACE IGNITION TEST METHODOLOGY OVERVIEW

The next section of this paper focuses on hot surface ignition properties of R134a and R1234yf refrigerants on typical exhaust system surfaces and includes a description of the testing methodology for the vehicle buck and the A/C system bench stand. This testing methodology varies from joint research previously conducted by Marc Spatz (Honeywell) and Barbara Minor (DuPont) which studied the auto-ignition properties of various refrigerants, including R1234yf, and was presented the SAE World Congress in 2008 [13]. The research described in that study documented auto-ignition properties of R1234yf both with and without PAG oil in a laboratory environment. The test methodology described in this paper reflects conditions that are more representative of the refrigerant/oil mixtures and under hood environments in a typical automobile.

There were two main test apparatus for this testing. The first was the vehicle buck that the refrigerant mixture was released onto (shown in [Figure A](#)). The second was the operational A/C system bench stand that released the refrigerant, (shown in [Figure F](#)) with the appropriate volume, orientation, and condition of AC refrigerant/PAG 46 oil mixture in a typical automobile.

The control variables for this testing were the R134a and R1234yf refrigerants and the under hood exhaust system surface temperatures. Prior to the start of the testing, a

number of safety precautions were developed and incorporated during the testing process. These precautions were incorporated to provide the maximum level of safety for on-site personnel as well as the test facility and equipment. They did not influence the results of the testing.

## VEHICLE TEST BUCK

For the purpose of this testing, a 2011 Ford Taurus SHO with a 3.5L, 24V, V6 EcoBoost™ engine was used. Prior to this test, this fully functional vehicle had accumulated approximately 14,000 miles. All under hood fluids were drained and removed prior to the test. The under hood appearance and arrangement of components were kept intact with the exception of a 25 mm by 35 mm nozzle that was added for fire suppression capabilities. A heat input manifold was installed to the exhaust manifold that facilitated the introduction of heat to the vehicle's exhaust system. Finally, thermocouples were added at various under hood locations to record test temperatures. A photo of this test buck is shown in [Figure A](#).



**Figure A. Exterior of 2011 Ford Taurus SHO Vehicle Buck**

Twelve thermocouples were welded to various locations in the immediate area from the exhaust manifold to the start of the exhaust down tube pipe of the Taurus SHO. The locations of these thermocouples were selected due to their relative proximity to the A/C system and because they represent some of the highest temperatures observed during Ford's thermal testing of the Taurus SHO. The thermocouple locations are described as follows:

1. Exhaust manifold flange
2. Heat tube near torch rosebud at collector
3. Manifold tube
4. Bottom of light off catalytic

5. Top of light off catalytic
6. Exhaust manifold
7. Exhaust turbo body
8. Turbo left front
9. Turbo outlet
10. Turbo inlet flange
11. Turbo bottom
12. Turbo piping connector

[Figure B](#) depicts a number of thermocouple locations with the heat shield removed for clarity. [Figure C](#) depicts the test condition with the heat shield reattached. The large red arrows shown in [Figures B](#) and [C](#) indicate the direction of the refrigerant mixture being discharged on the hot exhaust system. The A/C line and portions of the exhaust system can be seen near the engine oil filter. The direction and location of the simulated leak near the exhaust system was selected because it represented the highest potential of ignition of the released refrigerant/PAG oil mixture.



**Figure B. Thermocouples (Heat Shield Removed)**

Once the thermocouples were installed, the production heat shield was reinstalled over the exhaust system. The thermocouple wires were routed in a manner so that they did not block the surface of the exhaust system from the refrigerant being dispersed. [Figure C](#) shows the production exhaust manifold shield reinstalled.

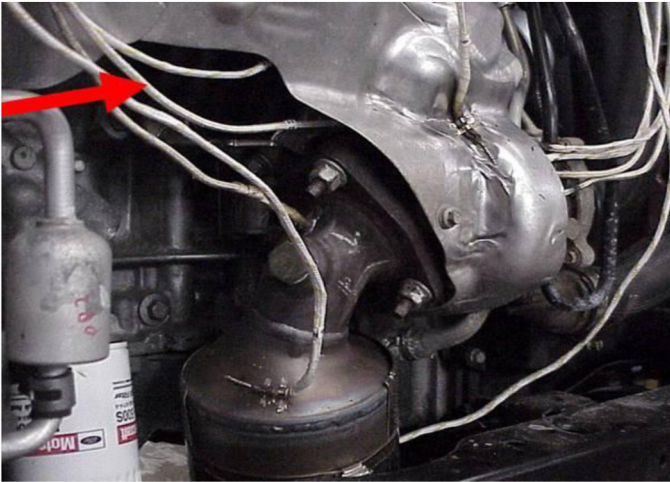


**Figure C. Test Condition (Heat Shield Reinstalled)**

Because the engine in the test buck was not capable of running, an alternative method of introducing heat into the engine's exhaust system was developed. This method allowed precise control of the exhaust system surface temperatures while maintaining the integrity of the exhaust system surfaces. The gas chosen to heat the vehicle's exhaust system was HGX mixed with oxygen. The gas was delivered through a torch that was inserted into the front exhaust system manifold (see [Figure D](#)). The flame was not exposed to the outside of the exhaust system and the cap prevented refrigerant from entering into the exhaust system.

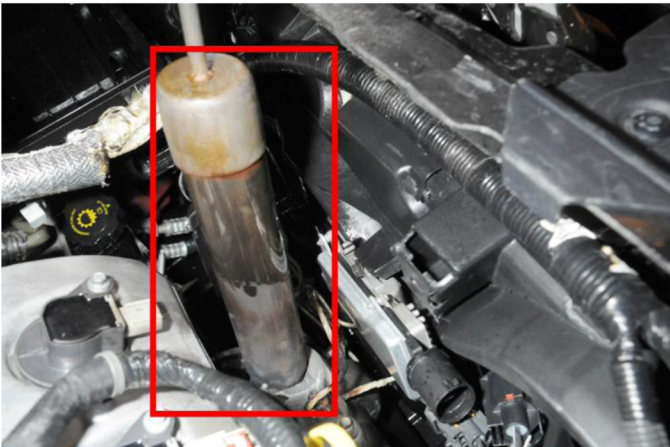


**Figure D. Heat Tube and Top Cap.**

The heat that was introduced into test buck's exhaust system was allowed to move through the system. [Figure E](#) reflects the routing of the exhaust system underneath the front passenger compartment of the buck and illustrates the point at which heat exited the system.



**Figure E. Exit Path for Heated Exhaust**

The maximum temperatures selected for this test were determined from internal heat management data from Ford. The intent of the heat management test is to verify that under severe operating conditions, the level of heat generated will not exceed the capabilities of materials in and around the exhaust system. The highest surface temperatures reflected in this test represent the maximum temperatures recorded during heat management testing at Ford Motor Company and do not represent typical operating surface temperatures of exhaust systems. Actual exhaust system surface temperatures can vary depending on a number of factors including, engine size, drive cycle, condition of the vehicle, ambient temperatures, etc. Lower exhaust system surface temperatures of several different vehicles under typical drive cycles were documented in research conducted by Engle, Olson, and Sharma and reflect significantly lower temperatures than those documented in this testing [14].

## A/C BENCH SYSTEM

A system bench stand was constructed that included the major components in an automotive air conditioning system. These components include the compressor, condenser, evaporator, and the A/C lines (see [Figure F](#)). This stand enabled the refrigerant to be released into the engine compartment of the buck in a volume and state that would simulate a release of the onboard refrigerant. [Figure F](#) reflects the A/C system components constructed for this test.