

Hot Surface Ignition of Gasoline-Ethanol Fuel Mixtures

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ABSTRACT

The purpose of this paper is to present the results of hot surface ignition (HSI) testing and American Society for Testing and Materials (ASTM) auto-ignition testing (AIT) performed on gasoline fuel mixtures containing varying levels of ethanol.

With the increased consumer interest in ethanol-based fuels as a measure of reducing the United States dependence on foreign oil, the use of E85 and other ethanol/petroleum fuel blends is on the increase. While some autoignition data for summer and winter blends of gasoline on hot surfaces exist beyond the standard ASTM E659-78 test procedure [1], there is little data on ethanol-based fuels and their HSI characteristics.

All these factors (and more) play a role in influencing HSI: the molecular structure of the fuel, the surface material temperature, the surface geometry of the material, the material properties of the hot surface, the fluid flow rate, the contact time, and environmental factors such as air flow in the immediate area of the fuel contact. This paper focuses specifically on the various blends of ethanol along with commercially available fuels tested for HSI in a controlled laboratory environment, where the temperature was varied but other influences were attempted to be held constant. The fuels tested were commercially available unleaded regular gasoline (CA ULR), commercially available E85 (CA E85), certification grade gasoline (indolene) and blends of indolene and ethanol. The HSI temperatures of each of the fuel blends determined by laboratory experimentation are compared to the autoignition temperatures obtained through ASTM

E659-78 test methodology. More than 1300 data points were collected.

The results depict a range of temperatures between levels at which HSI was not observed in any samples to where HSI was observed 100% of the time, for each type of fuel tested. The testing showed that as the level of ethanol increased beyond 10%, temperatures for observed HSI events tended to decrease and stabilized around 75% ethanol concentration, although the ASTM-AIT temperatures remained relatively constant throughout the varying concentrations of ethanol. For each fuel composition tested, the observed HSI temperature was significantly higher than its corresponding ASTM-AIT temperature.

This work is important in that it not only provides HSI data for varying gasoline/ethanol concentrations; it also points out limitations in using ASTM-AIT data for predicting HSI fire initiation in an automotive field environment.

INTRODUCTION

HSI data for ignitable liquids provides an important piece of the puzzle in the science of fire investigation. However, very few studies and literature exist to correlate the effects of all the factors influencing HSI in an automotive field environment.

NFPA (National Fire Protection Association) 921, Guide for Fire & Explosion Investigation (2008 edition) references the autoignition temperature of gasoline to be 495 °F – 536 °F based on the TDS (Technical Data Sheets) and MSDS (Material Safety

Data Sheets) from manufacturers. These data sheets do not reference the test methodology but it is assumed that it may have been derived using the ASTM E659-78 test procedure. NFPA 921 also references studies simulating field conditions in motor vehicles that have shown the minimum temperature of a heated surface required to ignite liquid gasoline is several hundred degrees greater than this range [2].

Several studies [3-7] have been conducted using unleaded regular gasoline to understand the various factors influencing the difference in the autoignition temperature reported per ASTM method and the likely hot surface ignition temperature in the automotive field environment. This literature was reviewed during the preparation of this paper. Studies [3,5] reported the statistical characteristics of hot surface ignition temperature of gasoline and other fluids. Studies [4,7] analyzed the hot surface ignition of gasoline on different materials. Study [7] measured ignition temperatures using thermocouples and IR thermography technique. Study [6] discusses ignition properties of gasoline, diesel, biodiesel and E85 fuels. All of the referenced studies reported substantially higher hot surface ignition temperatures when compared to the ASTM E659-78 methodology and noted that to control all the factors influencing the hot surface ignition temperature for different ignitable fluids is substantially difficult.

This study attempts to determine the ignition characteristics of gasoline with varying levels of ethanol on heated surfaces. Fuels tested in this study include CA ULR, CA E85, indolene, E10 with indolene, E25 with indolene, E50 with indolene, E75 with indolene and E85 with indolene. In the present study, fuel samples were poured onto a heated surface to determine the range of surface temperatures that would result in an observed ignition of the vaporized fluid in the absence of a piloted ignition source. The data from this study was compared with ASTM-AIT data obtained from an approved laboratory using the sample set.

METHODOLOGY

The test methodology for this set of experiments was fundamentally common with that which had been previously used to study the HSI temperatures of used and new engine oil, transmission fluid, windshield solvent, power steering fluid, brake fluid and engine coolant [8]. Modifications were made as necessary to support the unique requirements associated with the testing of gasoline-based fuels. Utilization of this common methodology would allow this work to add to the previously obtained body of knowledge relating to HSI temperatures of under hood fluids.

LABORATORY SETUP - The test setup is shown in Figure 1, and basically consisted of cast iron crucibles being placed on electric hot plates in order to provide a heated surface and the absence of any open flame that might act as a piloted ignition source.



Figure 1. Equipment Setup

The crucibles that were used for the hot surface ignition study were sand cast, gray iron, 0.5 inch thick and 6 inches in diameter. A 24 gage K-Type thermocouple was spot-welded (Unitek 250 Spot Welder) to the center of the upper surface of the crucible. A 240V electric hot plate (Chromalox Model ROPH-204) was used to heat the cast iron crucibles. The internal temperature controls within the hot plate were bypassed and the temperatures were manually controlled to eliminate the temperature hysteresis that was prevalent with the standard controls. Electrical power to the hot plate was supplied by a 240V variable transformer. Because of the higher temperatures required to ignite gasoline fuels compared to previous fluids tested, the inside of the hot plate was insulated with ceramic wool to minimize heat loss. The outer wall of the crucible was wrapped with similar ceramic wool material retained within a custom-built frame. An insulated flat cover with a handle for the crucible was used to maintain uniform temperature on the upper surface of the crucible. Temperature was monitored continuously (Omega data logger Model DP 465), and the output power from the transformer was adjusted manually to reach the required set temperature. The crucibles were placed on the hot plates within a laboratory hood which was force-ventilated to the outside. A glass door on the hood could be raised or lowered for access to the test equipment as well as to limit random air flow in the vicinity of the crucibles.

FUEL BLENDS – Indolene, a certification grade gasoline, which is formulated to a minimum of 93 Octane Research Octane Number (RON) and with no oxygenates or detergents was mixed with ethanol in different percentages to obtain fuel samples. Indolene, E10 with indolene, E25 with indolene, E50 with indolene, E75 with indolene & E85 with

indolene were procured from an approved supplier. Commercially available 87 octane unleaded regular gasoline (CA ULR) and E85 (CA E85) samples were purchased at a gas pump station in the Metropolitan Detroit area. Prescribed quantities of all fuel samples were submitted to Phoenix Chemical Laboratory in Chicago, IL to conduct autoignition temperature tests per ASTM E659 - 78. All samples were identified and stored in tightly-closed containers in a metal cabinet between evaluations, and the containers were stirred prior to drawing any test fuel samples to ensure a representative test sample was obtained.

PROCEDURE - A protocol was established for cleaning of the crucible & welding the thermocouple in a repeatable manner within the center of the crucible after each set of ten readings. It included details for routing that minimized collection of liquid fuel on the thermocouple insulation. To prepare the surface of the crucible for testing, the crucibles underwent either a sand blast (Trinco Dry Blast Model 60X48/PC) or Roto-Blast (Pang born Model 6LK-7) operation. A Drummond pipette (Model 4-000-100) was used to obtain measured fluid volumes for testing. Studies to eliminate splashing against the crucible vertical wall (which could lead to the fuel migrating out of the crucible) helped identify a discharge rate of 1.8mL to 2.1mL per second (continuous stream) from the pipette. A discharge angle for the pipette was also established as 30 to 45 degrees from the horizontal plane in order to control the location where the fuel was dispersed onto the crucible and avoid being directly in the potential flame path.

In order to minimize uncontrolled air flow in the vicinity of the crucible, the glass door of the hood was positioned below the level of the crucible during the testing and the exhaust fan was turned off prior to beginning each evaluation. Test sample fluid volume (10mL) was measured with the pipette. The crucible was covered and the temperature was raised to approximately 25 °F above the target temperature. At this time, the cover was removed and the crucible was allowed to cool. When the target temperature was achieved and was within ± 1 °F, the contents of the graduated pipette were poured at an angle (30 to 45 degrees) in the center of the crucible with the prescribed discharge rate. Hood air temperature was recorded (Omega data logger DP 465) during each reading. If flames were observed prior to complete release of the sample fluid, the fluid release was stopped and the exhaust fan was turned on. If no flame occurred after the complete release of the sample fluid, time was noted for complete evaporation of the sample from the crucible prior to turning on the exhaust fan. Between samples, the exhaust fan remained "on" to purge any fuel vapors from the hood area. At the conclusion of each sample, the inside of the crucible

was inspected for any remaining residue, and was blown out with compressed air to clear out any loose ash (if any) content. The crucibles were cleaned using sand blast or Roto-blast equipment after each set of ten samples. New thermocouples were spot-welded in place after cleaning of the crucibles.

The starting test temperature for the different fuel samples was initially selected based on the ASTM E659 test results. When no ignition event was observed at these levels, the temperature was raised by 100 °F and another test sample was run. The results were not recorded until a temperature was reached when an ignition event was visually observed. At that point, ten readings were taken to record the frequency of flame occurrence at that temperature. To determine the upper limit of observations, the temperature was raised by 10 °F and another set of ten readings was obtained at the new setting. This procedure was repeated until two consecutive temperature settings yielded a 100% occurrence of flame. Similarly, to determine the lower limit of observations, the temperature was reduced in 10 °F increments and data was taken until two consecutive sets of ten samples were obtained with no occurrence of flame.

RESULTS

Table 1 below lists the hot flame autoignition temperatures for the different test fuels using the ASTM E659-78 method. This test is designed to identify the lowest temperature at which ignition is observed under a closely controlled set of laboratory conditions.

Fuel Mixture	ASTM Autoignition Temperature (°F)
Indolene	745
CA ULR	670
E10	780
E25	765
E50	785
E75	805
E85	795
CA E85	795

Table 1: ASTM E659-78 Test Data

As can be seen from the data, it appears there may be a slight increase in AIT with the introduction of ethanol to the indolene mixture, but the concentration of ethanol does not appear to be a significant factor. There does appear to be a difference between the CA ULR when compared to either indolene or E10, but since there was no specific chemical analysis performed on the commercial fuels, this paper does not offer a