CHARACTERIZING FUEL BY GAS CHROMATOGRAPHY: MAKING SURE THAT INDYCAR RACE TEAMS ARE PLAYING BY THE RULES

You pull into your local gas station to fill up. Assuming you remember which side your gas tank filler cap is on, and what is the optimum grade for your car, you start pumping gas into your tank. But have you ever wondered why most of the gasoline now sold in the United States contains ethanol. Depending on where you live, you will find three general categories of ethanol-gasoline blends …. E10, E15, and E85, which is gasoline containing up to 10%, 15% and 85% fuel-grade ethanol respectively. The majority of motor gasoline sold in the US does not exceed 10% by volume, but up to 15% ethanol content is sold in the Midwest….and in particular the corn-belt, where most of US ethanol production capacity is located.

Ethanol Blended Gasoline

Ethanol is blended into U.S. motor gasoline to meet the requirements of the 1990 Clean Air Act and the Renewable Fuel Standard described in the Energy Independence and Security Act of 2007, which is administered through the U.S. EPA's Renewable Fuel Standard Program. All gasoline engine vehicles manufactured today can use E10. However, only flex-fuel (FFV) and light-duty vehicles manufactured after 2001 are approved by the EPA to use E15. A flexible-fuel vehicle (FFV), sometimes known as dual-fuel vehicle is an alternative fuel vehicle with an engine designed to run on more than one fuel. This is usually gasoline blended with either ethanol or methanol, which are stored in the same common tank. It's also important to emphasize that FFVs can use E85 fuel. Except for a few engine and fuel system modifications, they are identical to gasoline-only models. FFVs experience no loss in performance when operating on E85, and some generate more horsepower than when operating on gasoline alone. However, since ethanol contains less energy per volume than gasoline, FFVs typically get about 15%–25% fewer miles per gallon when running on E85 fuel.

INDYCAR Racing

If you are an avid follower of motor racing, such as Formula 1, NASCAR or INDYCAR, you probably know that good fuel consumption is just one component in designing a race car. Fuel consumption is just as important as horsepower, torque and performance. Take for example the fuel that's used by cars in the Indianapolis 500, the premier race of the Verizon IndyCar Series. Verizon IndyCar Series race cars are shown in Figure 1.

The IndyCar organization has tried a number of different fuels over the years, including 100 percent fuel-grade ethanol and methanol with various mixtures of gasoline. From 2007-2011, the mixture was 98% ethanol and about 2% racing gasoline which had an octane rating of 113. Octane rating is the measure of a fuel's ability to resist "knocking" during combustion, caused by the air/fuel mixture detonating prematurely in the engine. In the U.S., unleaded gasoline typically has octane ratings of 87 (regular), 88–90 (midgrade), and 91–94 (premium). Today the IndyCar Series is using a variation of E85, which contains 85% ethanol and 15% high-octane racing fuel, which delivers an octane rating of 105. So it can be seen that the fuel for an IndyCar is significantly higher octane rating that gasoline we buy from the pump. This is the reason they can lap at an average speed of 210 mph, with top speeds of over 230 mph. But the downside is that it has a huge impact on the car's fuel consumption….it's been estimated that 1.3 gallons of fuel are used every lap of an Indycar race…in other words, less than 2 miles per gallon.

Clearly the Octane rating has a significant impact on the performance of a car, because all the IndyCars are of a similar design. They are all single-seat, open-cockpit car that feature a 2.2-liter, twin turbocharged, direct-injected V-6 engine supplied by Chevrolet or Honda, which are optimized to run at 12,000 RPM with an estimated 500-700 horsepower depending on the turbocharger boost setting. However, there are other ways of getting an edge at certain times during an IndyCar race, such as a turbocharger boost pressure called "push-to-pass", which was initiated about half-way through the 2015 season. This is a switch inside the cockpit, which will give the drivers an extra boost when they are trying to pass a car in front of them. However, they are only allowed to use this feature a maximum of 10-times per race, as explained by Marvin Riley, the Director of Engine Development of the Verizon IndyCar series:

"It is estimated that this will increase the internal engine pressure from 160 kilopascals (kPa) to 165 kPa, translating to a gain of approximately 20 horsepower in the Chevrolet and Honda engines. Normal boost pressure on road and street courses – before the overtake assist is engaged – remains at 150 kPa in 2016. A total of approximately 60 added horsepower will now be available for push-to-pass activations during the 16 road- and street-course races in the 2016-17 racing season (March-September), nearly doubling the on-track effect for passing over 2015."

Fuel Testing Protocol

The rules and regulations in the design of an Indycar are very strict, so it's extremely difficult for teams to gain a significant advantage, when the cars are a similar weight, engine type, engine size, gearbox, chassis, cockpit, wheelbase, tire, suspension, gas tank size and fuel (1). So for that reason, the race result is very much dictated by the skill and expertise of the drivers. In addition, one of the major areas of enforcement is in the fuel used. It is supplied by the same oil company (Sunoco: E85 fuel) and pumped from the same underground tank, containing exactly the same mixture of ethanol and gasoline. Fuel quality is such an important component of the rules that for the past 40 years, the Indianapolis 500 and more recently, the Verizon IndyCar Series has used one company to carry out all the fuel testing to ensure that no teams are getting an edge by using illegal additives to give their cars an octane boost.

History of Fuel Testing

In 1995, Tim Ruppel, a Senior GC Applications Specialist at PerkinElmer was involved in the initial development of the gas chromatographic testing method including selecting the appropriate column material, stationary phase, film thickness, column length, and diameter to provide an efficient separation of potential volatile compounds in the race fuel. The current method which combined two methods, each with analysis times of 20 minutes has been optimized into a single method that takes less than five minutes to carry out a complete separation, as exemplified by the chromatogram of E85 fuel in Figure 2.

Let's take a closer look at the logistics of testing the fuel in an IndyCar race.

All cars receive Sunoco fuel from a central source. During pre-race qualifications and the race itself, fuel is delivered to each team's pit fuel tank. Each tank is sealed to prevent tampering. Fuel is delivered by gravity feed, and each tank's

Figure 1 (Above): INDYCAR race cars (courtesy of INDYCAR)

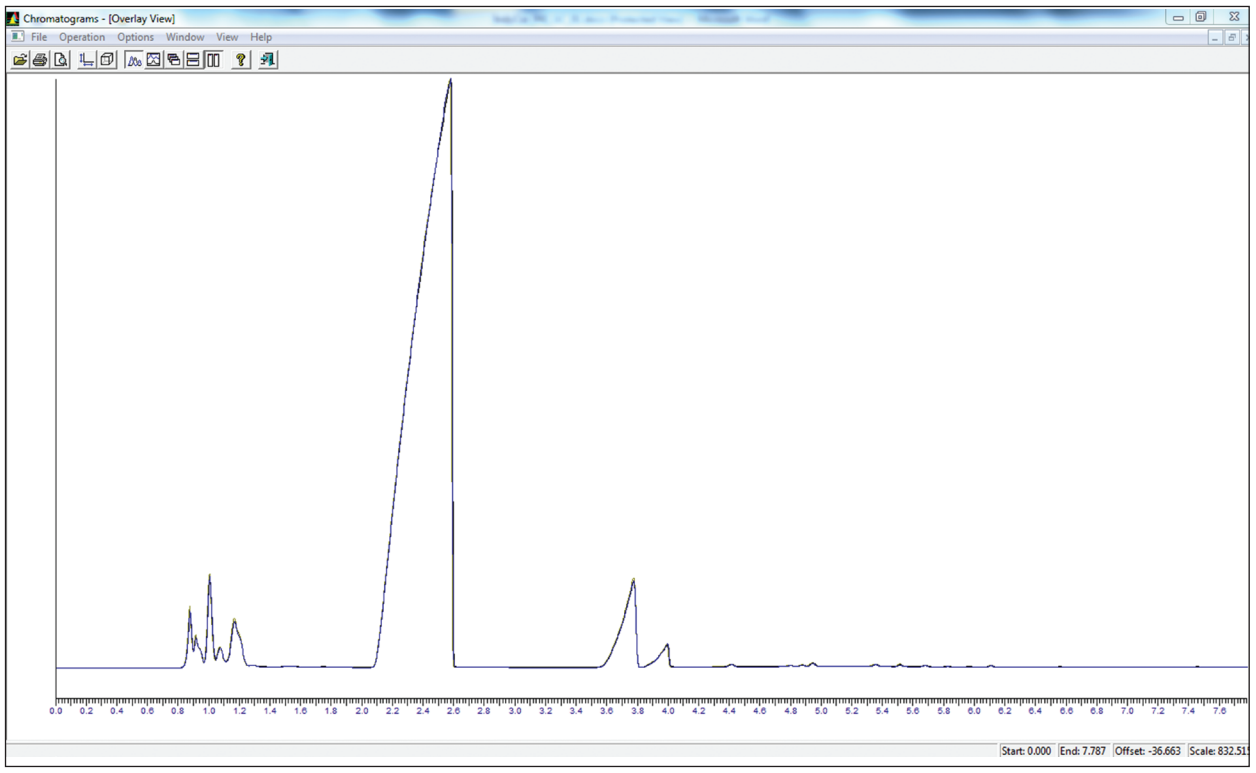

Figure 2: Typical chromatogram of E85 fuel used in today's INDYCAR Series (Courtesy of PerkinElmer Inc.)

leveling system is fastened to prevent adjustment of the tank to a steeper angle, which would accelerate the delivery of fuel (the time needed to refuel is part of the race time). Fuel is sampled from the central supply prior to pit tank filling, and a sample is taken from each car upon pre-race qualification and race completion….as exemplified in Figure 3.

The samples are then taken to a mobile lab on-site and analyzed by gas chromatography in under five minutes. Chromatographic profiles from each car must match the team's pit fuel tank profile. Any discrepancies are further investigated, and may result in disciplinary action. The test monitors potential additives that could boost performance and give an advantage over teams using the officially-sanctioned E85 fuel. For example, the chromatogram shown in Figure 1 which is a plot of retention time (x-axis) and fuel component concentration (y-axis), shows the major ethanol peak in the middle, while the smaller peaks to the left and right are components of gasoline, often referred to as BTEX…. the aromatic hydrocarbons, Benzene, Toluene, Ethylene and Xylene. In addition, there is always a small percentage of water in any fuel that contains ethanol or methanol, which would show up as an additional peak. This chromatogram is considered a typical fingerprint of an E85 fuel, but if any contaminants or additives were in the fuel, they would also be seen in the chromatogram, which on further investigation, could be identified if needed.

Race Testing Logistics

PerkinElmer is the official instrument supplier and fuel certification sponsor for the IndyCar Series. Fuel testing is a big responsibility—analyzing fuel samples from the race cars at all 16 IndyCar races to ensure no one is attempting to gain an advantage. This mobile lab has been used for fuel testing at every IndyCar race for the past five years, and based on recent numbers from the trailer's driver, it has traveled around 150,000 miles in that time.

So how is the fuel testing carried out throughout the year? The mobile lab is located in an IndyCar Series semi-trailer used by the race series' Technical Inspection Group. Though the lab just occupies a small section in the trailer, it includes one PerkinElmer Clarus® GC system with a thermal conductivity detector (TCD) and one analyst at each race (see Figure 4). Jesse Leonard, a PerkinElmer Senior GC Service Specialist, who attends many of the races, explains how it works,

"While we're there at the track we take samples from the cars and analyze them on the instrument to ensure that the fuel is not being adulterated in any way. It is against race regulations to add or remove anything from the series provided fuel. The lab typically tests 12 to 20 cars at each race event, as the top six or seven cars per race and then the top six in the qualifying round are usually tested, meaning 30 injections on the GC per event. PerkinElmer is actually able to provide information the same day to the league officials so that they can take action on it immediately, rather than after the race weekend is over"

Suspicious Results

For a lab that travels so often and does so many tests, they face surprisingly few challenges, with testing going smoothly and uneventful for the most of the time. However, there have been examples of teams trying to gain a competitive advantage on the track through modifying the fuel provided by the league.

"We have identified cases in which this has happened," explains Jeff Horton, the IndyCar Director of Engineering Safety, "Back in 2009 when the cars were using 98% ethanol fuel, we found that one race team had found a way to dry their pit fuel supply, which was giving them a slight performance edge over the other cars."

Brett Boyer, a PerkinElmer GC Service Specialist, who was carrying out the analysis, had a better understanding of what was going on when he explained,

"I was suspicious when there was less water in the gas chromatogram than in the supplied fuel, which told me that the water had been removed. I took samples to our fuel supplier's lab for additional testing and those results were confirmed. Water is typically removed from ethanol using molecular sieve technology."

This proved to be the case and needless to say, the guilty race team received a very hefty fine for their actions.

Figure 4: PerkinElmer's Clarus GC System used to test IndyCar fuel (Courtesy of PerkinElmer Inc.)

Figure 3: PerkinElmer's Jesse Leonard is seen sampling the fuel from a car at the Indy Grand Prix of Alabama at Barber Motorsports Park (Courtesy of PerkinElmer Inc.)

Jeff Horton told us there have also been other examples of the GC system detecting compounds that should not be in the fuel, but not in an advantageous way. The 18.5-gallon gas tank in an IndyCar is known as a safety fuel cell, which is basically a very flexible, extremely strong bladder or fuel bag that prevents spillage in the event of an accident. Made from high tensile strength elastomer (polymer) components and engineered to withstand the fuel's chemical attack, the bladder is the first line of defense in a crash. However, some of the early designs were not completely resistant to chemical attack by the fuel and as a result some of the compounds in the polymer were being dissolved by the fuel, specifically in samples taken from the filter system, where the contaminants were being concentrated. Jeff explained that the first sign of this was that unknown peaks were seen in the gas chromatogram. But of course, the challenge was finding out what the peaks were. Tim Ruppel, a GC Applications Specialist from Chicago takes up the story,

"Using a GC TCD detector, we were only able to say that these peaks shouldn't have been present, because they were not in the fuel tested from the main tank. So we took some of the contaminated fuel back to our Tech Center facility in Oakbrook (Illinois) and ran them on the GC fitted with an MS (mass spectrometer) detector, which is a technique that can identify the unknown compounds in a sample. What it told us was that the peaks were actually phthalate esters, which are mainly used as plasticizers to increase the flexibility, transparency, and durability of polymers."

Mystery solved….the fuel was leaching out the plasticizers from the inside of the fuel bladder.

This level of support has proved invaluable to the IndyCar organization, because if it was allowed to go undetected, this kind of problem could have been disastrous, because it would have actually damaged the engines…and not given them any type of performance boost!

We'll leave the final words to Marvin Riley, whose job is to make sure that no team gets any unfair advantage by bending the rules regarding the performance of the engine,

"The Verizon IndyCar Series and the Indianapolis 500 are proud to be associated with PerkinElmer, who have been our partners for over 40 years. Their GC instrumentation, together with the knowledge and expertise of their technical specialists has made my job easier by ensuring that when it comes to fuel characterization, there is no question that all teams are on a level playing field."

Further Reading

1. Verizon IndyCar Series Procedures and Rules: http://www.INDYCAR.com/Fan-Info/INDYCAR-101/Rulebook/Chp14-TechSpecifications

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