How Does One Measure Ethanol's Octane?

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Whether talking to someone in the racing community or someone in the business of simply selling ethanol, most folks do not fully understand ethanol's octane. Part of that is due to the fact that the current ASTM test methods for determining octane clearly undervalues the octane performance of ethanol. To best understand the octane performance of ethanol, it's important to break down the key fuel parameters for octane of both gasoline and ethanol.

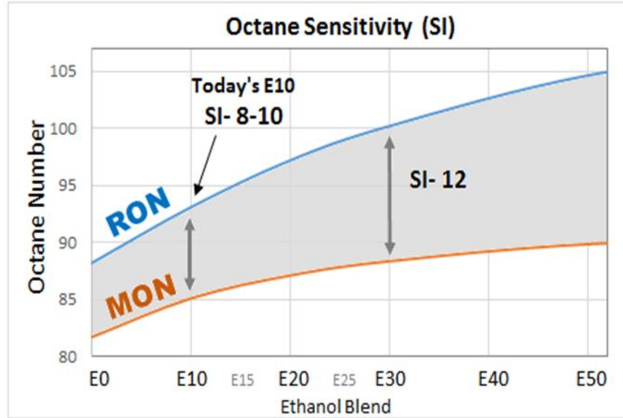
ICM, Inc. co-authored a Society of Automotive Engineering Paper (2012-01-1277) titled *Effect of Heat of Vaporization, Chemical Octane, and Sensitivity on knock limit for Ethanol – Gasoline Blends*. Note there are three parts mentioned here; heat of vaporization, chemical octane and octane sensitivity. All three of these fuel parameters are valuable but it is primarily **chemical octane** that is labeled on the fuel selection button when consumers fill up. For the engineers working in the auto industry, all three are valuable in order to improve engine efficiency.

To discuss ethanol's octane benefit, one first needs to have a general understanding of how octane is labeled. In the United States, both Research Octane Number (RON) and Motor Octane Number (MON) are used. RON is the higher number and often considered the best measurement for modern vehicles on the road today. The MON is relevant for racing and aviation fuels.

The same octane test engine is used to determine both RON and MON but operated at different RPM and in-take air temperature. In the United States, the R+M/2 simply means we are averaging the RON and MON results. This R+M/2 is called the Anti-Knock Index, or simply AKI.

Most Europe and Asian countries list just the RON value and here lies one piece of the puzzle. Europe does have higher octane, but Europe's Regular 95 RON is similar to the United States' 91 AKI Premium. Some parts of the United States sell 93 AKI Premium fuels, averaging between 97 to 98 RON.

When your vehicle exceeds the knock limit of the fuel, that's when **octane sensitivity** (SI) comes into play. Octane sensitivity helps improve efficiency by requiring less retarding of engine ignition timing.



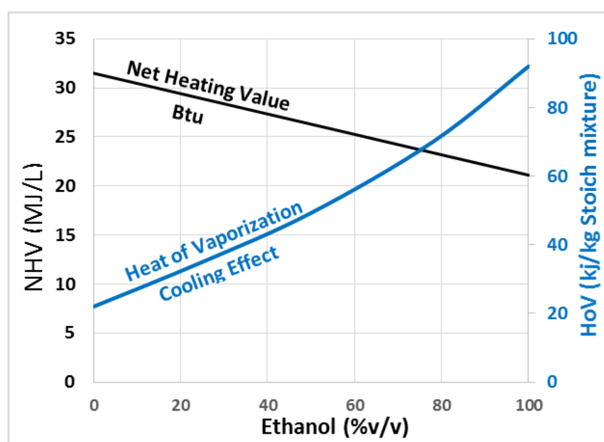
As mentioned earlier, fuel is tested for both RON and MON using the same engine but at different RPM and temperature. The average between RON and MON is AKI while the difference between RON and MON is called Octane Sensitivity (SI).

The benefit for today's engines utilizing higher sensitivity fuel enables a greater range of efficiency at higher engine load. It's difficult to raise SI at an oil refinery since most components of gasoline only offer a limited benefit. This is a huge opportunity ethanol since no other component in gasoline can compete when determining octane sensitivity.

Additionally, future gasoline engines could operate using compression ignition, which is similar to how diesel combusts. Currently, auto engineers are suggesting an SI of greater than 11 or even 12 would be the desired target. Since ethanol by itself has an SI of 20, simply adding 15-20% more ethanol to today's gasoline would achieve what auto engineers want, an SI of 12.

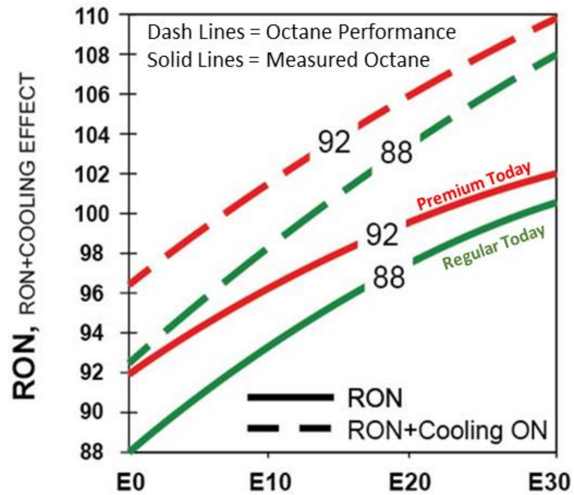
The **Heat of vaporization** (HoV or cooling effect) benefits octane performance and can also be part of overall improvements to engine efficiency. The cooling effect of ethanol lowers the combustion temperature which in turn lowers the octane needs of the engine.

Part of the challenge though is that while ethanol's cooling effect helps lower the octane needs of the engine, the cooling effect has less impact on how we measure octane. For this reason, one could have an E50 fuel with the same octane rating as an E0 unleaded gasoline yet the E50 will blow the doors off the E0 in regards to octane performance.



Some like to say ethanol is less efficient, and that is incorrect. Ethanol has less energy per gallon but has 4 times the cooling effect per unit of energy compared to gasoline. Ethanol provides more horsepower and efficiency per unit of energy and this is partly due to the cooling effect of ethanol.

This combination of octane (RON) plus cooling effect was demonstrated in the previously mentioned SAE paper 2012-01-1277, and charted in a subsequent Ford technical paper. Gasoline has a small cooling effect but, as ethanol is added to gasoline, this paper demonstrated the octane performance compared to measured octane by adding RON plus Cooling Effect. While an E30 may test at a 100 RON, the overall performance could be as high as a 106 RON.



(Figure 5) Anderson JE et al. High octane number ethanol–gasoline blends: Quantifying the potential benefits in the United States. Fuel (2012), http://dx.doi.org/10.1016/j.fuel.2012.03.017

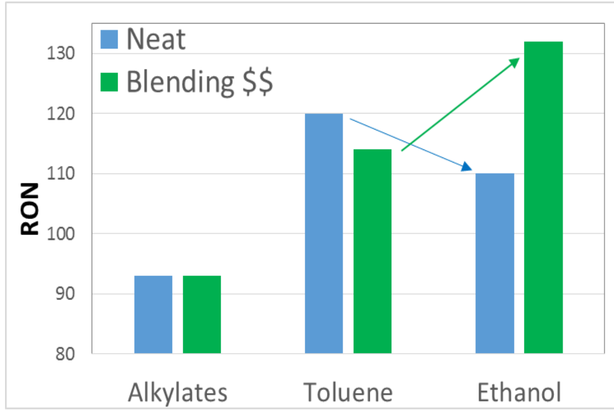
The difference in measured octane versus the octane performance of ethanol is especially complicated for those who are interested in race fuels. When testing E85, it is likely to see 110 RON / 90 MON with an AKI of 100. Yet when comparing E85 to Sunoco's 110 AKI leaded race fuel (yes leaded), E85 will show higher octane performance yet have an AKI 10 points under that of the Sunoco race fuel.

A lot of talk recently has been centered on how to raise the octane level here in the US to improve efficiency and thus improve miles per gallon. This is especially a challenge in the United States since the government doesn't regulate minimum octane. Subsequently the US has some of the lowest octane fuel compared to Europe and Asia.

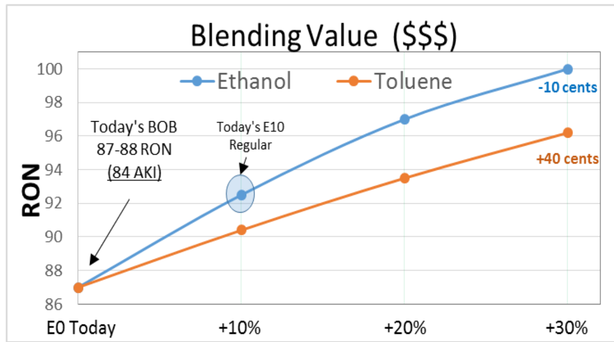
Another challenge to increasing the US octane market is that oil companies know they will sell more gallons of gasoline by pushing regular grade. This is done by increasing the consumer cost for premium fuel. The more people buy regular gasoline, the more often they have to fill up compared to those who use premium fuel. This may not sound like much, but we are talking about billions of gallons of gasoline in the US market.

The world of octane, primarily from the oil refineries of today is very complicated. Oil refineries can increase octane by either adding or not adding certain components during the refinery process. Oil refineries have basically two production options for increasing the octane stream at refineries today, by either creating more high octane alkylates or more aromatics. Alkylates are more favorable for vehicle performance and reducing toxic emissions while aromatics have a higher octane rating per gallon. It's important to note that aromatics in gasoline are the key source for toxic emissions including PM2.5 and ozone, as well as causing increased material compatibility problems.

One should learn from the past that when evaluating the octane benefits of any component of gasoline to include ethanol. One shouldn't look at the octane numbers of 100% toluene because it's impossible to ever see vehicles run on 100% aromatics.



This means the octane **blending value** for any component should be the primary economic driver.



The most common aromatic in gasoline today is toluene (methyl-benzene) and averages around 5 to 10 percent in the US gasoline pool. The upper chart shows the neat RON results (blue bar) if testing a high octane alkylates stream from an oil refinery, along with pure toluene and pure ethanol.

What needs to be pointed out by either the two arrows in the top chart or the RON response in the lower chart is that ethanol has nearly twice the octane increase compared to toluene if adding up to 30% by volume.

This is a huge economic benefit for consumers in the future when they can purchase E30 for less than E10 Regular, yet have more octane performance than any E10 Premium fuel in the market today.

Simply Add Ethanol To Current E10 Regular
100 RON (94 AKI) Sensitivity of 12
Twice the Cooling Effect
Lower Tailpipe & Evaporative Emissions
Little to No MPG Loss

Several recent presentations by auto engineers suggest that a new fuel of 100 RON with a minimum sensitivity of 12 be made available for future cars. While some may say this would be a new fuel, others say it has been available for over 10 years and it is called E30.

E30 is not a new fuel when we already have the fuel available in the market today. I've been using it for nearly 10 years since it is sold at several local gas stations. All you have to do is add more ethanol to existing E10 which already makes up 97% of the US gasoline market.