Anti-Detonation Injection & Low Octane Fuel
Resolving the Octane Deficit

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Anti-Detonation Injection (ADI) is not a new technology. Indeed, papers published as early as 1913 make reference to water injection as not being "something new". It's first use dates to 1900 in Hungary. Testing was later conducted in 1913, 1914, 1917, 1933, 1935 and 1938. In 1935 when Wright Aeronautical was trying to induce carburetor icing it was noted that the engine ran smoother and with lower temperatures when water was injected. However the greatest body of work on this subject was accumulated during WWII. It is from this that we learn the most about the usefulness of ADI specifically as it relates to resolving octane issues today.

ADI may be used for two different purposes. During WWII ADI was used to give a burst of power well beyond rated power in aircraft engines. As much as 30% more power was developed in for example the R-2800. The idea being that if an enemy aircraft was on your tail the throttle would be advanced beyond a detent, the spark – automatically advanced, and the mixture automatically leaned to give more power. Using ADI for this purpose (more power) is only possible with a fuel equal in octane number to the engine requirement. ADI was not limited to the R-2800. Virtually all of our front line airplanes used ADI during WWII.

ADI was recognized then, and can be used today for a completely different purpose, allowing the use of a lower octane fuel than that on which the engine was originally rated. Using ADI for this purpose was recognized during testing in the 1930's and 1940's. It was proposed and used at that time to allow 87 octane in engines that needed 100 octane or more for takeoff and climb. When 100, 100/130 & 115/145 octane fuels became widely available there was no longer a need for ADI and it was therefore for the most part, dropped.

Today we find ourselves in a somewhat similar situation to that of the late 30's and early 40's, not knowing if or when we may run out of 100 octane fuel. Then – they couldn't make high octane fuel fast enough in large enough quantities. Today we face environmental pressure to remove TEL from avgas, with a resultant decrease in octane. It is fortunate indeed that ADI exists because we know from the historical literature, with absolutely no doubt, that most of the largest of our piston engines today can use fuel with an octane rating at least 12 points below that of 100LL, and maintain an adequate operating margin against detonation at the same time. This is all made abundantly clear in the historical literature. In a paper written by Rowe in 1946 one of his conclusions was that "Water injection permits the use of 91 and 87 octane fuels in place of 100 octane for equivalent power ouput up to and including take-off power". This was confirmed during testing on the I0-520 in 1986 on automotive fuel with a MON of 86.5.

While water can be used alone, or alcohol alone, a 60/40 mixture of water/methanol was determined in the 1940's as being the most advantageous and it is this mixture that we used when we developed our ADI STC's in the 1980's. Alcohol provides Btu's to the charge, which is not supplied by water alone. Alcohol also provides oxygen, and lowers the freezing point. A 60/40 mixture brings the freeze point down to -40 Celsius. The low boiling point of straight methanol could give trouble from vapor lock within the ADI system. The addition of water raises the boiling point. Hence a 60/40 mixture was determined to be the optimum mixture.

There are a couple of different reasons as to why ADI will allow lower octane fuel, but for the most part it has to do with cooling. We cool engines either with a water jacket or with fins. Injection of water/methanol into the fuel/air charge or in the air induction system upstream of the combustion chamber is simply a third method of engine cooling. ADI cools the pistons, valves, plugs, cylinder deposits and the cylinder head itself, thereby suppressing detonation and pre-ignition, allowing either more power, or reduced octane. It is also thought to have something to do with a combination of the high latent heat of vaporization and some function of specific heat. Heat of vaporization of gasoline is about 150 Btu's per lb. Water/methanol is between 900 and 1100 Btu's per lb. Calculations conducted in the 1940's demonstrated that CHT cooling represents 30-40% of the available heat of vaporization. Latent heat of vaporization however is not the only factor involved.

Movement of the flame front is sensitive to different temperatures inside the combustion chamber and since ADI alters the temperature, it also alters the flame front. The flame front is accelerated when it passes over the hot exhaust valve and retarded as it passes over the intake valve. It is also accelerated as it passes over the hot center of the piston. The sidewalls of the combustion chamber appear to hold back the flame front as it absorbs heat. Therefore the flame front tends to advance as the sharp point of an egg instead of as a sphere.

As the gas is compressed and burned, it reaches a point where the flame front has moved 2/3rds of the way across the combustion chamber. From that point on, what happens depends on the temperature of the last gas to burn. This gas, if in a hot area, is ready to detonate with very little more flame movement. However if this gas is cooled or it's temperature is held back by use of a vaporizing cooling medium such as ADI, the flame front completes its travel without self-igniting, and thus with no detonation.

The general result of adding 60/40 water/methanol to the charge is to increase the power with constant manifold pressure. If the power is kept constant, the required manifold pressure decreases. This is thought to happen because water/methanol reduces the charge temperature, which increases the volumetric efficiency of the engine. The methanol also adds to the heating value of the fuel.

British documents from the Royal Aircraft Establishment referred to ADI as a dual fuel system. Low octane fuel being satisfactory for cruise, ADI serves to resolve the octane deficit at high throttle settings. So indeed it could be viewed as a dual fuel system.

During our testing of the I0-520 in the 1980's it was found that detonation may take place at cruise settings if the CHT's are allowed to approach red line. Therefore our ADI system, now being administered by Air Plains Services in Wellington, Kansas (www.airplains.com) is tied into the CHT's to automatically maintain a safe margin against detonation as it will activate if one or more cylinders approaches red line. A warning light on the instrument panel is activated to call the pilots attention to it. The pilot then enriches the mixture, opens the cowl flaps, or reduces power to reduce the CHT's.

There are other benefits to using water/methanol injection:

Engines that used it in the 1940's were reported as being "remarkably clean". There are few if any deposits in the combustion chamber, but those that are there are more easily removed. Fewer deposits makes pre-ignition less likely.

It may sound as if corrosion could be a factor given the corrosive nature of methanol. However when water/methanol is injected in proper amounts and under proper conditions there is no evidence of corrosion. This was confirmed by the engine manufacturers of the day and more recently in Continental I0-470 & I0-520 engines that were using ADI over a period of twenty years, from 1989 to 2009. Given that the fluid is immediately vaporized upon injection, ADI cannot be a cause of corrosion. As for the water, it should be pointed out that water is present anyway in the form of vapor as a normal product of combustion, about one gallon of water for each gallon of gasoline.

ADI reduces CHT by 30-40 degrees C, and may contribute to reduced ring wear. The additional oxygen present in the alcohol gives a "supercharging" effect resulting in a drop in the intake manifold air temperature. Additional benefits of ADI include reduced nitrogen oxide emissions, increase in mpg, and increased volumetric efficiency.

When operating with water/alcohol injection it may be necessary to lean the mixture to "Best Power", to regain power lost through over-richness. This is possible since internal cooling from a rich fuel mixture is no longer required.

Since one is displacing gasoline with the water/alcohol fluid, the net result is an increase in miles per gallon. Operating with ADI gives a smoother running engine, with consequently less fatigue to reciprocating parts.

The amount of anti-detonate necessary is actually quite small, approximately 1/3rd cc per minute, per cubic inch displacement. In the I0-520 and I0-470 approximately ½ gallon per engine per takeoff is the amount used. On an engine the size of the R-2800 between 1-2 gallons was consumed per takeoff. This will vary depending on when the pilot reduces power following takeoff. A large ADI tank is unnecessary given the relatively small amount of anti-detonate used.

From the historical literature generated mostly in the 1940's by Wright Aeronautical, Pratt & Whitney, the Royal Aircraft Establishment, and other researchers, it is abundantly clear that ADI will allow the use of lower octane fuel in engines originally rated on 100 octane or higher aviation fuel. There is no reason why it could not again be called upon to fill the octane gap that has confounded all attempts to replace 100LL over the course of the past twenty years. Indeed as mentioned earlier, ADI can easily make up an octane deficit of 12 points whilst some papers indicate as much as 15 points. Testing we conducted in the 1980's showed that modern 100 octane engines could safely operate on automotive gasoline of less than 87 MON.

Therefore it is safe to assume that ADI can easily make engines originally rated on 100 or more octane points perfectly safe on fuel, automotive or aviation, with an octane rating of 94, 91 or perhaps lower. FAA wanted more margin however so the STC's for our ADI systems were written for 91AKI minimum.

It should also be noted that testing has proven certain vintage engines that use non-hardened upper cylinder components such as valves, guides, and seats, will have a reduced service life without a metallic element in the fuel to provide lubricity during high operating temperatures. If only ½ gram of lead per gallon was used then vintage engines would not have to be sacrificed. Reducing lead content by 75% ought to be acceptable to environmental groups, though that would remain to be seen.

Bridging the octane gap is a simple matter with ADI. Clearly a fuel of 100 octane, a drop in replacement for 100LL would be preferable to modifications. This is exactly what happened in the 1940's with the development and subsequent manufacture in vast quantities of high octane leaded aviation gasoline. Once that happened, ADI became redundant, and for the most part, was abandoned. Today, heavily leaded fuel is clearly unacceptable. Given the political climate we face, ADI can be the solution to a problem that has vexed General Aviation for well over 20 years. The fact that it is old tech is irrelevant. Quite simply, it's a system that was proven beyond any doubt, many many years ago. There is no reason to believe that it would not work equally well today.

Bibliography

Van Hartesveldt, C.H, April 1949, Antidetonant Injection. SAE Quarterly Transactions Vol. 3, No. 2, Paper presented at the SAE Summer Meeting, French Lick, June 11, 1948.

Colwell, A.T, Cummings, R.E., & Anderson, D.E., SAE Journal (Transactions), Vol. 53, No. 6. Paper Presented at the SAE War Engineering Annual Meeting. Detroit. Jan. 8, 1945

Rowe, M.R., SAE Journal (Transactions), Vol. 54, No. 1. Paper presented at a meeting of the Southern California Section of the SAE, Los Angeles, August 24, 1945

Royal Aircraft Establishment, Farnborough Hants, Report No. ENG 4134, November 1945

Weatherford, W.D., & Quillian, R.D. Jr., SAE Combined Fuels and Lubricants and Transportation Meetings, Philadelphia, Novembrer 4-6, 1970.