the truth About why lead was added to Gasoline

BY GORDON MILLAR, P.E.

Of the letters I receive at *Classic Boating* with regard to vintage marine engines, at least half and maybe more are questions regarding fuel. Operators of vintage marine engines continue to be concerned about the use of modern automotive fuels in their historic engines. The questions about fuel are about evenly divided between concern that modern automotive fuels are unleaded and secondly, that they are higher in octane number than the fuels available for marine use when the engines were first put in service.

The weak link in our understanding of fuels for our vintage engines is the fact that although we can find old service and repair manuals and even manufacturing specifications for the engines in question back into the early 1920s, information about the fuels and the engines' fuel requirements seems to have faded into the fog of history.

If you are willing to accept a short answer to both questions, the use of automotive unleaded fuel and the impact of higher octane numbers on our engines, the answer is straightforward. The fuels we have today are superior in every way to the marine fuel of the 20s and 30s. If you accept this answer to these questions, there is no need to read on, but if you are interested in the technology behind the answer, give it one more shot.

A Brief History of Fuel Development

Atmospheric spark ignition engines, which as the name implies operated without any effective compression ratio, were first used for industrial applications in the 1850s. These engines were large, heavy, and totally unsuitable for any type of vehicular application. In 1861, Dr. Nicholas Augustus Otto designed and built the first compression engine with controlled ignition which operated on the four-stroke cycle principle which is still in use today in most production engines. By compressing the fuel-air charge, power output and efficiency were dramatically improved, but almost immediately ran into the limitation of explosive abnormal combustion due to the inability of the fuel available at the time to resist self-ignition.

Engineers struggled with the fuel limitation problem right up to and for most of World War I. From successive experiments and not a few disasters, it became clear that certain fuels were inherently more resistant to self-ignition than others. By selective refining, these fuels could be extracted from basic crude oil, and engines with compression ratios in the range of 4:5 could be successfully operated.

In the early 20s, two inventors working almost independently in England and the United States came to the correct conclusion that the more compact the fuel molecule, the higher the resistance the fuel was to destructive self-ignition. This realization triggered the search for refining techniques and fuel additives that would increase the resistance of fuel to the destructive effect of knock.

Thomas Midgely, working in Dayton, Ohio, under the direction of Charles F. Kettering, determined that the use of tetraethyllead as an additive would enhance the ability of gasoline to resist self-ignition and allow the use of higher compression ratios. The compression ratio race was on.

Tetraethyllead

Although in retrospect it oversimplifies the problem, Midgely observed that when the engine was operating normally, the exhaust flame was a light blue and almost clear. When the engine started to knock, the flame turned red and was more incandescent than the flame of an engine operating normally.

With this limited laboratory knowledge, Midgely searched for compounds which would color the flame blue. Over 1,000 compounds were tried, none of which really had much effect, until tetraethyllead was introduced in the fuel and found to be an extremely effective suppressor of abnormal combustion. In later years, we found that the color of the flame was really unimportant, but the control of the precombustion chemical reactions was the key to knock suppression, and tetraethyllead was enormously effective in this application.

Development of the Octane Number Scale

Shortly after the introduction of tetraethyllead to commercial motor fuels, engineers recognized they needed a means to measure the effectiveness of refining processes and the use of additives. Prior to 1929, fuels were rated using a test engine in which the compression ratio could be varied between 2.7:1 and 8:1. Measurement was in terms of HUCR (Highest Useable Compression Ratio). In 1929, almost concurrently with the development of the octane number scale, a single-cylinder test engine was designed under the guidance of the Society of Automotive Engineers Cooperative Fuel Research Committee (CRC) and manufactured by Waukesha Motor Company in Waukesha, Wisconsin. This single-cylinder test engine was a variable compression ratio, constant speed engine which rated fuels according to the just developed octane number scale.

The octane number scale of 0 to 100 represents how a particular fuel rates when compared to a blend of isooctane (100) and normal heptane (0). This octane number scale remains in use today, and although numbers are now achievable above 100, these numbers are determined in a somewhat different fashion. For the motor fuels available to us for use in our vintage marine engines, there is no need to discuss fuels with equivalent octane number ratings above 100. These fuels are used almost exclusively in aviation piston engines and for racing.

In the early 1930s, it became clear that a single testing technique for octane number did not always accurately predict the performance of a commercial fuel in automotive or marine application. Two separate tests for octane number both using the same test engine were developed. In the first case, the engine runs at 600 rpm with fixed ignition-timing and temperatures. This test technique is called the research method, or RON.

A second more severe test procedure operates the engine at 900 rpm with an automatic spark advance linked to compression ratio. This test technique is called the motor method, or MON. Both test techniques still compare a commercial fuel in question with the percentage of isooctane in a mixture of isooctane and normal heptane. For example, if the fuel under test matches the performance of a mixture of 80% isooctane and 20% normal heptane, then the fuel has an octane number rating of 80.

Most commercial fuels showed a difference between MON and RON of something in the range of eight numbers. A fuel might rate 80 by the motor method and 88 by the research method. This fuel has a sensitivity of eight.

From a technical point of view, the research octane number of a fuel tells us how the fuel will operate at light load, such as automotive city driving. The motor method tells us more about how a fuel will operate at higher engine speeds and under much heavier load. It is the motor method octane number (MON) that is important for marine engine application for the simple reason that marine engines operate at higher speeds and heavier loads far more often than their automotive counterparts.

What Do We See On the Pump?

In the 1950s or 60s, in conjunction with the initial efforts on the part of the government to control exhaust emissions, the Department of Transportation under Becky Anker-Johnson decided that consumers should know the octane number of the fuel they were buying. As is always the case, marketing departments like big numbers and campaigned to put the research octane number, RON, on the pump. Most of the technical world felt the lower motor method number, MON, was more appropriate and certainly more conservative. The federal government, with its inherent political wisdom, decided to simply add the numbers and divide by two, which resulted in a number for which no SAE or ASTM standard exists and is euphorically called the octane number index, ONI. Although this number tells us very little about the true performance of a fuel, it is nevertheless the criterion by which fuels are marketed in today's imperfect world.

The Real Role of Tetraethyllead

Tetraethyllead (TEL) and its close cousin tetramethyllead (TML) were both developed for the single purpose of eliminating abnormal combustion in the form of knock. Knock is the self-ignition of the fuel-air charge which is compressed by the flame front in a remote part of a combustion chamber and self-ignites with explosive force.

The introduction of tetraethyllead was not an easy task, as the deposits created by this additive fouled plugs, corroded valves, and generally wreaked havoc with the mechanical elements of a combustion chamber. Several decades of work went into the design of engines to successfully digest lead. These modifications included hardened valve seats and valve faces, interference angles between the valve and valve seat, counterbored valve guides to eliminate deposits on the valve stem and valve rotators which permitted valves to seat in a different position on each stroke of the engine and thus eliminate the microscopic stalactites and stalagmites that held valves open and contributed to valve burning.

Along with these modifications to the combustion chamber, scavengers were introduced with the tetraethyllead which consisted of the halides of chlorine and bromine, which under high temperatures combined with the lead into a soft, almost fluffy, material which was easily scavenged from the combustion chamber. Of great historical significance is the fact that at no time during the decades-long activity was tetraethyllead ever considered as a valve lubricant. That concept is a recent introduction to history and is a falsification of what actually happened. Tetraethyllead was developed exclusively to control knock.

On the rarest of occasions tetraethyllead may prevent valve seat recession if no hardened valve inserts are used, but almost every industrial engine, including our vintage marine engines, going all the way back to the 20s used hardened valve seat inserts. The number of engines in which valve seat recession is a problem in our vintage marine engine inventory is for practical purposes, zero.

Unleaded Marine Fuel

During the entire history of the vintage boat era, both boat builders and marine engine builders were enormously sensitive to the problems of fuel system corrosion. As refining processes changed to produce the higher octane number, it became clear that the fuels were not suitable for marine use as they reacted actively with the copper tanks used in virtually all marine applications. As a result, refiners offered to the marine industry and made available at dockside pumps an unleaded straight run gasoline with a motor octane number between 72 and 80. Although this number seems low by today's standards, it was perfectly acceptable in the 6-1/2,7:1 compression ratio engines in what is now the vintage boat era.

This fuel was unleaded, as the marine engines of the time had not yet benefited from the mechanical design changes which were due to appear towards the end of the wooden boat era. Although today boat owners are urged to add a lead substitute to their fuel to "replace the tetraethyllead," the truth is that all of our vintage engines were designed to run primarily on unleaded marine fuel which was marketed dockside until about 1955, and no additives whatsoever are necessary when today's unleaded motor fuels are used.

The Influence of Combustion Chamber Design

Throughout the history of internal combustion piston engine design, combustion chamber shape has been a major consideration. In the early low compression engines, there was a lot of freedom in how to shape a combustion chamber because the clearance volume was large. As compression ratios increased, however, the clearance volume decreased and combustion chamber shape became extremely critical.

Although there are as many valve geometry configurations as there are engine designers, they all boil down to two generic arrangements. The first is the traditional side valve L-head design where the valves are located in the block with small recesses in the cylinder head to accommodate valve motion. The L- or flathead combustion chamber has a large surface to volume ratio and little or no turbulence. In technical terms, this combustion chamber shape is a quiescent chamber. The spark plug is usually located in the cylinder head between the valves and the flame front proceeds from the point of ignition across the chamber in a uniform steady motion.

Flat head engines can seldom be built with compression ratios much over 9 or 9½ without fairly complicated machining geometry. Flat head chambers also require as much as forty degrees of spark advance and their high propensity to knock is tempered only by the large quench area of the piston, which is a high price to pay in fuel economy for the offsetting lower costs in manufacturing.

The overhead valve combustion chamber which appeared very early in the engine design game is a very compact combustion vessel with a low surface to volume ratio. This type of combustion chamber employs a great deal of swirl and turbulence and very short flame front travel. As a result of these characteristics, spark advance curves tend to be more in the twenty-five degree range and the chambers have a somewhat lower octane number requirement than the flat head engines at the same compression ratio.

In addition to the good breathing characteristics of an overhead valve combustion chamber, the possibility also exists for measurably higher compression ratios without the necessity for a super fussy machining effort. Compression ratios as high as 11 or 12 are not uncommon in racing engines, and even at these ratios the compact combustion chamber has manageable octane number requirement and good breathing.

Most high performance engines in both automobiles and other vehicles are of the overhead valve configuration either in the form of a pancake, a pent-roof, or hemispheric design. Two very famous engines, the Oldsmobile Rocket introduced in 1948 and the Chrysler Hemi of a year or two later, pushed production compression ratios into the range of 10 and operated satisfactorily on the leaded premium fuels of those years. Even today, the Chrysler Hemi is considered one of the most powerful and best designed engines found in marine application.

Vintage marine engines are split roughly in half between flat head and overhead valve designs. Chris-Craft, for whatever their reasons, stuck relentlessly to the flat head design up through the mid-50s, when they introduced the Chris-Craft version of the small block Chevrolet in the form of the 185hp Chris-Craft 263.

Almost every marine engine builder, Kermath, Scripps, Gray Marine, and Chrysler, gravitated much earlier to the overhead valve design, although for a time, some builders offered both versions in the marine engine lineup.

The success of the overhead valve engine configuration and its ability to operate at higher compression ratios with modest octane number requirement has pretty well dictated that portion of engine design architecture for the past two decades. Even lawn mowers and other small engine-powered devices have gravitated to the overhead valve design in spite of the somewhat increased complexity and cost which consumers obviously feel is worth the price.

Reformulated Fuels

Lurking on the horizon of the fuel landscape is the introduction of reformulated fuels (RFG) which are designed to reduce emissions without the need for the intense cleansing action of the three-way catalytic converters. These fuels which have already been introduced in California are designed primarily for use in vehicles that are not equipped with emission controls and have been successful in reducing emissions by measureable amounts.

The question obviously arises of whether the reformulated fuels will in any way pose problems in the operation of vintage marine engines when they become the standard automotive fuel of the next century. In a nutshell, the answer is probably no, but as with every projection, there is always some risk that problems not yet identified might appear. In projecting the impact of reformulated gasoline, one is reminded of a notice printed in the *London Times* several years ago, "The regular meeting of the London Clairvoyant Society has been canceled due to unforeseen events."

Reformulated gasoline is designed to reduce emissions from vaporization of the raw fuel by lowering the Reid vapor pressure to the range of 7.0 to 7.4 psi. Normal gasolines can go as high as 13 psi. In addition to lowering the vapor pressure, the reformulated gasolines also carry oxygenated compounds that provide more complete combustion so that the emissions of CO, unburned carbons and NO_x are reduced, and the task of the catalytic converter simplified.

The Use of Additives

I sometimes end up crossways with many friends in the marina business when I tell readers to run, not walk, from anybody who tries to sell them an additive for any purpose whatsoever. Most additives are nothing more than a light mineral oil with some Betty Crocker coloring and metallic additives which, at best, do no harm, and at worst, can cost you an engine rebuild. Some additives of methanol and ethanol can be used in areas of severe winter to prevent gas line freeze, but "you are carrying coals to Newcastle." Fuels sold in areas where winter is a problem already contain all the additives necessary to prevent fuel line freezing and provide good storage stability.

The idea that anything you can put in your fuel will lubricate the valves or the top end of the engine is sheer folly. Peak combustion temperatures easily reach 2,000°F. to 3,000°F. and any petroleum compound is vaporized at these temperatures and discharged through the exhaust system as CO_2 and water. I know from experience that testimony after testimony of users will attest to a horsepower improvement, a longer engine life, easier starting, and a host of other good things that happen when additive XYZ is added to their fuel or oil. When asked for engineering or scientific verification, it turns out none exists and the improvement is exclusively in the eyes of the beholder.

Having said this one more time, I expect the usual flood of critical commentary, but I stick to my guns. Put nothing in your tank except fuel and nothing in your engine except a premium quality, multi-viscosity motor oil. Anything else and you run the risk of disaster.

Final Comments

The unleaded motor fuels available today are extremely good with high octane number, exceptional corrosion resistance and pure to the extent that if they were edible, you would live your life disease-free.

As is always the case, something may accidentally get in your fuel system that does not belong there, but we are fortunate here in the U.S. to have the finest, purest, lowest cost fuel infrastructure available anywhere in the world.

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