Early in the 1970s, the Environmental Protection Agency (EPA) moved to phase out the use of lead-based additives in gasoline because of risks to the public from exposure to lead in automotive exhaust. The federal government required automotive manufacturers to adhere to stringent guidelines limiting exhaust emission levels. Catalytic converters became the standard method of control. However, fuels containing lead contaminated catalytic converters, making them incapable of controlling exhaust emissions. Removing lead additives from fuel solved this problem but created a second problem of low octane levels.

Before the phase-out, refiners added an average of 2.5 grams of lead to each gallon of leaded gasoline. From 1982 through 1986, the EPA reduced allowable levels to 0.10 grams per leaded gallon (gplg) with an anticipated ban by 1988.

The proposed ban posed a unique problem for many older spark-ignition engines still in use. In 1985, 1.8 million tractors, 271,000 combines and 750,000 trucks powered by gasoline engines were in use on farms throughout the U.S. Approximately 42% of the tractors were used in light duty applications, while nearly all combines received hard use. Truck engine use varied from light to hard.

The farming community expressed concern that such older engines, if operated on unleaded fuels, might experience premature failure. In response, Congress ordered a study under the 1985 Food Security Act conducted jointly by the EPA and the United States Department of Agriculture (USDA) to determine the effects of unleaded fuels and fuel additives on gasoline-powered agricultural equipment.

**Octane and Valve Lubrication**

Historically, tetraethyl lead was added to gasoline to boost the octane level. Octane ratings are a measure of the knock resistance of gasoline. Engine knock occurs when gases ahead of the flame front in the combustion chamber ignite spontaneously with an uncontrolled release of energy. Knock is avoided when the flame front begins at the spark plug and sweeps smoothly across the combustion chamber. Prolonged engine knock can lead to piston damage and ultimately engine failure. Typically, gasolines with higher octane ratings are used to alleviate this problem. Many fuel suppliers currently add upwards of 10% ethyl alcohol to unleaded gasoline to boost octane levels.

Lead not only boosted octane ratings, but also provided lubrication at the valve seat. Before the phase-out of leaded fuels, engine manufacturers selected valve seat materials with lead lubricating properties in mind. After lead was removed from gasoline, many of the older engines were found to experience excessive wear or recession at the valve seat. (See Figure 1.) Concern about valve seat recession motivated the 1985 study.

**Findings of the Joint EPA/USDA Study**

The joint study consisted of three principal parts: engine dynamometer testing, a farm engine-use survey and a cylinder head survey. The USDA selected engines for the dynamometer tests that were representative of...
Engines still in use on farms. Recreational vehicle (RV) owners' concerns prompted the EPA to select an additional engine for the study. Tractor engines selected included John Deere “B,” Farmall “H,” Ford “8N” and an International Harvester 240. Additional engines included a John Deere 95 (303) combine engine, a pre-1974 Chevrolet 292 truck engine and a pre-1984 General Motors 454 RV engine.

Contract investigators completed all testing and surveys during 1986 and 1987. Two outside consultants were employed to ensure that the tests were designed and conducted in an appropriate manner.

Accepted standards for duty cycles were used as guidelines for conducting the dynamometer tests. Each test was run for up to 200 hours depending on the progression of valve seat recession. At periodic intervals the tests were stopped to allow for valve train wear measurements. At the conclusion of testing the cylinder heads were removed for final measurements and to assess the amount and nature of combustion chamber deposits.

As expected, engines operated on leaded fuel containing 1.2 g/ul experienced minimal valve seat recession. No recession in excess of 0.006 inch was found in six of the engines tested.

Engine tests using low-lead fuel (0.10 g/ul) showed valve seat recession of up to 0.010 inch for exhaust valves of the General Motors 292 “A” truck engine. The remainder of the engines tested exhibited recessions no greater than 0.006 inch.

Engines operated on unleaded fuels with no additives experienced the greatest degree of valve seat recession with the exception of the Farmall “H” and the International Harvester 240. The cylinder head of the latter was found to be “harder” than most other heads purchased. When the tests were repeated, first with a “softer” head and then with one with cast iron valve seat inserts, valve seat recession was found to be excessive. Engines experiencing valve seat recession in excess of 0.015 inch included the Ford “8N,” International Harvester 240 (for tests conducted with the “softer” head and with cast iron valve seat inserts), General Motors 292 “A” (and “B” with a modified duty cycle), John Deere 303 and the General Motors 454.

**Non-Leaded Additives**

The study also tested two proprietary non-leaded additives manufactured by Lubrizol Inc. and E.I. duPont de Nemours and Company (DuPont). These additives,
at various concentrations, were tested in a variety of engines, including the John Deere 303, GM's 292 "A" and "B" and the GM 454. These tests indicated that the additives used at recommended rates provided some degree of protection. At four times the concentration recommended, Lubrizol's "PowerShield" additive eliminated valve seat recession.

Both additives produced engine deposits and increased phosphorous levels in the engine lubricating oil. Additionally, increased levels of sodium and sulfur were found in the lubricating oil with the use of the Lubrizol additive. These results raised several new questions as to the overall effectiveness of additives. Investigators concluded that with further product development the additives may have potential as substitutes for lead.

What Does All This Mean to Kentucky Farmers?

The ban on marketing leaded fuels has been postponed indefinitely as a result of the joint study, but farmers may find leaded fuel in short supply. In many areas of the state fuel distributors have already discontinued marketing leaded fuels largely because demand and regional economics are no longer favorable. As a result many farmers are finding it difficult to purchase leaded fuel. Leaded fuel is likely to account for only 10% of total sales in the 1990s.

EPA's report to the President and Congress (Oct. 1988) on the use of leaded/unleaded fuels in older agricultural equipment concluded:
- Low-lead gasoline (0.10 gpg) is adequate to avoid valve seat recession in most agricultural engines.
- A significant number of gasoline farm engines are vulnerable to excessive valve seat recession if operated on unleaded fuels.
- Non-leaded additives have potential as lead substitutes although further product development is warranted.

RECOMMENDATIONS

Farmers unable to purchase leaded fuel may wish to consider the following alternatives:
1. When possible, use diesel-powered equipment in place of gasoline-powered equipment that might be vulnerable under heavy load applications.
2. Use unleaded fuel of appropriate octane in place of leaded fuels where:
   - hardened steel valve seats (stellite) are present
   - soft valve seats are present and the engine is used specifically for light-duty applications or
   - where soft valve seats are present and low engine speeds (under 1700 RPM) are maintained.

3. To avoid damage in situations where the previous two recommendations do not apply:
   - reduce engine loading by shifting to a lower gear and reducing engine speed
   - enrich carburetor air-fuel mixture setting
   - maintain engine cooling systems and eliminate air flow restrictions which trap heat
   - overhaul the cylinder head sooner than expected, making sure to install hardened valve seats and disable valve rotators and/or
   - use a lead-free lubrication additive in unleaded fuels during periods of heavy use.

The study did not adequately address what owners should do about older engines vulnerable to exhaust valve seat recession when they must continue using these engines in high load applications and when they cannot afford the cost of a cylinder head overhaul or valve job. Their only recourse is to purchase and use lead substitute additives.

Lead replacement additives for unleaded fuels proved to be only partially acceptable when concentrations substantially above the product manufacturer's recommendations were used. While successful in reducing valve seat wear, they caused increased combustion chamber deposits when used in these higher concentrations. One salvation for owners of such equipment is the development of new additives since the 1985-87 USDA/EPA study.

The Use of Additives

Instead of using corrective measures to eliminate or reduce valve seat wear, farmers and RV owners may wish to consider the use of non-lead additives. EPA's report lists more than 80 additive manufacturers/distributors. Many firms marketing such additives originally purchased their formulations from either Lubrizol or DuPont.

Potential users of such products will have to rely on word of mouth or manufacturer/distributor claims. Few if any independent studies have been conducted to verify marketing claims. Farmers and RV owners are encouraged to consider the cost trade-off between using additives and perhaps performing an early cylinder head overhaul.

Guidelines to Determine Equipment at Risk

The survey also identified engines at risk when operated on unleaded fuel. These results are summarized in Tables 1 and 2. Although by no means complete, the tables should alert farmers with suspect engines in a large number of situations. If your engine or tractor model is not listed in either table, contact a local dealer or the original manufacturer if possible.
Local automotive machine shops and truck repair services may also be an excellent source of information.

**Caution:** Before the EPA phased out leaded fuels, some cylinder heads may have had valve jobs in which the original "harder" seats were replaced with "softer" ones. This may create problems for owners of equipment which was originally thought to be safe for operation on unleaded fuels.

Table 1. Engines Originally Manufactured with Hard Valve Seat Inserts (engines not vulnerable to valve seat recession)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Engine Models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ford Motor Co.</strong></td>
<td>all agricultural engines</td>
</tr>
<tr>
<td><strong>International Harvester</strong></td>
<td>Farmall H, M, Super H, Super M, W-4, W-6, W-9, 300, 350, 400, 450, 454, 464, 544, 574, 674 (four cylinder engines) and all 6-cylinder engines</td>
</tr>
<tr>
<td><strong>Minneapolis Moline</strong></td>
<td>most engines</td>
</tr>
<tr>
<td><strong>J.I. Case</strong></td>
<td>many engines</td>
</tr>
</tbody>
</table>

Table 2. Engines Originally Manufactured with Ordinary Cast-Iron (Soft) Valve Seat Inserts (engines vulnerable to valve seat recession)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Engine Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>John Deere</strong></td>
<td>all engines except those manufactured to run on LP gas (stellite seats were used in these cylinder heads, some of which are being used as replacement for gasoline engine cylinder heads)</td>
</tr>
</tbody>
</table>

**ACKNOWLEDGMENTS**

The cross-sectional drawing of a typical cylinder head was adapted from *Engine and Tractor Power* by Carroll E. Goering © 1989 American Society of Agricultural Engineering. Used with permission.

**REFERENCES**