United States
Environmental Protection
Agency

Office of
Air and Radiation
Washington DC 20460

October 1988

Air

EPA

Report to the President and Congress on the Need for Leaded Gasoline on the Farm

Table of Contents

Executive Summary

BACKGROUND

The Environmental Protection Agency's (EPA) phasedown of lead in gasoline (and previously proposed ban) have caused concern among owners of vehicles and equipment designed to use leaded gasoline that their engines might suffer valve recession if EPA bans lead in gasoline. Because this concern is most prevalent for these engines under heavy load, such as in agricultural service, a provision was placed in the 1985 Food Security Act (Act) requiring EPA, in conjunction with the United States Department of Agriculture (USDA), to conduct a study on the possible valve recession effects of unleaded and low-lead gasolines, as well as non-lead valve lubricating additives. Under the Act, EPA and USDA had to jointly publish the study. EPA then was required to hold a public hearing and accept comments on the study.

EPA hearings on the study, with USDA participation, were held in Rosslyn, Virginia; Des Moines, Iowa; and Indianapolis, Indiana during the first part of June, 1987. Thirty-nine persons testified, including staff for Senator Quayle and Representative Tauke, and the Lt. Governor of Indiana, John Mutz. Representatives of the American Farm Bureau Federation, the National Council of Farmer Cooperatives, Women Involved in Farm Economics (WIFE), the Indiana Farm Bureau, Inc., the Indiana Corn Growers Association, and the Indiana Beef Cattle Association were among those from the agricultural sector. The public comment period closed on August 10, 1987.

The Act also required EPA to evaluate the study results and comments in order to "make findings and recommendations on the need for lead additives in gasoline to be used on a farm for farming purposes, including a determination of whether a modification of the regulations limiting lead content of gasoline would be appropriate in the case of gasoline used on a farm for farming purposes."

EPA was also required to submit a report to the President and to the Congress, including the study, a summary of comments and EPA's recommendations.

REPORT SUMMARY

The study tested eight engines designed to use leaded gasoline on various fuels with and without lead, and on two additives. The study found leaded gasoline at the 0.10 gram per leaded gallon (gplg) standard was generally satisfactory for engine performance. The study also found that medium- and high-speed engines with soft valve seats and some high-speed truck engines with induction hardened cast-iron or soft steel valve seats will experience excessive valve-seat wear if operated on unleaded gasoline. Non-lead alternative valve lubricating additives demonstrated the ability to reduce wear, and, in one case, totally eliminated wear with a quadrupling of the manufacturer's recommended concentration. However, their use resulted in engine deposits with unknown implications.

A survey of farm engine use has shown that there were 1.8 million gasoline-powered tractors, 271,000 gasoline-powered combines, and 750,000 gasoline-powered trucks larger than one-ton capacity in 1985. Many of these engines are 20 years of age or older. Of the 1.8 million tractors, 42 percent are used exclusively in light-duty applications and can operate satisfactorily on unleaded gasoline. The other 58 percent would be vulnerable to excessive valve-seat recession if operated on unleaded gasoline, unless they are low-speed engines or have hardened exhaust valve seats.

A preliminary analysis of a survey of tractor engines suggests that 33 percent may have hardened valve-seat inserts. These would not be vulnerable to valve-seat recession with unleaded gasoline. The remaining 67 percent are potentially vulnerable if operated in medium- or heavy-duty applications.

All combine engines receive hard use and are likely to experience excessive valve-seat recession if they have cast-iron (soft) valve seats and are operated on unleaded gasoline.

Trucks receive a range of light to hard uses. Based on these engines tests, it appears that a large number of farm trucks could be vulnerable to excessive valve-seat recession if operated on unleaded gasoline.

Comments were received from a large number of organizations, including farm groups, state governments, equipment manufacturers, refiners, farmer cooperatives, additive manufacturers and fleet operators. In addition, over 600 written comments were received from individuals, some 60 percent of whom were owners of recreational vehicles. The main comment from all groups was a request that EPA not ban leaded gasoline. In some cases there were requests for an increase in the permissible lead level. There also were requests that EPA specify a minimum level of lead in gasoline. Data were presented suggesting that some leaded gasoline currently being marketed contains less than 0.10 gplg,

with some instances of no lead at all. The American Petroleum Institute wanted to keep the current 0.10 gplg quarterly average limit. Several commenters asked EPA to do more testing and one wanted EPA to develop a rating system for exhaust valve anti-wear additives.

The USDA, which participated in the joint study, also sent a letter to EPA. They want EPA to 1) not ban leaded gasoline; 2) take steps necessary to assure that companies continue to sell leaded gasoline to the farming community; 3) require a range of 0.10-0.15 gram of lead in each gallon of leaded gasoline; and 4) continue testing non-lead additives or work with others to establish an acceptable procedure for additive manufacturers to demonstrate overall efficacy of their products.

The suggestion by several commenters for more testing, including field testing, was not to suggest that EPA-USDA testing procedures were inadequate, but rather to more accurately pinpoint the possible engines at risk, or to test parameters such as idle mixture, or absence of valve rotators, as ways to retard valve recession. The only commenter objecting to EPA-USDA's results was Lubrizol, an anti-wear additive producer. Lubrizol took issue with the study's result that seemed to indicate their additive would have to be used at four times the recommended concentration to stop valve recession. They said that their own tests have shown their additive works at the recommended concentration.

After a review of the comments, EPA concluded that:

1) A significant number of farm engines are gasoline-powered. Many tractors, combines, and trucks would be vulnerable to excessive valve-seat recession if operated on unleaded gasoline.

2) Leaded gasoline at the 0.10 gplg level is adequate to avoid valve recession in most of these engines.

3) Exclusive use of unleaded gasoline can lead to valve recession in many engines designed for leaded gasoline when operated at medium to high engine speeds.

4) Some leaded gasoline could have significantly less lead than 0.10 gplg.

5) Leaded gasoline demand continues to drop. Many refiners are planning to drop leaded gasoline in selected regions of the country and market a mid-octane unleaded product. Leaded gasoline is expected to be only about 10 percent of total gasoline usage in the 1990's. At this level

of usage, leaded gasoline will probably become a specialty product and will become difficult to find. However, leaded gasoline will probably be found in areas or marketing outlets where the demand is greatest (e.g., farm areas).

6) Non-lead additives have significant potential as substitutes for lead although further product development work is warranted.

The following are recommended actions for users for reducing or eliminating valve-seat recession in farm equipment:

1) Where diesel-powered equipment is available, it should be used in heavy-duty operations in preference to gasoline-powered equipment that might be vulnerable to valve-seat recession.

2) Unleaded gasoline of sufficient octane may be used if an engine has the following:

   - Hard steel valve seats; or

   - Soft valve seats, but is used exclusively for light-duty, low-speed operations; or

   - Soft valve seats, but is a low-RPM engine (less than 1700 revolutions per minute (RPM)).

3) In situations where only unleaded gasoline is available, and for engines that will be vulnerable to valve-seat recession, take the following steps:

   - Reduce heavy loads on an engine by shifting down and reducing engine speed (i.e. take longer to do tasks that put a heavy strain on the engine).

   - Enrich the carburetor air-to-fuel mixture.

   - Keep engines in good repair and follow proper maintenance requirements, particularly with respect to the cooling system, and keep engines free from attachments that can restrict air flow and trap heat.

   - Use an alternative valve lubricating additive, where available, during periods of heavy use to reduce the risk or extent of damage.

   - Do a valve job sooner than planned. Install hard steel valve seats at the next engine overhaul. If the engine has valve rotators, have them removed or disabled.

At this time, the EPA does not have any final plans to ban leaded gasoline, but will continue to aggressively evaluate both the health effects of lead and the potential for engine damage from such an action. EPA will continue to monitor the lead content of leaded gasoline and will hold a workshop to discuss issues concerning valve protection for agricultural engines and the appropriateness of EPA's definition of leaded gasoline.

In addition to the workshop, EPA will continue to review data developed by the manufacturers of non-lead alternative valve lubricating additives and will meet with selected specialists and other interested persons to review the test data and identify ways to determine the efficacy of non-lead additives.

EPA will emphasize that engines designed for leaded gasoline will operate satisfactorily on unleaded gasoline at light loads, and low speeds, and that many (those with hard steel valve seats) will also operate satisfactorily on unleaded gasoline at any speed or load.

EPA will publicize information on engines at risk and issue recommendations on preventing valve-seat wear should leaded gasoline be unavailable. EPA will seek the assistance of the USDA in disseminating such information. EPA has consistently provided guidance to individual inquiries and will continue to do so.

I. INTRODUCTION

On March 7, 1985, the Environmental Protection Agency (EPA) issued a Final Rule promulgating a low-lead standard of 0.10 gram of lead per gallon of leaded gasoline (gplg) effective January 1, 1986, and an interim standard of 0.50 gplg effective on July 1, 1985. In addition, a proposal to ban leaded gasoline as early as January 1, 1988 was announced in a supplemental notice of proposed rulemaking. Throughout the lead phasedown program, concern has been raised that low-lead or unleaded gasoline may cause valve-seat recession in engines designed to operate on leaded gasoline. Since there are large numbers of older engines in the farm community that use leaded gasoline, the effect of the tighter lead phasedown standard and the proposal to ban leaded gasoline raised a great deal of concern. Section 1765 of the Food Security Act of 1985, (Pub. L. No. 99-198, Section 1765, 99 Stat. 1354, 1653 (1985)) (Act) required the EPA to jointly conduct a study with the U.S. Department of Agriculture (USDA) on the use of fuel with and without lead additives, and with alternative non-lead lubricating additives, in agricultural engines designed to operate on leaded gasoline.

In addition, the Act required that EPA, following issuance of the study, conduct a public hearing, solicit public comments, and submit a report to the President and the Congress with findings and recommendations on the need for lead additives in gasoline to be used on the farm for farming purposes.

This report summarizes the study and public comments, identifies agricultural engines that would be at risk if operated on unleaded gasoline, discusses actions to be taken by the EPA, and outlines potential solutions to prevent valve-seat recession when leaded gasoline is no longer generally available to farmers.

II. SUMMARY OF JOINT STUDY

The Joint EPA-USDA study consisted of three parts: Engine Dynamometer Testing, a Farm Engine-Use Survey and a Cylinder Head Survey. The work for all three parts of the study was completed mostly in calendar year 1986. Dynamometer testing started in June 1986 and was completed in early 1987. The farm engine-use and cylinder head surveys were performed in 1986. The total contracting cost was $830,000. Considerable time was spent in the oversight and management of the study by EPA and USDA officials.

In addition, technical advice and oversight were provided by two outside consultants to insure testing was performed appropriately. The consultants commented on the original program design, visited the test facility on several occasions and consulted on major program decisions throughout the study.

The farm equipment engines tested in the study were selected by the USDA and confirmed with industry experts regarding their acceptability in this type of a program. EPA selected a recreational vehicle (RV) type engine for testing due to the concern expressed by RV owners related to potential valve-seat recession if operated on unleaded fuel. Appendix 1, the joint EPA-USDA study and the contractor's report, contains additional information about the engines tested.

The dynamometer testing for the tractor and combine engines was designed to reflect a full range of tractor and combine use conditions. The duty cycle for tractors/combines was selected after consultation with industry and agricultural experts as well as representatives from universities and USDA. The farm truck duty cycle represented normal conditions for farm trucks larger than one-ton capacity. The RV duty cycle was developed to represent typical RV engine operation.

The study analyzed the potential for mechanical problems, including valve-seat wear, that may result from using various gasoline fuels in farm machinery. In summary, engine dynamometer testing found that the engines generally performed satisfactorily on low-lead gasoline at the 0.10 gram per leaded gallon (gplg) standard.

The study also found that medium- and high-speed engines with soft valve seats and some high-speed truck engines with induction hardened cast-iron or soft steel valve seats will experience excessive valve-seat wear if operated exclusively on unleaded gasoline. Non-lead alternative lubricating additives were found to reduce, and in one instance completely eliminate, valve-seat recession when used in a high enough concentration in the unleaded gasoline. Appendix 1 has additional information about duty cycles used and test results.

The Farm Engine-Use Survey conducted by the USDA National Agricultural Statistics Service determined the number and use patterns of agricultural machinery on farms. The survey obtained information about tractors, combines, and trucks.

The survey showed 2.6 million tractors on farms in 1985 were powered by diesel engines. The survey also showed that in 1985 there were 1.8 million gasoline-powered tractors, 271,000 gasoline-powered combines and 750,000 gasoline-powered trucks with greater than 1-ton capacity being used on farms. The survey also showed that about 42 percent of the gasoline-powered tractors are used exclusively in light-duty tasks and therefore have little risk of valve-seat recession. All combine engines receive hard use and trucks receive a range of light to hard uses.

The Radian Corporation conducted the Cylinder Head Survey which showed that 33 percent of all gasoline-powered tractors may have hard valve seats. These would not be vulnerable to valve-seat recession.

On April 28, 1987 the EPA issued a Federal Register notice announcing the availability of the Joint EPA-USDA study that presented data on the testing which had been recently completed at the National Institute for Petroleum and Energy Research (NIPER). The Federal Register notice also solicited responses on the following specific questions:

1. Suitability of the engine tests:

(a) Were the number and types of engines tested adequate to assess valve-seat recession on farm machinery?

(b) What is the suitability of the duty cycles used and application of the test results to actual in-use conditions?

(c) What is the adequacy of 0.10 gplg of gasoline to protect farm machinery from valve-seat recession?

(d) What is the potential usefulness of non-lead additives to protect engines from valve-seat recession or other problems which may occur if the engines are operated with unleaded fuel?

2. The GM 292 engine experienced most of its recession during the unleaded fuel test in cylinders number 5 and 6. Is there anything in the design of this engine that would cause these cylinders to recede more than others? Does the problem relate to the cooling system, carburetion system and/or valve train design? Would these designs be considered typical of other truck engines used for farming purposes?

3. The unleaded test results showed little or no recession on tractor engines which did not have valve rotators, while other engines tested which used valve rotators showed substantial recession. If engines were designed to use valve rotators and they were removed, what effect on engine performance or durability would result? What is the importance of valve rotators regarding valve-seat recession?

4. Valve-guide wear appeared to increase while operating on unleaded fuel. Were the increases experienced typical of valve-guide wear during 200 hours of use? Would one expect the wear to continue if additional hours were accumulated or was this wear due to initial break-in of the guides? What performance problems would be expected with the level of valve-guide wear found in this study?

5. The GM 292-A engine, when tested on 0.10 gplg gasoline, experienced a head gasket problem and an increase in recession. Can the intake and exhaust valve-seat recession before and after the gasket was replaced be attributable to the head gasket problem? In general, is a head gasket failure likely to cause valve-seat recession?

6. What other problems may contribute to valve-seat recession besides fuel type? Specifically address the role of air-fuel ratio and the role of other factors that affect heat in the engine.

7. During the additive testing, increases in sodium, sulfur, and phosphorus content in the oil were experienced. Will these elevated levels have an impact on engine components or performance?

8. Additives tested increased deposits in the combustion chamber and on the valves. What effect might these deposits have on engines?

9. Two additives demonstrated an ability to reduce valve-seat recession. Are there any other additives that may also reduce recession?

10. Other parameters measured, including valve spring force and height, showed greater changes from their original levels when operated on unleaded gasoline than when operated on leaded gasoline. Were any of these changes outside acceptable limits? What performance problems would be expected if any? What is the normal deterioration of valve spring force and height?

11. Other factors to be considered:

(a) What is the cost of rebuilding engines to repair valve assemblies due to valve recession?

(b) How much wear can a valve seat withstand before the cylinder head will need to be replaced or valve-seat inserts installed? Is this amount of wear normally limited by available material in the valve-seat area or by the amount of valve lash adjustment available?

(c) What is the future availability and cost of non-lead additives to protect engines against valve-seat recession?

(d) What is the assessment of future sales and prices of leaded gasoline?

(e) How viable (availability, safety, and cost) are leaded additives marketed in consumer-sized packages?

III. SUMMARY OF COMMENTS

Commenters at the public hearings included local and national farm groups, individual farmers, state governments, equipment manufacturers, refiners, farm co-ops, additive manufacturers and fleet operators. (See Appendix 2 for a list of commenters and their affiliations.)

The majority of the written comments were from individuals that own trucks, recreational vehicles, farm equipment, boats or automobiles that were designed to use leaded gasoline. Written comments were also received from the Lubrizol Corporation and the International Society for VEHICLE Preservation (ISVP), which had also testified at the public hearings. In addition, the American Petroleum Institute, Sun Refining and Marketing Company, local governments, state extension services and other additive manufacturers submitted written comments. A listing of the commenters is in Appendix 2.

In addition to the comments from various organizations, EPA also received comments from nearly 600 individuals who also asked EPA not to ban leaded gasoline. Some commenters requested an increase in the allowable lead level from 0.10 gplg to as high as 0.50 gplg. Others felt that the EPA should do more testing to both identify which engines are at risk, as well as to provide a solution for the farmers in terms of an alternative valve lubricant to lead.

The major reasons given by commenters for not banning leaded gasoline were that it costs a great deal to replace or repair recreational vehicles and farm equipment, and that most older equipment which uses leaded gasoline is located in areas that are not heavily populated, and therefore, that the health benefits of a lead ban would be limited.

Table 1 is a breakdown of the types of equipment owned by the individuals which submitted comments. The percentages refer only to individuals and do not reflect the number of organizations which have commented, such as the American Farm Bureau Federation.

TABLE 1

Type of Equipment	% of Comments
Recreational Vehicle	61%
Farm	14%
Car	4%
Truck	3%
RV, Farm and Truck	16%
Boat	1%
Miscellaneous	1%

Response to Questions

The following comments are responses to the 11 questions raised in the *Federal Register* notice announcing availability of the test results.

1. Suitability of Engine Tests:

Question: (a) Were the number and types of engines tested adequate to assess valve-seat recession on farm machinery?

Comments: (1) American Farm Bureau Federation (AFBF) - the engines selected for the study are representative of those found on farms.

(2) ISVP - the number and types of engines tested were not adequate.

(3) Lubrizol Corporation (Lubrizol) - the selection of engine types is reasonable, although too few repeat tests on fuels were run.

(4) Polar Molecular Corporation (Polar Molecular) - the types of engines tested were adequate.

(5) Professor Lien (Purdue University) - the number of engines tested was not sufficient to assure statistical reliability.

(6) Indiana Farm Bureau, Inc. - too few engines were tested, and the tests were not of sufficient duration.

(7) Indiana Farm Bureau Cooperative Association, Inc. - the engine selection was not representative of farm machinery designed for leaded gasoline.

Response: The Agency agrees that repeat tests on engines would have been desirable, and that if more engines types were tested, we would have a higher statistical reliability of the data. Unfortunately, we were constrained by time and cost factors and could not increase the scope of the testing.

We believe the testing that was performed, while not conducted on a large engine sample, provided reliable information on the effects of particular fuels on engines designed for leaded gasoline.

Question: (b) What is the suitability of the duty cycles used and application of the test results to actual in-use conditions?

Comments: (1) Congressman Tauke - the cycle could be an underestimate if reports are correct that the test was not run at a high enough stress level compared to actual use. In addition, the cycle used was an old test that required engines to run at low engine speeds, which results in low wear rates.

(2) AFBF - the duty cycles used during the study fairly represent actual farm use.

(3) ISVP - the tests were in the low and low-medium range of the duty cycle, and thus inconclusive.

(4) Ethyl Corporation (Ethyl) - the tests are insufficiently rigorous to predict that premature valve failure will not result from the use of gasoline containing only 0.10 gplg. The test conditions are not rigorous enough to predict engine performance under a variety of actual operating conditions.

(5) Polar Molecular - the high ends of the duty cycles were representative of how engines may be used. The low end and idle conditions which are prevalent 95 percent of the time that such engines are operated is not represented at all.

(6) TK-7 Corporation (TK-7) - a little broader range of tests should be performed with more hours. The tests should be run at 70-80 percent of maximum power, not 40-50 percent.

Response: Tractor and combine engines were run at the governor speed, not a low engine speed. The duty cycle was not intended to be the harshest cycle one could imagine, rather it was meant to represent the typical parameters of medium and heavy in-use operations. The farm truck and RV cycles were developed to be representative of engines in-use. The cycles included light and heavy modes. Therefore, we believe that the test results are valid.

Question: (c) What is the adequacy of 0.10 gplg of gasoline to protect farm machinery from valve-seat recession?

Comments: (1) Congressman Tauke - if the lead levels are less than 0.10 gplg, farmers would have problems.

(2) AFBF - wear levels could be reduced to acceptable levels in all engines with the use of low-lead gasoline. The 0.10 gram per gallon standard will give the needed margin of protection for older farm equipment. The 0.10 gplg is the minimum amount needed to protect older engines.

(3) ISVP - stated that a number of engines would have a tendency to fail under hard use even at concentrations of 1.1 gplg, and asked the rhetorical question "can you imagine what is going to happen when they have only .1 gplg to protect them?" ISVP recommended a minimum standard of 0.10 gplg.

(4) Ethyl - disagrees with EPA-USDA report that gasoline containing only 0.10 gplg provides adequate protection to exhaust valve seats. The 0.10 gplg level is required in engines operating under moderate conditions. The 0.10 gplg level helps, but does not fully protect engines operating under moderate to severe conditions. The 0.10 gplg level plus methylcyclopentadienyl manganese tricarbonyl (MMT) 1/ at a concentration of 0.10 gram per gallon of manganese will protect valve seats under severe operating conditions.

(5) Lubrizol - from the data developed only general trends can be drawn.

(6) Polar Molecular - 0.10 gplg is adequate to protect farm machinery from valve-seat recession except in very extreme operating conditions.

(7) Indiana Farm Bureau, Inc. - the EPA-USDA test indicates that 0.10 gplg is adequate for engine valve protection.

(8) National Council of Farmer Cooperatives - 0.10 gplg proved satisfactory for the engines tested.

(9) E.I. DuPont de Nemours and Company (DuPont) - 0.10 gplg has not been adequately demonstrated to preclude valve-seat damage at normal service conditions. The minimum should be 0.20 gplg for every gallon to avert valve-seat damage at moderate to severe conditions.

1/ MMT is a manganese compound which enhances octane and appears to reduce valve-seat recession when used in combination with lead.

(10) Professor Lien (Purdue University) - the 0.10 gplg level is marginal; it would take care of most engines studied without causing undue wear and damage to the engine. A level of 0.20 gplg is probably needed to protect all engines.

(11) Navistar International - a significant number of failures will occur in older engines designed for leaded gasoline if lead content is restricted to 0.10 gplg. Recommend a minimum lead level of 0.20 gplg.

(12) Indiana Farm Bureau Cooperative Association, Inc. - cannot be sure that 0.10 gplg will be adequate to protect farm equipment. We interpret the data to say that it is not and request that the lead limit on leaded gasoline be set at 0.25 gplg until risk can be minimized.

(13) Indiana Beef Cattle Association - 0.10 gplg is satisfactory.

(14) Union Oil Company of California (Unocal) - lead levels below 0.10 gplg will not adequately protect non-hardened valve seats in engines run under severe conditions. Under more moderate conditions 0.10 gplg is adequate.

Response: As previously stated, the duty cycles were chosen to represent the range of operating conditions normally encounted in agricultural service. Certain extremely severe conditions may exist for which 0.10 gplg would not be enough to eliminate valve-seat recession. However, for most engines and operating conditions the data demonstrate that 0.10 gplg will be adequate.

Question: (d) What is the potential usefulness of non-lead additives to protect engines from valve-seat recession or other problems which may occur if the engines are operated with unleaded fuel? (Also see questions 7 and 8).

Comments: (1) AFBF - the study failed to produce much good news relating to the use of additives to replace lead. The AFBF does not feel that lead substitute additives are currently an acceptable alternative for farmers and ranchers.

(2) ISVP - Lubrizol has provided new data showing positive results for their "PowerShield" additive.

(3) Lubrizol - new data on their additive contradicts EPA-USDA results and shows that it protects engines from valve-seat recession at Lubrizol's recommended concentration. In addition, Lubrizol states that three U.S. Original Equipment Manufacturers (OEM) have confirmed satisfactory performance at Lubrizol's recommended concentration. (The OEM's were not identified in the comments submitted by Lubrizol. Follow-up checks revealed that only one of the OEM's did any testing and only two of the three OEM's are recommending using the additive at this time.)

(4) Polar Molecular - reported they have an additive that proved effective in tests the company had conducted.

(5) Unocal - DuPont's additive, DMA-4, at the recommended concentrations in Unocal's anti-wear additive known as Valve Saver, is equal to or better than 0.10 gplg for control of exhaust valve-seat recession.

(6) National Council of Farmer Cooperatives - testing of alternative additives to date does not show conclusively that any alternative to lead would perform the valve lubricating function.

(7) Indiana Farm Bureau, Inc. - no additive tested to replace lead gave an adequate measure of protection.

(8) Indiana Beef Cattle Association - none of the additives tested gave an adequate measure of protection.

(9) American Petroleum Institute - the study's conclusion, that some older engines may benefit from the addition of lead or equivalent additive treatment, appears consistent with other test results reported in the technical literature.

(10) Professor Lien (Purdue University) - the two additives did not measure up to the performance of the lead additive in controlling valve-seat recession.

(11) Iowa Secretary of Agriculture - research and testing should be conducted and encouraged for an alternative acceptable additive.

Response - Although important questions remain unanswered about the additives, the study found that they reduced valve-seat recession and thus have significant potential as substitutes for lead. EPA will continue to review manufacturers' data and will meet with interested persons to review the test data and identify ways to determine the efficacy of non-lead additives.

Question: 2. The GM 292 engine experienced most of its recession during the unleaded fuel test in cylinders number 5 and 6. Is there anything in the design of this engine that would cause these cylinders to recede more than others? Does the problem relate to the cooling system, carburetion system and/or valve train design? Would these designs be considered typical of other truck engines used for farming purposes?

Comments: (1) Professor Lien (Purdue University) - the reason for the valve-seat recession during the unleaded fuel test in cylinders 5 and 6 of the GM 292 engine could be caused by many things. Some of which may be:

a. Restricted coolant flow for some reason in the head and block around these two cylinders.

b. Variable air/fuel (A/F) ratio due to restrictions in the intake manifold serving these two cylinders.

c. Possibly the exhaust manifold may have restrictions providing high exhaust temperatures in those two cylinders.

d. This condition cannot be considered typical without testing additional engines of the same type.

Response: The causes of the valve recession in cylinders 5 and 6 are still unknown, but could possibly be the result of variations in A/F ratios and temperature, or other factors unrelated to the usage of unleaded gasoline.

Question: 3. The unleaded test results showed little or no recession on tractor engines which did not have valve rotators, while other engines tested which used valve rotators showed substantial recession. If engines were designed to use valve rotators and they were removed, what effect on engine performance or durability would result? What is the importance of valve rotators regarding valve-seat recession?

Comments: (1) ISVP - valve recession will occur quicker on engines with rotators when run on unleaded gasoline.

(2) Professor Lien (Purdue University) - removing the valve rotators would be beneficial with the use of unleaded fuel unless an additive with lubricating properties for unleaded fuel was developed.

Response: The comments are consistent with EPA's opinion.

Question: 4. Valve-guide wear appeared to increase while operating on unleaded fuel. Were the increases experienced typical of valve-guide wear during 200 hours of use? Would one expect the wear to continue if additional hours were accumulated or was this wear due to initial break-in of the guides? What performance problems would be expected with the level of valve-guide wear found in this study?

Comment: (1) Professor Lien (Purdue University) - the increased valve-guide wear while operating on unleaded fuel could be caused by the lack of lubricating properties of the leaded fuel.

Response: Insufficient information was submitted to reach any conclusions different than what was in the study, namely that unleaded fuel resulted in some increased valve-guide wear.

Question: 5. The GM 292-A engine, when tested on 0.10 gplg gasoline, experienced a head gasket problem and an increase in recession. Can the intake and exhaust valve-seat recession before and after the gasket was replaced be attributable to the head gasket problem? In general, is a head gasket failure likely to cause valve-seat recession?

Comments: None

Response: It is inconclusive whether the head gasket failure caused the valve-seat recession. Since the head gasket failed at about the time recession occurred on the GM 292A engine, it may have contributed to the valve-seat recession. Excessive heat may contribute significantly to valve-seat recession. The head gasket failure is one factor which could cause excessive heat. EPA ran another GM 292 engine on 0.10 gplg. This second engine (with no gasket problems) showed little or no valve-seat recession using 0.10 gplg.

Question: 6. What other problems may contribute to valve-seat recession besides fuel type? Specifically address the role of air-fuel ratio and the role of other factors that affect heat in the engine.

Comments: (1) Professor Lien (Purdue University) - other problems that may contribute to valve-seat recession besides fuel type may be:

a. Engine speed, i.e., frequency of valve opening and closing.

b. Height and contour of cam on the camshaft indicating how high the valve is lifted by the cam and how fast it closes.

c. Strength of valve spring and ability to conduct heat away from the valve guide.

d. Very lean mixture.

e. Possibly detonation.

(2) ISVP - humidity, altitude and temperature could affect valve-seat recession.

(3) Lubrizol - other items which affect valve-seat recession besides fuel type are: preparation/grinding of valves and seats, hardness/metallurgy of seats, head casting uniformity, heat transfer through individual valves/seats, use of valve rotators, exhaust valve temperature, air/fuel ratio, speed/load, ignition timing, exhaust gas recirculation (EGR) rate and valve spring loading.

(4) Winsert, Inc. (a valve-seat-insert manufacturer) - recession is not only dependent upon the hardness of the valve seat but also the chemistry and metallurgical composition of the seat area and the hot-hardness (i.e., the hardness measured when the metal is hot). High combustion chamber temperature is a critical factor in determining valve-seat wear.

Response: EPA agrees that a number of design and operating factors probably contribute to valve-seat recession.

Question: 7. During the additive testing, increases in sodium, sulfur, and phosphorus content in the oil were experienced. Will these elevated levels have an impact on engine components or performance?

(1) ISVP - the increase in the oil of sodium, sulfur and phosphorus will not have a negative impact.

(2) Lubrizol - there were no adverse effects with respect to cleanliness or wear or oil deterioration due to increased sodium levels. Sulfur increase was less than what is typically found in gasoline. Phosphorus is not present in the additive and should not increase in the oil.

(3) Professor Lien (Purdue University) - recommendations resulting from a cleaned up, OEM equipped engine in the laboratory cannot be translated directly to the farm tractor in the field with several hundred hours operation since overhaul. Extensive tests above and beyond those reported in the EPA and EPA-USDA reports should be conducted to determine the additive effect of elevated levels of sodium, sulfur and phosphorus in the crankcase oil on engine components and/or performance.

(4) Polar Molecular - concerned that sodium, sulfur and phosphorus in the two additives tested could cause corrosive wear, especially in engines that are operated at heavy duty infrequently and have long periods of intermittent light use or storage. The presence of sodium would be expected to enhance water retention in the crankcase oil, which could increase corrosive wear of cylinders and rings.

Response: The comments are varied, ranging from no adverse impact to possible corrosion. The range of comments precludes making definitive conclusions. Additional testing by the manufacturers is warranted.

Question: 8. Additives tested increased deposits in the combustion chamber and on the valves. What effect might these deposits have on engines?

Comments: (1) Lubrizol - evaluation to the equivalent of 10,000 miles in a variety of engine dynamometer and vehicle tests did not indicate any concern for secondary effects with respect to emissions, octane requirement, spark plug fouling, general engine cleanliness or used oil properties.

(2) Professor Lien (Purdue University) - deposits could cause the compression ratio to be increased, the valve may not close properly and deposits forming in the valve guide could also cause valve sticking with ultimate valve failure.

(3) Polar Molecular - deposits would create additional octane requirement, increased hydrocarbon emissions and may cause exhaust-valve burning.

(4) Unocal - tests conducted by Unocal on the DuPont Additive (DMA-4) showed the additive did not increase octane requirement. During Unocal's testing no problems associated with intake valve deposits were observed. According to Unocal, data supplied by DuPont indicate that the effect of DMA-4 on intake valve deposits when tested in the Opal Intake System is to decrease deposits when the concentration of DMA-4 is increased.

Response: Combustion chamber deposits can cause Octane Requirement Increase (ORI). During the testing at NIPER combustion chamber deposits were observed but it is not clear from the testing whether the deposits would significantly alter octane requirements. During the testing of the DuPont additive one intake valve was unable to close completely and was beginning to burn. The full implications of the deposits, including the potential for eliminating them, are not known.

Question: 9. Two additives demonstrated an ability to reduce valve-seat recession. Are there any other additives that may also reduce recession?

Comments: (1) Ethyl - 0.1 gram of lead plus 0.1 gram of MMT per leaded gallon will protect engines against valve-seat recession during severe duty cycles.

(2) Two other manufacturers of additives (Polar Molecular and TK-7) asserted that their products, Duralt and TK-7 respectively, would also reduce valve-seat recession.

(3) National Council of Farmer Cooperatives - urged EPA, USDA and private industry to continue testing alternative additives.

Response: EPA will continue to review data submitted by the manufacturers. At this time, EPA has data on the two additives tested in the EPA-USDA study and from Lubrizol, Unocal (DuPont additive), Ethyl (lead plus MMT), and TK-7.

Question: 10. Other parameters measured, including valve spring force and height, showed greater changes from their original levels when operated on unleaded gasoline than when operated on leaded gasoline. Were any of these changes outside acceptable limits? What performance problems would be expected if any? What is the normal deterioration of valve spring force and height?

Comments: (1) ISVP - hundreds of thousands of engines would need to be looked at to determine if the wear found in EPA's program is atypical. Additional research and funding is requested from Congress.

(2) Professor Lien (Purdue University) - excessive heat may also affect valve springs.

Response: Not enough information was submitted to reach any conclusions.

Question: 11. Other factors to be considered:

(a) What is the cost of rebuilding engines to repair valve assemblies due to valve recession?

Comments: (1) ISVP - cost of rebuilding an engine to repair valve-seat damage is from $1200-$1800.

(2) Polar Molecular - cost to repair valve assemblies may be $500. Although, cost of repairing an engine that's suffered damage due to corrosive wear is more like $1000-$2000.

(3) Professor Lien (Purdue University) - costs to service valves on a 4-cylinder engine would be $250-$300 for the machine shop. An additional cost of $500 or more for removing and replacing the cylinder head from the engine, transportation to and from the machine shop, or other related charges is to be expected.

Response: EPA concurs that the cost to repair valve-seat recession can be as high as $2,000. If the valve seats were replaced at the time of a scheduled general overhaul, then hard steel valve seats could be installed at an additional cost of a few dollars per cylinder.

Question: (b) How much wear can a valve seat withstand before the cylinder head will need to be replaced or valve-seat inserts installed? Is this amount of wear normally limited by available material in the valve-seat area or by the amount of valve lash adjustment available?

Comment: (1) ISVP - there are too many variables to accurately say how much valve-seat wear an engine can take.

Response: Not enough information was submitted to reach any new conclusions. Information from engine manufacturers presented in the joint EPA-USDA report indicates that a valve-seat overhaul likely would be needed after 75 to 200 thousandths of an inch of valve-seat recession, and some engines require valve adjustments after every 15 thousandths of an inch of wear.

Question: (c) What is the future availability and cost of non-lead additives to protect engines against valve-seat recession?

Comments: (1) ISVP - non-lead additives are expensive when they must be added by the consumer. If they are to be used, ISVP thinks they should be added to bulk gasoline.

(2) Polár Molecular - non-lead additives will be available.

Response: Additives which are sold in consumer-sized packages increase the price per gallon of gasoline between 6 cents/gallon to 39 cents/gallon. If the additives are introduced into bulk gasoline, the price increase could range from 1 cent/gallon to 22 cents/gallon.

Question: (d) What is the assessment of future sales and prices of leaded gasoline?

Comments: (1) ISVP - the price of leaded gasoline will slowly creep up. By January 1, 1989, the majority of gasoline with an exhaust valve anti-wear additive will be off the market.

(2) Crown Central Petroleum Corporation (Crown) - will continue to sell leaded gasoline as long as it is economically feasible and customer demand is sufficient.

(3) Polar Molecular - as the volume of leaded sales declines the price will go up accordingly, but shouldn't be prohibitive to the farmer; since he could use it only when he really needs protection.

(4) Sun Refining and Marketing Company - attrition of such engines has already regionalized leaded sales. Lead in urban areas will diminish without regulation. The sale of leaded gasoline will continue to fade.

(5) National Council of Farmer Cooperatives - thinks the refineries they are familiar with, like the cooperative refinery in McPherson, Kansas, will continue to supply low-lead gasoline as long as the demand is there. They think that Williams Pipeline will continue to allow low-lead gasoline to flow through its system. However, there's going to be a point in time when the demand will drop so low that they can't afford to have the product in inventory or we may not be willing to pay the price to either have that product refined and/or transported. Sales of leaded gasoline depend on economics. We don't really know how long leaded gasoline will be available. Availability of leaded gasoline is heavily dependent on how long it is carried by the interstate pipelines.

(6) Coastal Refining and Marketing Central Region, Coastal Mart, Inc., Central Region, Derby Refining Company Central Region - will continue to sell low lead regular gasoline to our wholesale distribution network, as well as our retail stations and stores until consumer demand diminishes sufficiently to make marketing of leaded gasoline unprofitable. Coastal would probably discontinue when leaded sales become 10-15 percent.

(7) Crown - staying in the leaded business depends on the demand, pipeline batch requirements, and actions of major refiners. It is unlikely that Crown would sell leaded gasoline if it were not available from the pipelines. The prices of leaded and unleaded are coming together on the wholesale level.

(8) Southern States Cooperative - it would be very difficult to supply leaded if market conditions ended the supply from pipelines. Would not be against blending lead themselves, but it is not likely.

(9) Indiana Farm Bureau Cooperative Association, Inc. - the price of leaded and unleaded is starting to stabilize. If leaded gasoline were no longer available from pipelines they would make it available if it could be justified from the standpoint of economics.

Response: It appears that while leaded gasoline volume will be declining there will probably be leaded gasoline available for areas where the demand is greatest. Availability in particular regions may depend on the willingness of pipelines to ship the product. The wholesale price of regular leaded gasoline is now generally greater than that of regular unleaded gasoline, and EPA expects this to be ultimately reflected in the retail prices.

Question: (e) How viable (availability, safety, and cost) are leaded additives marketed in consumer-sized packages?

Comments: (1) DuPont - DuPont will not sell tetraethyl lead to anyone planning to blend and package lead antiknocks in a consumer-sized container or planning to resell antiknocks for this purpose.

(2) ISVP - cost for leaded additives in consumer-sized packages should not exceed $2.95 a quart (usually enough to treat 20 gallons). From a health point of view, lead should not be on the market as a consumer additive.

(3) Ethyl - for more than 50 years, Ethyl Corporation has sold and distributed its lead anitknocks only to those companies properly trained and equipped to handle the chemical. Due to the potential health risks, Ethyl Corporation will continue to sell its tetraethyl lead and Ethyl MMT Antiknock Compound only to refiners and blenders. Ethyl Corporation does not intend to extend its metallic antiknock markets to include sales for use in consumer-sized packages. Sales of lead in concentrated canned additives are expensive, inconvenient and subject to consumer misapplication.

(4) Polar Molecular - lead is not the sort of product you want to handle in a consumer package.

Response: Commenters are not favorable to providing lead in a consumer-sized container. As long as leaded gasoline is available, there is very little need for such a product. Based on the comments from Ethyl and DuPont, its general availability is questionable. While such products are presently not regulated, should problems arise, regulatory action would be considered.

<u>Additional Issues Raised by Commenters</u>

In addition to the foregoing, the following are major comments which are not direct responses to questions raised in the <u>Federal Register</u> notice announcing the study's availability:

Comment: 1. Do not ban lead - nearly every comment received expressed concern over EPA's proposal to ban leaded gasoline. The commenters indicated they did not want EPA to ban leaded gasoline since data showed leaded engines would be harmed if operated on unleaded fuel.

Response: At this time EPA has no final plans to ban leaded gasoline. EPA will continue to evaluate both the health effects and potential for engine damage from such an action.

Comment: 2. Require a minimum amount of lead in leaded gasoline. DuPont and the State of Iowa provided data that showed some leaded gasoline (5-19 percent) is being sold with a lower level of lead than allowed by the 0.10 gplg standard.

In some instances no lead was found in gasoline being sold as leaded. Because of these data, commenters including USDA, Iowa Secretary of Agriculture, Indiana Farm Bureau Cooperative Association, Inc., ISVP, Marathon Oil, DuPont, Ethyl, and Harley Davidson commented that a minimum lead level should be required. They differed somewhat on the level of the minimum. In addition, ISVP suggested a range (both a minimum and a maximum) for each gallon of leaded gasoline.

Response: EPA will continue to monitor the lead content of leaded gasoline and will hold a workshop to discuss issues concerning valve protection for agricultural engines and the appropriateness of EPA's definition of leaded gasoline.

Comment: 3. Some commenters wanted to increase the average lead content or maximum allowable lead level.

(1) DuPont supports a 0.20 gplg minimum and 0.25 gplg maximum.

(2) The ISVP supports a 0.10 gplg minimum, 0.49 gplg maximum, and an average of 0.225 gplg.

(3) Indiana Farm Bureau Cooperative Association, Inc. supports a lead limit of no less than 0.25 gplg.

(4) Women Involved in Farm Economics (WIFE) supports retaining a little more than 0.10 gplg.

(5) Navistar International supports 0.2 gplg.

(6) Marathon Petroleum Company supports a minimum of 0.1 gplg and a maximum of 0.15 gplg.

(7) USDA supports a range of 0.10 gplg to 0.15 gplg.

Response: The EPA-USDA testing showed that 0.10 gplg (the current standard) is generally adequate to protect engines from valve-seat recession; therefore, EPA believes that there is no reason to increase the maximum allowable limit.

Comment: 4. ISVP commented:

(1) EPA should develop an equivalent rating system for exhaust valve anti-wear additives other than lead.

(2) EPA should promulgate regulations requiring posting at the pump of the equivalent effective exhaust valve anti-wear additive range.

Response: The EPA is willing to meet with anyone wishing to test non-lead additives to evaluate their efficacy and to help in the design of a testing program.

Comment: 5. National Council of Farmer Cooperatives commented:

(1) EPA and USDA should work together to test alternative additives.

(2) USDA should continue to inform farmers about this problem.

(3) EPA should avoid taking regulatory action that would cause the supply of leaded gasoline to disappear prematurely.

Response: EPA is willing to review and discuss all available test data on additives with the USDA and additive manufacturers, and to assist in the development of other test programs. At this time EPA has no final plans to ban leaded gasoline, and will widely disseminate this report and other information on how to reduce valve recession.

Comment: 6. Lt. Governor John M. Mutz, State of Indiana, asked EPA to keep the 0.10 gplg standard until a substitute additive is found, and indicated that the State plans on conducting a testing program.

Response: At this time EPA has no final plans to ban leaded gasoline.

Comment: 7. Department of Commerce, State of Indiana, believes a much more comprehensive study should be taken to examine the economic externalities of this policy. Specifically, the Agency should conduct field tests, determine more accurately which engines are at risk using low-lead and no-lead gasoline, perform a cost analysis of recession and related problems, test more engines under high load conditions, determine the impact of a phaseout on farming style trends and sort out the additive puzzle.

Response: EPA agrees that the study did not answer all questions related to the need for leaded gasoline. However, the suggestions listed go well beyond the scope of the study required by the Act. Nevertheless, EPA will continue to study the issue and is willing to meet with others to discuss available data on valve-seat recession and to advise in the development of testing programs to evaluate additives.

Comment: 8. Harley Davidson, Inc. said that motorcycles designed for leaded gasoline will be harmed if operated on unleaded fuel.

Response: At this time EPA has no final plans to ban leaded gasoline.

Comment: 9. United Parcel Service (UPS) was very much alarmed by the EPA-USDA results since they have about 49,000 delivery vehicles powered by engines designed for leaded gasoline. About 28,000 delivery vehicles are powered by the GM 292 engine. These trucks carry heavy loads up to 16,000 pounds per 100 horsepower, and remain in use for many years.

Response: Some UPS trucks could be damaged by unleaded gasoline. At this time EPA has no final plans to ban sales of leaded gasoline. Leaded gasoline is likely to be available long enough that UPS can retrofit most of its engines with hardened valve seats during scheduled overhauls.

Comment: 10. Winsert, Inc. agrees that if all engines convert to non-lead fuel, many will experience valve-seat recession problems unless the valve seats are replaced with better materials or a substitute additive can be found.

Response: At this time EPA has no final plans to ban sales of leaded gasoline.

IV. U.S DEPARTMENT OF AGRICULTURE COMMENTS:

The following are comments provided to the EPA by USDA (a copy of the letter forwarding these comments is in Appendix 3). USDA requests that EPA should: 1) not ban sales of leaded gasoline; 2) take steps necessary to assure that companies continue to sell leaded gasoline to the farming community; 3) require a range of 0.10-0.15 gram of lead per gallon of leaded gasoline; and 4) continue testing non-lead additives or work with others to establish an acceptable procedure for additive manufacturers to demonstrate overall efficacy of their products.

The following are responses to USDA's specific comments:

1) The EPA has no final plans to ban leaded gasoline, but will continue to evaluate health benefits of a ban and potential damage to older engines from a ban.

2) Testimony at the hearings indicated that gasoline marketers will supply leaded gasoline to those areas where a large enough demand exists. Since the farming community appears to have a continuing demand, the supply of leaded gasoline to farming areas should continue in the near future.

3) EPA will continue to monitor the lead content of leaded gasoline and will hold a workshop to discuss issues concerning valve protection for agricultural engines and the appropriateness of EPA's definition of leaded gasoline.

4) EPA has made a commitment to USDA to stay involved in resolving the additive question. EPA is prepared to meet with USDA and testing and additive experts to both evaluate the data available from the EPA-USDA program and other testing programs, and to assist in the development of procedures which could be used to evaluate the efficacy of additives.

V. ENGINES AT RISK WITH UNLEADED GASOLINE

As part of the Joint EPA-USDA Study, a survey was conducted by the National Agricultural Statistics Reporting Service of the USDA. The survey was intended to determine how many gasoline-powered tractors, combines and trucks were operating on the farm and how they are being used. The survey showed that 1.8 million tractors, 271,000 combines and 750,000 trucks operated on farms in 1985 were gasoline-powered. Depending on the valve-seat material and duty cycle of the engines, many of these engines will be at some risk of having valve-seat recession if operated on unleaded gasoline. The USDA and a contractor for the EPA contacted industry representatives in an attempt to determine what materials were used when these older engines were originally built. This would help owners identify whether their engines were at a risk from valve-seat recession.

Engines that have hard valve-seat inserts, and especially those with high-quality hard steel inserts, are not likely to experience excessive valve-seat wear regardless of the type of gasoline used, or how the engine is used. Some tractors were originally built with hard valve-seat inserts. Information for many tractors was not available. Based on available information, USDA determined that the following tractors were originally built with hard valve-seat inserts:

° All Ford Motor Company agricultural engines.

- Farmall/International Harvester H, M, Super H, Super M, W-4, W-6, W-9, 300, 350, 400, 450, 454, 464, 544, 574, and 674 (4-cylinder engines).
- All Farmall/International Harvester 6-cylinder engines.
- Most Minneapolis Moline engines.
- Many J.I. Case engines.

Some of the tractors built with ordinary cast-iron ("soft") exhaust valve seats include:

- All John Deere engines except those having heads built for liquid propane (LP) engines.2/
- Farmall/International Harvester Cub, A, B, C, Super A, Super C, 100, 130, 140, 200, 230, 240, 330, 340, 404, 424, 444, and 504, (60, 113, 123, 135, 146, and 153 CID 4-cylinder engines).

There were many other combine and truck gasoline engines for which EPA was unable to determine if they originally had soft or hard seats. EPA would encourage owners to check with their dealers for specific information on their equipment.

Over the years many engines have been rebuilt due to normal wear. In that process valve seats that were originally soft may have been replaced with harder material, and vice versa. Therefore, a part of the EPA-USDA study was to conduct a survey of valve-seat material that is actually in use currently

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2/ John Deere used stellite (hard) inserts in cylinder heads built for liquid propane gas engines. Some of these heads also were used as replacement heads for gasoline engines. Unleaded gasoline does not cause excessive wear in heads having stellite inserts.

in gasoline-powered tractors. The survey showed that about one-third of the tractors have hard valve seats (either originally or after a rebuild) and should be able to operate satisfactorily on unleaded gasoline.

Finally, since engines will not generally suffer valve-seat recession in light-duty use regardless of seat material and/or fuel used, the survey included an analysis of the number of tractors in light-duty use. The survey showed that 42 percent of the tractors are used exclusively in a light-duty operating condition, and they should be able to operate satisfactorily on unleaded gasoline regardless of the type of valve-seat material.

The survey found that 750,000 trucks greater than one-ton capacity were used on the farm in 1985. There were approximately 488,000 trucks which were 1972 or earlier model year. Since 1973, nearly all trucks have been produced with hardened exhaust valve seats. Therefore, approximately 262,000 (35 percent) were produced with hardened exhaust valve seats. The testing at NIPER showed that some automotive-type engines used in combines, trucks, and RV's also may experience excessive valve-seat recession, even if they have induction hardened or soft steel valve seats, when operated exclusively on unleaded gasoline. Induction hardened valve seats do not provide as much protection as high-quality hard steel valve-seat inserts.

During the testing program at NIPER, it was concluded that certain engine characteristics, in addition to the hardness of the valve seat and severity of operation, may contribute to recession. These include a lean air/fuel ratio, the presence of valve rotators, and increased temperature of the coolant. The implication is that proper maintenance of the carburetor/ fuel system and cooling system can help reduce the risk of recession.

VI. AVAILABILITY OF LEADED GASOLINE OR EQUIVALENT ADDITIVES

A. The percentage of total gasoline production which is leaded has been steadily declining. In 1983 leaded gasoline represented about 46 percent of the total U.S. gasoline production, while in 1986 it decreased to about 30 percent. Estimates are that in 1988 leaded gasoline will represent less than 20 percent of total gasoline production and will drop to 10 percent in the 1990's. At this level leaded gasoline will become a specialty product and will be difficult to find. Although, with high enough demand in the farming community it may be more available in those areas.

Ethyl Corporation (Ethyl) has indicated that if pipelines stop carrying leaded product, it would be possible for Ethyl to truck in a combination of lead plus MMT to be blended at a terminal. This would allow for the development of an alternative system for the production of leaded gasoline.

In the event that leaded gasoline is difficult to find, there should be some options available to the consumer. EPA expects manufacturers to continue to develop additives to reduce valve-seat recession. A current list of available additives is in Appendix 4.

B. Lubrizol - Lubrizol's additive has been shown to stop valve-seat recession. Some questions remain unanswered about the proper concentration of the additive and the long term impacts of certain engine deposits. EPA automotive engine experts do not believe that the deposits will have a substantial adverse effect on the durability of farm equipment, although octane demand may be increased somewhat. The Lubrizol additive shows considerable promise as a substitute for lead that can be used by individual vehicle owners.

C. DuPont - The testing of the DuPont additive in the EPA-USDA program showed a reduction in valve-seat recession but not complete elimination. However, deposits were found on intake valves, in the combustion chamber and in the lubricating oil. The deposits on one intake valve did not allow the valve to close completely. It was beginning to burn, which would lead to valve or valve-seat damage.

Unocal tests of the DuPont additive (DMA-4) did not reveal a deposit problem. Although we believe that further testing and development are warranted, it appears that the DuPont additive may be useful to vehicle owners.

DuPont also markets a lead-MMT additive, but it is not available in consumer-sized packages. The lead-MMT additive is available for bulk sales.

D. Ethyl - An additive, HiTEC 1000, produced by Ethyl, is a mixture whose final concentration is 0.10 gram of lead and 0.10 gram of manganese in the form of MMT per leaded gallon. This product was not evaluated in the EPA-USDA test program since it was found that 0.10 gplg was sufficient to prevent valve-seat recession in all the engines. Data provided by Ethyl showed that for a harsher duty cycle than tested by EPA-USDA, 0.10 gplg did not eliminate valve-seat recession, but when the same engine on that duty cycle was operated on a mixture of HiTEC 1000, valve-seat recession was eliminated. Ethyl does not assert that MMT by itself will deal with the valve recession problem, but rather that due to a synergistic effect, lead and MMT have a combined ability to reduce or eliminate valve recession better than lead alone. Ethyl also indicated that 75 percent of leaded gasoline now contains some amount of MMT.

We have been informed by Ethyl that HiTEC 1000 will not be marketed in consumer-sized packages. It is marketed in bulk leaded gasoline.

E. TK-7 Corporation (TK-7) - Data were provided by TK-7 on their additive claiming a positive effect on valve-seat recession but not total elimination. This additive was not tested in the EPA-USDA program since the manufacturer's data were provided to EPA for review after all the testing had been scheduled.

F. Polar Molecular - Initially EPA had selected the Polar Molecular additive to be evaluated in the EPA-USDA test program. At Polar Molecular's request EPA did not test their additive. The reason cited by Polar Molecular was that the duty cycle tested did not have enough low-speed and low-load portions to fairly evaluate potential deposit formation of additives on valve surfaces under these conditions.

G. Other additives listed in Appendix 4 were not tested by EPA-USDA and test results were not provided by any other manufacturers. However, many of the companies on the list actually package the Lubrizol additive.

Conclusion: EPA believes that the availability of MMT improves the prospects that leaded gasoline will remain available in areas where it is most needed. It appears that non-lead additives will provide useful alternatives in areas where leaded gasoline becomes hard to find. Although no additives have been identified that are perfect substitutes for lead and some questions remain unanswered about engine deposits, two non-lead additives (by Lubrizol and DuPont) look very promising for use by individual consumers to reduce potential valve damage. EPA will continue to work with these companies and others to help resolve the remaining questions.

VII. LEAD CONTENT AND LABELING ISSUES

Based on comments at the public hearings, written comments and a review of EPA gasoline survey data, it has become clear that some gasoline is being sold as leaded which has a lead concentration much less than 0.10 gplg.

According to testimony provided by DuPont, about 19 percent of leaded gasoline shipped through the Williams pipeline between October 1986 and April 1987 had lead levels less than 0.10 gplg, ten percent had lead levels of 0.07 gplg or less, and three percent had lead levels of 0.05 gplg or less. Some had no detectable lead. In addition, the State of Iowa conducted a survey which showed four percent of the leaded retail outlets had lead levels less than 0.01 gplg in leaded gasoline. EPA data show that over the past year four percent had lead levels of 0.06 gplg or less, and 6.5 percent had lead levels of 0.08 gplg or less. DuPont testified that when banked lead usage rights expire after 1987, most leaded gasoline will contain less than 0.10 gplg.

Because of these findings, the concern has been raised that there may be some owners purchasing gasoline labeled as "leaded" in order to get valve-seat lubrication, yet not getting the needed protection for their engines. To address this concern, EPA will be monitoring the level of lead in leaded gasoline and will hold a workshop to discuss issues concerning valve protection for agricultural engines and the appropriateness of EPA's definition of leaded gasoline.

It is EPA's understanding that refiners typically will try to make their leaded gasoline as close to 0.10 gplg as possible, since it is economically advantageous to use as much lead as permissible in leaded grades.

Furthermore, should a batch of leaded gasoline be produced with significantly less than 0.10 gplg, it would be put in a distribution system with other leaded gasoline, presumably at or near 0.10 gplg. While this commingling would lower the overall lead concentration, it would raise the concentration of the low batch to that overall average.

If a farmer fills an empty storage tank with gasoline having less than 0.10 gram of lead per gallon, he may lack sufficient protection for his equipment through several hundred hours of operation.

Some agricultural engines can operate on unleaded gasoline and, based on studies by Doelling 3/ in the early 1970's, it appears that other engines can operate satisfactorily on

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3/ Ralph P. Doelling, "An Engine's Definition of Unleaded Gasoline," Society of Automotive Engineers Paper No. 710841.

leaded gasoline containing less than 0.10 gplg of lead. Based on information from Ethyl, it appears that this would be especially true if the fuel also contained MMT. Many other engines however, are likely to need 0.10 gplg of lead to avoid excessive valve-seat recession. Since MMT is expected to be used in most leaded gasoline, and given the expected incidence of leaded gasoline containing less than 0.10 gplg of lead, EPA does not anticipate that such gasoline will pose a significant problem for farm engines. Nevertheless, EPA will continue monitoring the amount of lead in leaded gasoline and will hold a workshop to discuss issues concerning valve protection for agricultural engines and the appropriateness of EPA's definition of leaded gasoline.

There is a possibility that some gasoline companies may attempt to sell unleaded gasoline as leaded. Sales of unleaded gasoline as leaded would be in violation of EPA labeling requirements and would be subject to enforcement action.

VIII. WAYS THAT FARMERS CAN REDUCE DAMAGE FROM UNLEADED GASOLINE

Since certain engines designed for leaded gasoline may have valve-seat recession if operated exclusively on unleaded gasoline, EPA recommends the following:

1) Where diesel-powered equipment is available it should be used in heavy-duty operations in preference to gasoline-powered equipment that might be vulnerable to valve-seat recession.

2) Unleaded gasoline of sufficient octane may be used if an engine has the following:

   - Hard steel valve seats; or

   - Soft valve seats, but is used exclusively for light-duty, low-speed operations; or

   - Soft valve seats, but is a low-speed engine (less than 1700 revolutions per minute (RPM)).

3) In situations where only unleaded gasoline is available for engines that will be vulnerable to valve-seat recession, take the following steps:

   - Reduce heavy loads on an engine by shifting down and reducing engine speed (i.e. take longer to do tasks that put a heavy strain on an engine).

   - Enrich the carburetor air-to-fuel mixture.

   - Keep engines in good repair and follow proper maintenance requirements, particularly with respect to the coolinq system, and keep engines free from attachments that can restrict air flow and trap heat.

   - Use an alternative valve lubricating additive, where available, during periods of heavy use to reduce the risk or extent of engine damage.

   - Do a valve overhaul sooner than planned. Install hard steel valve seats at the next engine overhaul. If the engine has valve rotators, have them removed or disabled.

IX. EPA'S SPECIFIC PLANS

At this time the Agency does not have any final plans to ban leaded gasoline, but will continue to aggressively evaluate the nationwide health effects of lead. Recent studies 4/ provide consistent evidence of delays in behavioral and physical development in children, as well as increases in blood pressure in adult males, as a result of low-level lead exposure. These studies are continuing and EPA will continue to review data as they become available.

EPA will also continue to aggressively evaluate the potential for engine damage from a ban on leaded gasoline. In addition, EPA will continue to monitor the lead content of leaded gasoline and will hold a workshop to discuss issues concerning valve protection for agricultural engines and the appropriateness of EPA's definition of leaded gasoline.

In addition to the workshop, EPA will continue to review data developed by the manufacturers of non-lead alternative valve lubricating additives and will meet with selected specialists and other interested persons to review the test data and identify ways to determine the efficacy of non-lead additives.

4/ Air Quality Criteria Document for Lead, June 1986, USEPA, Environmental Criteria and Assessment Office, EPA-600/8-83/028a-dF.

"Lead and Child Development", J. M. Davis and D. J. Svendsgaard, Nature, vol 329, 1987, pg. 297-300.

EPA will emphasize that engines designed for leaded gasoline will operate satisfactorily on unleaded gasoline at light loads and low speeds, and that some (those with hard steel valve seats) will also operate satisfactorily on unleaded gasoline at any speed or load.

EPA will publicize information on engines at risk and issue recommendations on preventing valve-seat wear should leaded gasoline be unavailable. EPA will seek the assistance of the USDA in disseminating such information. EPA has consistently provided guidance to individual inquiries, and will continue to do so.

APPENDIX 1

United States Environmental Protection Agency
Office of Mobile Sources
Washington, DC 20460

United States Department of Agriculture
Office of Energy
Washington, DC 20250

EPA

USDA

A Joint Report
April 1987

Effects of Using Unleaded and Low-lead Gasoline, and Non-lead Additives on Agricultural Engines Designed for Leaded Gasoline

Table of Contents

Effects of Using Unleaded and Low-lead Gasoline, and Non-Lead Additives on Agricultural Engines Designed for Leaded Gasoline

April 1987

U.S. Environmental Protection Agency

U.S. Department of Agriculture

Washington, D.C.

I. Background

Due to health concerns from public exposure to lead in automotive exhaust, the Environmental Protection Agency (EPA) undertook a lead phasedown program in the early 1970's to remove lead from gasoline. At that time, refiners used approximately 2.5 grams per leaded gallon (gplg). In 1982 the amount of lead permitted in leaded gasoline was reduced to 1.10 gplg. On March 7, 1985, EPA further reduced the allowable level to 0.50 gplg, effective July 1, 1985 and 0.10 gplg on January 1, 1986. A complete ban on leaded gasoline has been considered for as early as 1988. The Agency has not proceeded with a total ban because of a concern that older engines designed for leaded gasoline may suffer premature valve seat wear if required to use unleaded gasoline exclusively, and a major health effect study of lead exposure required further review.

The Agency determined that 0.10 gplg would be satifactory to protect those older engines, based on testing that had been done in the early 1970's. Results of those tests are summarized in Costs and Benefits of Reducing Lead in Gasoline--Final Regulatory Impact Analysis (EPA-230-05-85-006, February, 1985). Generally, these tests showed that certain engines when operated on unleaded fuel for continuous high speeds, experienced valve seat recession. However, at lower speeds, valve seat recession was greatly reduced. One study showed that between 0.04 and 0.07 gplg would be satisfactory to protect valve seats. Based on this and other studies, EPA concluded that 0.10 gplg would be sufficient to protect exhaust valve seats from recession in engines designed for leaded gasoline.

The farming community expressed a concern that older farm engines designed to operate on leaded gasoline may experience engine damage if operated on low-lead or unleaded gasoline. In response to that concern, Congress required a study to be conducted under Section 1765 of the Food Security Act of 1985 (P.L. 99-198) (Act).

The Act required the Administrator of EPA and the Secretary of Agriculture (USDA) to "jointly conduct a study of the use of fuels containing lead additives and alternative lubricating additives," on gasoline-powered agricultural machinery. The study was to analyze the potential for mechanical problems (including but not limited to valve seat recession) that may occur with the use of other fuels in farm machinery. The Secretary of Agriculture was to specify the types and items of agricultural machinery to be included in the study and all testing of engines was to reflect actual agricultural conditions, including revolutions per minute and loads placed on the engines.

II. Scope of study

The study's overall goals are to determine the risk to engines if gasoline is limited to either low-lead or unleaded and to evaluate alternative additives to lead. The study has a complex design because the relationship between gasoline type and engine durability is a function of both engine design and usage patterns. The primary engine component at risk with a fuel change is the exhaust valve seat. This wears by receding into the cylinder head. If wear is severe enough, the exhaust valve eventually will not seat properly and engine failure will follow. Factors influencing the risk of wear include engine speed (rpm), load, temperature and cylinder head design. Information is needed on all of these factors to assess the risk of engine failure.

Little information was available about rpm and load levels for agricultural equipment under actual use conditions. Further, concern arose that since most of the equipment is not new, the valve seats could have been modified during overhauls so that original equipment specifications would no longer accurately reflect the type of valve seats in use.

The study was divided into three areas: Agricultural machinery testing on engine dynamometers; farm use survey of gasoline-powered equipment; and field measurement of the type of valve seat material in exhaust valve seats in gasoline-powered tractors.

A. Dynamometer Testing

The design of the testing portion of this study was initiated with a letter from EPA on December 6, 1985 to 25 potential commenters from EPA, USDA, the American Farm Bureau Federation (AFBF), tractor manufacturers, university professors, and independent consultants. The letter forwarded a statement of work suggested for the study. Comments were received from most of the recipients of the letter and suggested a wide variety of changes. A meeting was held on January 27, 1986 with all commenters who wished to attend to discuss the program and reach a consensus on engines to test, duty cycles and other details of the test program. Twenty-one commenters attended the meeting. Based on discussions at this session, EPA revised the statement of work and sent it back to the commenters for a final review. Through this procedure and further contacts with engine manufacturers and others, EPA and USDA representatives agreed on a test procedure for tractors, combines, and farm trucks, including the selection of engines and duty cycles.

In addition, EPA decided to include a recreational vehicle (RV) engine in the study because of a concern expressed by RV owners related to potential engine damage while operating these engines on low-lead or unleaded gasoline. EPA developed a duty cycle to be used on the RV engine, after discussions with consultants and original-equipment manufacturers.

Engine testing was performed by the National Institute for Petroleum and Energy Research (NIPER), an independent research laboratory located at Bartlesville, Oklahoma. (See Appendix 6 for information on how to obtain a copy of their report.) Technical advice and oversight were provided by two consultants, Dr. Louis I. Leviticus of the Nebraska Tractor Testing Laboratory, Lincoln, Nebraska and Dr. Ralph Fleming of Energy, Fuels and Engine Consulting Services, Accokeek, Maryland. The consultants commented on the original program design, visited the test facility on several occasions and consulted on major program decisions throughout the study. Their evaluation of the test program is in Appendix 2.

B. Farm Engine-Use Survey

The second area of this study was a survey of the number and use of selected gasoline-powered farm equipment (tractors, combines and trucks). Questions were added to a Farm Labor Survey conducted in July 1986 by the National Agricultural Statistics Service, USDA. (See Appendix 5 for a copy of the survey form and see Appendix 6 for information on how to obtain a copy of the manual that accompanied the questionnaire.) Survey results were related to the results of the dynamometer tests in order to characterize the degree of risk encountered by farm equipment. Highlights of that analysis are included in this report. More extensive analysis of the data may reveal additional information about the use of these engines.

C. Cylinder Head Survey

Valve seat recession is affected by the type and hardness of the material used in valve seats. A field survey of cylinder heads was performed to determine what material (cast iron, soft steel, hard steel or stellite) is in the exhaust valve seats of tractors. Due to overhauls, engines may no longer have valve seats meeting original equipment specifications.

The survey, conducted by the Radian Corporation, Sacramento, California, involved sending an engineer to test cylinder heads removed by eight tractor dismantling and salvage firms located throughout the United States. (See Appendix 6 for additional information on how to obtain a copy of the protocol and quality assurance plan for this survey.)

III. Agricultural Machinery Testing on Engine Dynamometers

A. Test Design

Lead combustion products serve as solid lubricants for some parts of the engine--primarily the exhaust valve seats. Engines designed for leaded gasoline typically have a valve seat geometry designed to prevent excessive accumulation of lead compounds. They may also use valve rotators for this purpose. Valve seat wear appears to be related primarily to engine speed and load.

A tractor duty cycle was designed to reflect a full range of tractor use conditions. The duty cycle had two parts. The first part consisted of 144 hours (16 hours/day) at governed engine speed and loads varying from no load to full power. This cycle was adopted from the cycle used by the Nebraska Tractor Testing Laboratory (SAE J708).1/ The second part consisted of a 56-hour continuous test at governed engine speed and 75% of maximum available power. This segment represents the maximum continuous load that is likely to be placed on these engines, such as pumping irrigation water. The combine engine was tested using the same duty cycle. (See Appendix 3 for a description of the duty cycles.)

The farm truck engine was operated throughout the 200 hours at varying engine speeds (2000-3600 rpm) and loads (25% to 85% of maximum power) representing normal conditions

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1/This cycle has a long history of use in testing the performance of new tractors.

for farm trucks larger than one-ton capacity. The RV engine was operated for 144 hours at varying engine speeds (2000-3600 rpm) and loads (45% to 85% of maximum power) followed by a 56-hour hour steady state cycle (100 HP, which is 52% of maximum power, at 3000 rpm). The farm truck and RV engines were operated for 16 hours on and 8 hours off throughout the tests. (See Appendix 3 for a description of the duty cycles.)

Before each test, the cylinder heads were changed and broken in on the next fuel being tested. Testing was conducted on leaded (1.2 gplg), unleaded, and low-lead (0.1 gplg) gasoline, and gasoline containing non-lead additives.2/ The principal focus of the testing was to record wear of exhaust valve seats. Valve clearance was set to manufacturers' specifications each time a measurement was taken. In addition, the contractor measured intake valve seat recession, valve stem length, valve guide and stem wear, valve tulip diameter and valve seat angle, valve spring force and height, and other measures of engine wear. Engine performance was monitored and emissions tests were performed on the exhaust gases. After each fuel test, engines were carefully examined for deposits and other conditions that may have resulted from the test. Elemental analyses of the lubricating oils were conducted. Cylinder heads and valve seat inserts were carefully selected to control the hardness of exhaust valve seats.

2/Leaded gasoline in this study contains tetraethyl lead.

Tractor and combine engines usually have solid valve lifters. A valve adjustment is needed in the engines after about every 15 thousandths of an inch of wear and new valve seats are needed after about 125 to 200 thousandths of an inch of wear. While repeated valve adjustments theoretically make it possible to continue operating an engine as valve seat recession occurs, as a practical matter, an engine operator is likely to burn a valve and, thus, require an overhaul of the valve assembly before all of the potential adjustments can be made. This is because valve seat wear gives an operator few clues to the problem until significant damage occurs. There is no increase in engine noise and misfiring and loss of power often are not noticed until after valves or valve seats have burned. Automotive-type engines usually have hydraulic valve lifters so regular valve adjustments are not needed. New valve seats are needed in these engines after about 75 thousandths of an inch of valve seat wear. New valve seats may be obtained by replacing the cylinder head or by machining out the valve seats and installing valve seat inserts.

Proper clearance also must be maintained between valve stems and valve guides. Worn valve stems and guides result in increased oil usage and may cause excessive valve and valve seat wear because the valve does not seat properly. When valve guide clearance increases by more than 2 thousandths of an inch, many manufacturers recommend that the valve guides be replaced or that the valves be replaced by ones with oversize stems.

See Appendix 6 for information on how to obtain a copy of the statement of work used in the study and a detailed description of the engine tests, including fuel and oil specifications, engine rebuilding procedures, recession measurement guidelines, and other test parameters which NIPER was required to follow.

B. Engines Tested

The five farm equipment engines initially selected by USDA were: John Deere "B", Farmall "H" and International Harvester 240 tractors, John Deere 303 cubic inch displacement (CID) combine engine, and a pre-1974 General Motors 292 CID (GM 292) truck engine. The engines, described in Appendix 4, represent a broad range of engine sizes and characteristics. EPA selected the pre-1984 General Motors 454 CID V-8 engine (GM 454) to represent engines used in RVs.

Plans called for purchase of a duplicate of the engine that experienced the most valve seat recession on unleaded gasoline, in order to focus more attention on tests of this engine. The GM 292 truck engine proved most vulnerable and a duplicate was purchased. At the request of the USDA and the American Farm Bureau Federation, a Ford 8N tractor engine also was procured for the study after it was learned that one of the other tractor engines selected did not need to be tested on low-lead gasoline and non-lead additives. Manufacturers' specifications for the John Deere "B", International 240, John Deere 303, and GM 292 engines called for ordinary cast iron cylinder heads without valve seat inserts. Hardness of these valve seats typically ranges from 9 to 25 on the Rockwell C scale.3/ The Farmall "H" was originally equipped with "gray iron" valve seat inserts (Rockwell C scale values of 26-36); the Ford 8N was originally equipped with harder exhaust valve seat inserts (Rockwell C scale 39-43); and the General Motors 454 CID engine was originally equipped with induction-hardened cast iron valve seats (no inserts) with a Rockwell C scale hardness of about 55 specified by the manufacturer.4/ The General Motors 454 and 292 engines are currently being manufactured with induction-hardened cast iron valve seats. All engines were tested with valve seats meeting original equipment specifications except the Farmall "H" and Ford 8N. Since the latter engines may have been rebuilt with different valve seat material, they were tested with ordinary cast iron valve seat inserts (Rockwell C scale value of 17).

C. Dynamometer Testing Limitations

The dynamometer testing portion of this study has a number of limitations. First, budget limitations did not permit testing enough engines to assure statistical reliability. Only one or at most two engines of any given type could be tested. Second, dynamometer tests typically show

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3/Lower numbers indicate softer materials.

4/Hardness of induction-hardened cast iron valve seats typically ranges from 40 to 60 on the Rockwell C scale.

more wear than is found during actual in-use operation of engines. Every attempt was made to make the tests representative of actual in-use conditions, but this was difficult because data on how the engines are used did not exist. Third, because of time and cost restrictions, valve design factors which could affect valve seat wear, such as the presence of valve rotators, were not examined fully. Finally, unforseen engine characteristics such as air/fuel ratios and mechanical problems, which appear to have an effect on valve seat wear rates, were not controlled in the study design.

IV. Results of Dynamometer Testing

A. Tests of Leaded Gasoline (1.2 gplg)

Baseline tests were run on the six original engines using gasoline containing 1.2 grams per leaded gallon (gplg). The duplicate truck engine (GM 292-B) and the additional tractor engine (Ford 8N) were not tested on gasoline containing 1.2 gplg because none of the original engines showed appreciable wear with this fuel.

Table 1 summarizes the maximum rates of valve seat recession (in thousandths of an inch per 100 hours) found while operating the engines on leaded, low-lead, and unleaded gasoline. Except for the GM 454 engine, essentially no valve seat recession was found and no unusual wear occurred on other engine components when leaded gasoline was used. It should be noted that the GM 292-A exhaust valve guide diameter increased by 1.8 thousandths of an inch and that the International Harvester 240 intake valve guide diameter increased by 14.3 thousandths of an inch (probably due to an oil line blockage that was corrected early in the test) which are substantially more than were observed in the other engines. Exhaust valve seat recession is not a problem with gasoline containing 1.2 grams per leaded gallon.

Table 1--Maximum exhaust valve seat recession rates*

Engine	Type of valve seat1/	Exhaust valve rotators	Leaded2/ 1.2 gplg	Leaded2/ 0.1 gplg	Unleaded: Intermittent phase3/	Unleaded: Steady state phase3/	Unleaded: Total2/
			Thousandths of an inch per 100 hours				
John Deere B, run 1	CI	No	0	NT	0	4/19.6	4/4.5
John Deere B, run 2	CI	No	NA	NA	5/5.7	0	6/4.7
Farmall H	CI	No	0	NT	0.7	0	0
International 240, run 1 ..	CI	Yes	1.5	0.5	0	0	0
International 240, run 2 ..	CI	Yes	NA	NA	16.7	44.6	23.5
International 240	CI inserts	Yes	NT	1.0	32.6	83.9	42.5
Ford 8N	CI inserts	Yes	NT	NT	11.8	50.0	15.0
John Deere 303 CID	CI	Yes	0.5	2.0	16.7	69.6	32.0
GM 454 CID	IHCI	Yes	3.0	2.5	20.8	14.3	16.0
GM 454 CID	SS inserts	Yes	NT	NT	11.8	5.4	8.5
GM 292 CID, engine A	CI	Yes	1.0	7/20.0 5.0	2/8/170.4	NA	8/170.4
GM 292 CID, engine B	CI	Yes	NT	1.0	NT	NT	NT
GM 292 CID, engine B	IHCI	Yes	NT	NT	2/5.5	NA	5.5
GM 292 CID, engine B, lighter load 9/........	CI	Yes	NT	NT	2/10/106.8	NA	10/106.8

NA denotes "not applicable." NT denotes "no test."

*See figures in Appendix 1 for recession data on individual cylinders.

1/ CI = ordinary cast iron; IHCI = induction-hardened cast iron; SS = soft steel. 2/ Recession based on measurement of cylinder heads before and after each fuel test. 3/ Recession estimates based on valve lash measurements recorded at intervals during each fuel test. This procedure is less accurate than "before and after" measurements. See NIPER report for more information on measurement techniques.

Table 1--Maximum exhaust valve seat recession rates*--continued

4/ Recession may have been influenced by improper alignment of rocker arm assembly. 5/ Operated 244 hours. 6/ Operated 300 hours. 7/ Results are for two tests. During the first test (the larger recession rate), the cylinder head gasket failed and may have generated additional heat which contributed to the recession. 8/ Engine could complete only 71 of the scheduled 200 hours due to recession. 9/ Engine was run without the 3600 rpm part of the duty cycle. 10/ Engine was stopped after 88 hours of operation due to recession.

B. Tests of Unleaded Gasoline

All engines procured for this test program were evaluated on unleaded gasoline. Recession data are summarized in Table 1 and Appendix 1, Figures 1-13. Principal findings are as follows.

1. The John Deere "B" tractor engine was tested twice on unleaded gasoline (Appendix 1, Figures 1 and 2). The first test found that one cylinder had 11 thousandths of an inch of recession after 200 hours of operation, all of which occurred during the steady state portion of the test. Examination of the engine after the test showed that the rocker arm was not striking the valve stem tip properly and it was believed that recession was due to this mechanical problem instead of the fuel. This may have caused valve guide diameter wear to increase from 1.0 thousandths of inch for the leaded fuel test to 3.2 thousandths of an inch during the first unleaded test. After properly aligning the rocker assembly, the unleaded test was repeated with a new cylinder head. Both exhaust valve seats experienced some recession after 80 hours, but no additional recession through 200 hours. The test was continued on the intermittent portion of the duty cycle for 100 more hours and no additional recession occurred. Valve guide diameter wear was consistent with the rate observed for leaded gasoline. Valve stem wear increased from 0.2 thousandths of an inch for leaded gasoline to 0.8 thousands of an inch for unleaded gasoline. No

other unusual wear was observed. The John Deere "B" tractor engine may experience a small amount of valve seat recession but should not have problems operating on unleaded gasoline.

2. The Farmall "H" tractor engine did not experience valve seat recession or any other unusual wear while operating on unleaded gasoline and was not tested any further (Appendix 1, Figure 3).

3. The John Deere 303 CID combine engine experienced substantial valve seat recession while operating on unleaded gasoline (Appendix 1, Figure 4). At 144 hours, all cylinders showed recession ranging from 10 to 24 thousandths of an inch. After the steady state portion of the test, total recession ranged from 41 to 63 thousandths of an inch. Valve guide wear increased from a maximum of 0.2 thousandths of an inch on leaded fuel to 1.5 thousandths of an inch on unleaded fuel.

4. The International Harvester 240 tractor engine was tested three times on unleaded gasoline. The first test showed no valve seat recession (Appendix 1, Figure 5). We subsequently found that the cylinder head used was among the hardest of the heads purchased for the tests. It was decided to test the engine a second time using a cylinder head at the softer end of the hardness range of heads available. Substantial valve seat recession (43-49 thousandths of an inch) occurred on two of the valve seats (Appendix 1, Figure 6). About one-half of the recession occurred during the 56-hour steady state portion of the test cycle.

Further investigation of the cylinder heads after the tests were completed revealed that the hardness of the metal in the seat area was essentially the same for both heads. Differences in wear in the International 240, therefore, were not due to differences in hardness of the valve seats. Evaluation of the data revealed that the air/fuel ratio was much higher during the test that exhibited valve seat recession even though the engine was set to the manufacturer's specifications (Table 2). The higher air/fuel ratio may have contributed to the valve seat recession since a leaner mixture would cause higher exhaust temperatures. After the test was completed, the carburetor was cleaned and the air/fuel ratio returned to its original level.

A third unleaded test was performed on the engine using exhaust valve seat inserts. The inserts were of about the same hardness as the valve seats in the first two unleaded tests on this engine. Appendix 1, Figure 7 shows that no recession occurred during the first 80 hours but then occurred very rapidly. After 144 hours of variable loads, recession ranged from 16 to 47 thousandths of an inch and then rose to 63 to 94 thousandths of an inch during the final 56 hours of steady state operation. The air-fuel ratio did not rise during this test. This test suggests that engines with valve seat inserts are more susceptible to recession than engines without inserts when the valve seats are of equal hardness.

Table 2--Average emissions and air-fuel ratios by engine and test fuel

Engine and fuel	CO 1/	HC 2/	NOx 3/	Air-fuel ratio
	Percent	ppm	ppm	
John Deere B				
1.2 gplg	5.3	3,303	679	13.0
Unleaded				
Run 1	9.3	3,202	202	10.9
Run 2	6.0	3,605	847	12.2
Farmall H				
1.2 gplg	5.1	3,544	1,008	13.0
Unleaded	4.2	2,187	1,116	13.4
International 240				
1.2 gplg	5.1	3,133	817	12.7
Unleaded				
Run 1	5.7	2,358	925	12.5
Run 2	2.1	1,338	1,380	14.3
Inserts	4.6	2,022	NA	12.9
0.1 gplg				
No inserts	6.3	2,606	868	12.3
Inserts	5.6	2,104	NA	12.5
John Deere 303 CID				
1.2 gplg	4.9	3,610	1,212	12.7
Unleaded	4.6	1,951	1,305	13.0
0.1 gplg	6.3	2,612	738	12.2
DuPont additive 4/ . . .	5.2	2,033	NA	12.7
Standard "PowerShield" additive 5/	7.3	2,482	NA	11.8
Ford 8N				
Unleaded	5.5	2,933	NA	12.5
GM 454 CID				
1.2 gplg	2.0	1,726	1,950	14.0
Unleaded				
No inserts	2.5	930	1,802	13.8
Steel inserts	3.4	813	NA	13.4
0.1 gplg	2.5	1,090	1,868	13.9
Standard "PowerShield" additive 5/	3.0	891	NA	13.6

Continued--

Table 2--Average emmissions and air-fuel ratios by engine and test fuel--continued

Engine and fuel	CO 1/	HC 2/	NOx 3/	Air-fuel ratio
	Percent	ppm	ppm	
GM 292 CID, engine A				
1.2 gplg	3.8	2,356	1,339	13.4
Unleaded	4.3	1,006	1,119	13.1
0.1 gplg				
Run 1	3.0	1,597	1,696	13.7
Run 2	3.9	1,182	NA	13.2
DuPont additive 4/	3.8	1,054	NA	13.3
Standard "PowerShield" additive 5/	2.7	1,205	1,924	13.6
GM 292 CID, engine B				
Unleaded				
IHCI 6/	3.9	1,436	1,398	13.1
Lighter load 7/ . . .	3.9	1,222	NA	13.2
0.1 gplg	5.2	1,416	NA	12.7
Concentrated "PowerShield" additive 8/	4.9	2,865	NA	12.7

1/ Carbon monoxide.
2/ Hydrocarbons.
3/ Nitrogen oxides.
4/ 200 pounds of additive per 1,000 barrels of gasoline.
5/ 250 pounds of additive per 1,000 barrels of gasoline.
6/ Induction-hardened cast iron exhaust valve seats.
7/ Engine was run without the 3,600 rpm part of the duty cycle.
8/ 1,000 pounds of additive per 1,000 barrels of gasoline.

Valve train inspection data show that exhaust valve guide wear was up to 2.2 thousandths of an inch without inserts and up to 8.7 thousandths of an inch with inserts compared to a maximum of 0.9 thousandths of an inch with leaded fuel and no inserts.

5. Tested with ordinary cast iron valve seat inserts, the Ford 8N had up to 17 thousandths of an inch of valve seat recession after 144 hours, and 17 to 29 thousandths of an inch of recession after 200 hours, a significant amount of wear (Appendix 1, Figure 8).

Two cylinders may have had above-normal valve guide wear based on comparisons with the leaded fuel tests on the other engines (the Ford 8N does not have a leaded-fuel baseline test since none of the original engines tested showed appreciable wear with this fuel).

6. The GM 292-A CID truck engine, when tested on unleaded fuel with ordinary cast iron valve seats, experienced the highest rate of recession (Table 1 and Appendix 1, Figure 9). In fact, the test had to be terminated after 71 hours due to fear that the engine would be severely damaged by excessive valve seat recession. Exhaust valve guide wear increased but not substantially more than found in the leaded test.

A duplicate engine, GM 292-B, was tested with the harshest portion of the duty cycle (3600 rpm) deleted. The wear rate was reduced by 40 percent, but the test still had to be terminated after 88 hours due to excessive valve seat recession

(Appendix 1, Figure 10). Subsequently, the GM 292-B engine was tested with induction-hardened cast iron exhaust valve seats, and experienced 11 thousandths of an inch of recession after 200 hours (Appendix 1, Figure 11). However, there was a greater change in exhaust valve guide diameter (a maximum of 4 thousandths of an inch versus 1.8 thousandths of an inch for leaded fuel) during this test. Valve length was reduced by up to 8 thousandths of an inch compared to increases of up to 4 thousandths of an inch for leaded fuel.

7. The GM 454 recreational vehicle engine was tested with induction-hardened cast iron valve seats. All cylinders showed significant recession, ranging from 14 to 30 thousandths of an inch after 144 hours. Total recession increased slightly to a maximum of 34 thousandths of an inch after the steady state portion of the test (Appendix 1, Figure 12). The induction hardening process for the GM 454 affects the valve seats to a depth of about 50 thousandths of an inch. Rapid wear would be expected after the induction-hardened portion of the valve seat is worn away. Exhaust valve guide wear increased from a maximum of 1 thousandths of an inch using leaded fuel to 4.6 thousandths of an inch while operating on unleaded fuel.

A second test on unleaded fuel was conducted using soft steel "XB" valve seat inserts (Rockwell C scale value of 42) designed for moderate-duty use. This test also showed valve seat recession but it was much less; 17 thousandths of an inch after 144 hours with little recession during the final steady state portion of the test (Appendix 1, Figure 13). Maximum exhaust valve guide wear of 1.7 thousandths of an inch occurred compared to 1 thousandths of an inch on leaded fuel.

8. Summary of Results on Unleaded Gasoline.

Engines operated at low speeds (e.g., John Deere B, rated at 1250 rpm; and Farmall H, rated at 1650 rpm) should have little or no problem operating on unleaded gasoline, regardless of the type of valve seat material. Engines which operate at medium rpm (e.g., International 240 and Ford 8N rated at 2000 rpm) are likely to experience significant valve seat recession unless they are used only for light-duty tasks or have hard steel valve seat inserts. Engines operated under heavy-duty steady state conditions may experience 2-4 times more recession than engines operated under a wider range of load conditions.

Farm equipment engines operating at higher speeds (e.g., John Deere 303 CID, rated at 2500 rpm) which have ordinary cast iron valve seats probably will experience considerable valve seat recession. Based on the tests of the GM 292 and GM 454 CID engines, we concluded that automotive-type engines of the type tested, when operated under conditions represented by the duty cycles used in these tests, are extremely susceptible to valve seat recession when they have ordinary cast iron valve seats. Furthermore, the tests on the GM 454 showed that engines could experience considerable recession even if they are equipped with induction-hardened cast iron valve seats which are still being installed in new vehicles. Based on tests of the GM 454, soft steel inserts also are vulnerable with unleaded fuel although wear rates appear to be lower than for induction-hardened cast iron seats. Unleaded gasoline also increases valve guide wear and may increase valve stem wear.

Factors other than the lead content of fuel also affect valve seat recession, probably because of heat differences. Higher air/fuel ratios appear to increase valve seat recession. Engines with valve seat inserts appear to be more susceptible to valve seat recession than engines with equally hard integral cylinder head seats. The use of valve rotators also may increase recession.

C. Tests of Low-lead Gasoline (0.1 gplg)

Four of the original six engines showed significant recession on unleaded gasoline and, therefore, were tested on gasoline containing 0.1 gplg. The John Deere 303, the International 240 (with and without valve seat inserts) and the GM 454 engines all operated satisfactorily on 0.1 gplg (Table 1 and Appendix 1, Figures 14, 15, 16, and 17).

Other parameters measured showed no changes for the International 240. Compared to leaded fuel, maximum valve guide wear increased from 1.0 thousandths of an inch to 2.0 thousandths of an inch in the GM 454 and from 0.2 thousandths on an inch to 1.2 thousandths of an inch in the John Deere 303.

The GM 292-A experienced significant recession after 91 hours (Appendix 1, Figure 18). Since the head gasket failed at about that time, and may have contributed to the valve seat recession, it was decided to retest the GM 292-A engine and the duplicate GM 292-B, engine on this fuel.[5] One of the engines showed no increase in wear compared to the leaded test. The other engine showed slightly more recession in one cylinder. Overall, little recession occurred in these subsequent tests (Appendix 1, Figures 19 and 20). Under good operating conditions, most farm engines probably will experience little or no valve seat wear using 0.1 gplg gasoline.

However, 0.1 gplg appears to be at or near the minimum level needed by most of these engines when they are properly maintained and operated under conditions similar to the duty cycles tested, unless other forms of valve seat protection are used (such as non-lead additives or more wear-resistant seat materials).

The technical specialists who worked on this study believe that excessive heat may contribute significantly to valve seat recession. The head gasket failure and differences in air/fuel ratios observed in this study are two of many

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[5]The exact time that the gasket failure started to occur is not known because it did not cause an abrupt change in the engine's behavior or in the performance measures being monitored, such as power, engine temperature and emissions. One of the consultants on the project (Dr. Ralph Fleming) examined the test data and engine characteristics to determine if the gasket failure caused the recession, and reported that a conclusive determination could not be made.

factors that could cause excessive heat that may not be detected by operators in everyday engine operations. An improperly maintained engine might experience excessive valve seat recession even when high concentrations of lead are in the gasoline, but good engine maintenance is especially important when using gasoline containing only 0.1 gplg or less of lead.

D. Tests of Non-lead Additives6/

Two proprietary additives were evaluated in the test program.7/ An additive manufactured by Lubrizol Corporation (Lubrizol) was tested on the John Deere 303, GM 454 and GM 292 A and B engines. The second additive, produced by E.I. duPont de Nemours and Company (DuPont), was evaluated on the GM 292-A and the John Deere 303 engines.

Table 3 and Appendix 1, Figures 21-25, summarize the rates of exhaust valve seat recession found while operating the engines on the Lubrizol and DuPont additives.

1. Test Results Using the Lubrizol Additive

Three formulations of the Lubrizol additive were tested.

6/Products containing tetraethyl lead to be added by the consumers were not evaluated because we would expect the same results as with the leaded-fuel tests that were conducted.

7/Additives were selected for testing in this program if the manufacturers indicated to EPA a desire to have their products tested and they provided data to EPA which showed that their products had the potential for reducing valve seat recession when used with unleaded gasoline.

Table 3—Maximum exhaust valve seat recession rate using non-lead additives*

Item	Unleaded gasoline	DuPont additive	Lubrizol additive: Modified "PowerShield"	Lubrizol additive: Standard "PowerShield"	Lubrizol additive: Concentrated "PowerShield"
	Pounds per 1,000 barrels of gasoline				
Additive treat rate		1/200	250	250	1,000
	Thousandths of an inch per 100 hours				
John Deere 303 CID					
Intermittent phase	3/16.7	2/4/4.2	2/5/15.0	3/7.6	NT
Steady state phase	3/69.5	NA	NA	3/60.7	NT
Total 2/	31.5	NA	NA	20.0	NT
GM 292 CID					
Engine A 2/	170.4	22	6/120	7/130	NT
Engine B 2/	NT	NT	NT	NT	0.5
GM 454 CID					
Intermittent phase 3/	20.8	NT	NT	3.5	NT
Steady state phase 3/	14.3	NT	NT	7.1	NT
Total 2/	16.0	NT	NT	4.5	NT

*See figures in Appendix 1 for recession data on individual cylinders.

NA denotes "not applicable" because the test was not completed.
NT denotes "no test."

1/ About double the concentration normally recommended by DuPont. 2/ Recession based on measurement of cylinder heads before and after each fuel test. 3/ Recession estimates based on valve lash measurements recorded at intervals during each test. This procedure is less accurate than "before and after" measurements. See NIPER report for more information on measurement techniques. 4/ Test terminated after 48 hours due to a problem not related to the fuel. 5/ Test terminated after 80 hours when NIPER was notified that the additive was not properly manufactured. 6/ Test terminated after 64 hours due to excessive valve seat recession. 7/ Test terminated after 84 hours due to excessive valve seat recession.

The first, a modified version of a product Lubrizol sells under the trade name "PowerShield" had little effect on valve seat recession. Lubrizol, subsequently, notified NIPER that the product had not been properly formulated and asked that "PowerShield" be tested. "PowerShield" was tested at the manufacturer's recommended concentration of 250 pounds per 1,000 barrels of gasoline. For the GM 454, recession was about comparable to that found using 1.2 gplg and 0.1 gplg. However, compared to unleaded gasoline, "PowerShield" slightly reduced but did not stop wear in the other two engines tested (John Deere 303 and GM 292-A) (Table 3 and Appendix 1, Figures 21, 22, and 23). Valve guide wear was above normal with "PowerShield" (based on the test using 1.2 gplg gasoline) in the John Deere 303 (3.3 thousandths of an inch compared to 0.2 thousandths of an inch with leaded).

"PowerShield" was tested in one engine (GM 292-B) at a concentration of 1,000 pounds of additive per 1,000 barrels of gasoline (four times the level normally recommended for the product). Valve seat recession was stopped (Appendix 1, Figure 24). Valve stem wear was slightly greater than was observed for both leaded and unleaded gasolines.

The "PowerShield" additive caused deposits to form in the combustion chamber of the engines. Engine deposits increased when the "PowerShield" concentration was quadrupled. Combustion chamber deposits can increase an engine's octane requirement, but it is not clear from this testing whether the deposits seen would significantly alter octane requirements or have any other effects on the engines.

"PowerShield" at the 250 pounds of additive per 1,000 barrels of gasoline also caused oily black deposits to form on intake runners, but the implications, if any, are not known. This occurred in both the GM 292-A and John Deere 303 engines and to a lesser extent in the GM 454.

Examination of lubricating oils revealed substantially higher levels of sodium in the oil after running the engines on "PowerShield." Two of the engines also had elevated levels of phosphorus and the engine that ran on "PowerShield" at 1,000 pounds of additive per 1,000 barrels of gasoline had much larger quantities of sulfur in the oil.

2. Test Results Using the DuPont Additive

Two engines (John Deere 303 and GM 292-A) were tested on the DuPont additive at about twice the concentration normally recommended by the manufacturer. The test on the John Deere 303 was terminated after only 48 hours due to a problem with the engine's cooling system. At that point, essentially no valve seat recession was occurring. However, 48 hours was not long enough to yield meaningful results.

The DuPont additive reduced valve seat recession in the GM 292-A engine, although, at 22 thousandths of an inch per 100 hours, wear was still excessive (Table 3, and Appendix 1, Figure 25). The additive caused deposits to form in the engine. A large amount of hard, sticky deposits was found on the intake valves. One intake valve was unable to close completely and was beginning to burn. Inside the combustion chamber, a glaze deposit had formed on valve surfaces. The full implications of these deposits, including the potential for eliminating them, are not known.

Examination of the lubricating oils revealed substantially higher levels of phosphorus after running engines on the DuPont additive.

3. Summary of Additive Testing

The DuPont additive, at about twice the concentraton normally recommended by the manufacturer, provided some degree of protection against valve seat recession. At the manufacturers recommended concentration, Lubrizol's "PowerShield" reduced recession. At four times the concentration normally recommended by the manufacturer, Lubrizol's "PowerShield" stopped recession in the one engine tested. Both additives produced engine deposits which raised unanswered questions. The DuPont additive increased the amount of phosphorus in the lubricating oil. "PowerShield" also increased the amount of sodium, sulfur, and phosphorus found in the lubricating oils. Nevertheless, although further product development work is essential, the additives may have potential as substitutes for lead.

V. Results of the Farm Engine-Use Survey and Cylinder Head Survey

The National Agricultural Statistics Service, USDA conducted a survey of farmers to learn how many gasoline-powered tractors, combines, and large trucks are in use on farms and how much they are used. The survey was conducted in July 1986. The questionnaire is in Appendix 5. (See Appendix 6 for information on how to obtain a copy of the manual that accompanied the questionnaire.)

At that time, farmers operated a total of 4.4 million tractors, of which 1.8 million were gasoline powered and 2.6 million were diesel powered. The gasoline-powered tractors, which average 26 years of age, were used an average of 250 hours in 1985. The amount of use varies with the size of the tractor (Table 4). Further, tractors with low annual hours of operation tend to see more light duty use (Table 5) than tractors that are used more.

About 42 percent of gasoline-powered farm tractors are used exclusively in light duty tasks and, therefore, have little risk of valve seat recession if operated on unleaded gasoline. The other 58 percent of tractors see some medium and heavy uses which potentially make them vulnerable to excessive valve seat wear if fueled with unleaded gasoline, unless they are low-rpm engines, have hardened exhaust valve seats, or are protected by a fuel additive.

Table 4--Distribution of gasoline-powered tractors by size and hours of use, 1985

Annual hours of use	Number of tractors	Average horsepower
20-49	213,784	31
50-99	324,146	34
100-149	321,520	38
150-249	350,372	43
250-499	303,857	46
500-749	141,992	49
750-1499	84,884	49
1,500 or more	33,160	54
All tractors	1,773,715	40

Table 5--Annual use of gasoline-powered tractors, 1985

Annual hours of use	Percentage distribution of use			
	Irrigation pumping	Hard use	Medium use	Light use
20-49	0.35	8.61	25.48	65.55
50-99	0.05	9.15	30.08	60.71
100-149	0.44	9.99	33.92	55.64
150-249	0.42	12.26	34.29	53.03
250-499	0.17	14.37	36.77	48.68
500-749	0.41	16.80	40.45	42.34
750-1.499	0.27	18.72	43.22	37.79
1,500 or more	0.16	23.00	43.54	33.31
All tractors	0.29	12.08	33.91	53.72

Farmers operate 271,000 gasoline-powered combines that average 19 years of age. On average, each combine harvested 220 acres of grain in 1985. Combines, like tractors, see a skewed use distribution (Table 6). All combine engines receive hard use and are likely to experience excessive valve seat recession if they have cast iron valve seats and are operated on unleaded gasoline.

About 750,000 gasoline-powered trucks larger than 1-ton capacity are used on farms. They average 19 years of age and were driven an average of 3,800 miles in 1985. Over half of the trucks were driven less than 2,000 miles (Table 7). Trucks receive a range of light to hard uses. Data are not available that would more precisely characterize this use although, on average, it is thought to be represented by the duty cycle specified for the tests conducted by NIPER.

The Radian Corporation conducted a survey of tractor dismantling operations to determine the type of material in tractors' valve seats. (See Appendix 6 for information on how to obtain a copy of the protocol and quality assurance plan for this survey.) An eddy-current test was used to identify stellite valve seats and steel/cast iron seats. A chemical test (for the presence of chromium) was then used to distinguish between valve seats made of steel and cast iron. Data were obtained from eight establishments located throughout the United States. This survey is subject to large sampling and measurement errors and the data have not been fully

Table 6--Distribution of number of gasoline-powered combines by number of acres harvested, 1985

Number of acres harvested	Number of combines
1-99	101,641
100-199	69,159
200-299	32,418
300-399	24,446
400-499	13,793
500-999	22,594
1,000 or more	6,294
All combines	270,345

Table 7--Annual miles of farm trucks

larger than 1 ton rated capacity, 1985

Total annual miles driven	Number of trucks
0-1,000	254,805
1,001-2,000	145,783
2,001-3,000	81,896
3,001-4,000	42,568
4,001-5,000	74,053
5,001-10,000	96,361
10,001-20,000	32,341
20,001 or more	5,955
All trucks	733,762

examined at this time. A preliminary analysis suggests that 33 percent of all gasoline-powered tractors may have hard valve seat inserts. These would not be vulnerable to valve seat recession with unleaded gasoline. The remaining 67 percent of the tractors have cast iron inserts or have seats that were machined into the cast iron heads. These tractors are potentially vulnerable to valve seat recession with unleaded fuel if the engines are operated under medium-duty and/or heavy-duty conditions.

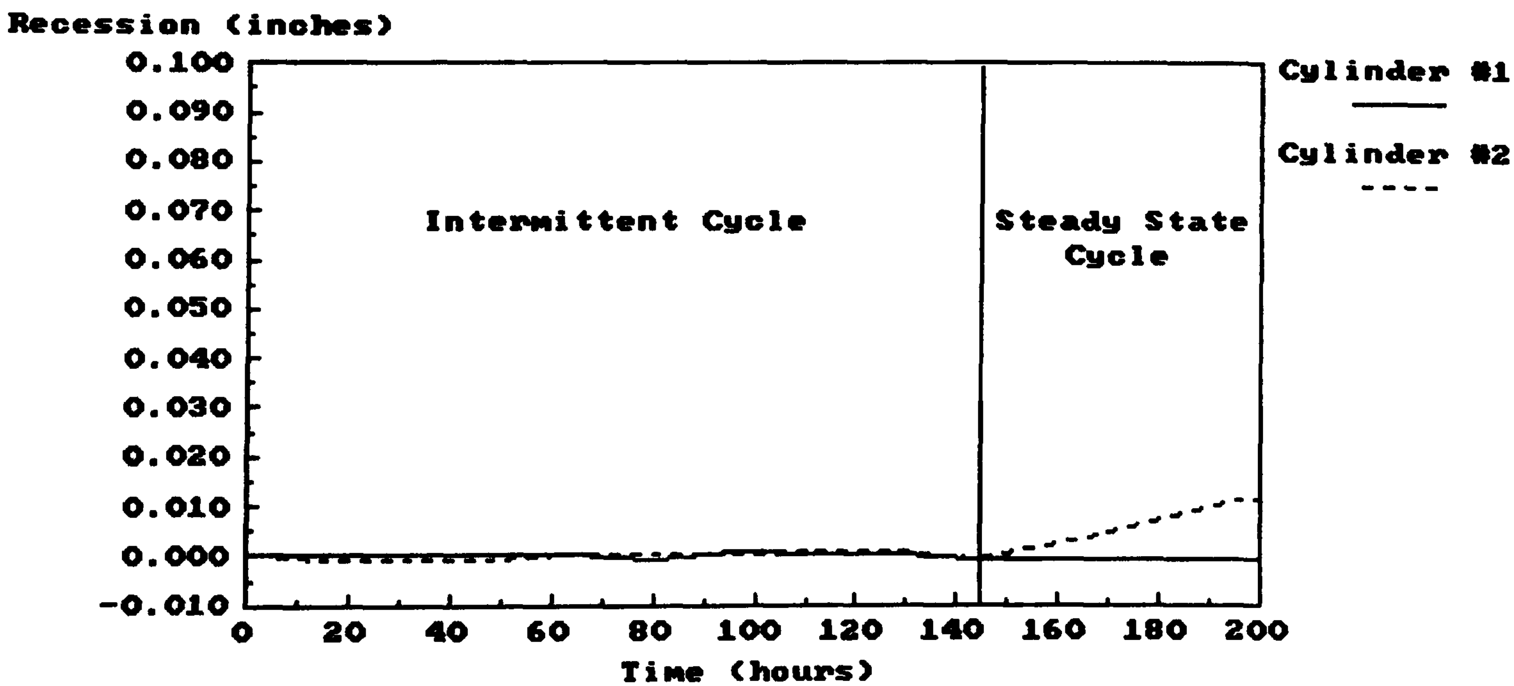
While hundreds of thousands gasoline-powered engines on tractors, combines, trucks and other large farm equipment face no risk of damage if fueled with unleaded gasoline, hundreds of thousands of others need lead or an effective substitute if they are to continue in their present uses without needing an engine overhaul.

Appendix 1

Exhaust Valve Seat Recession by Cylinder

Figure 1

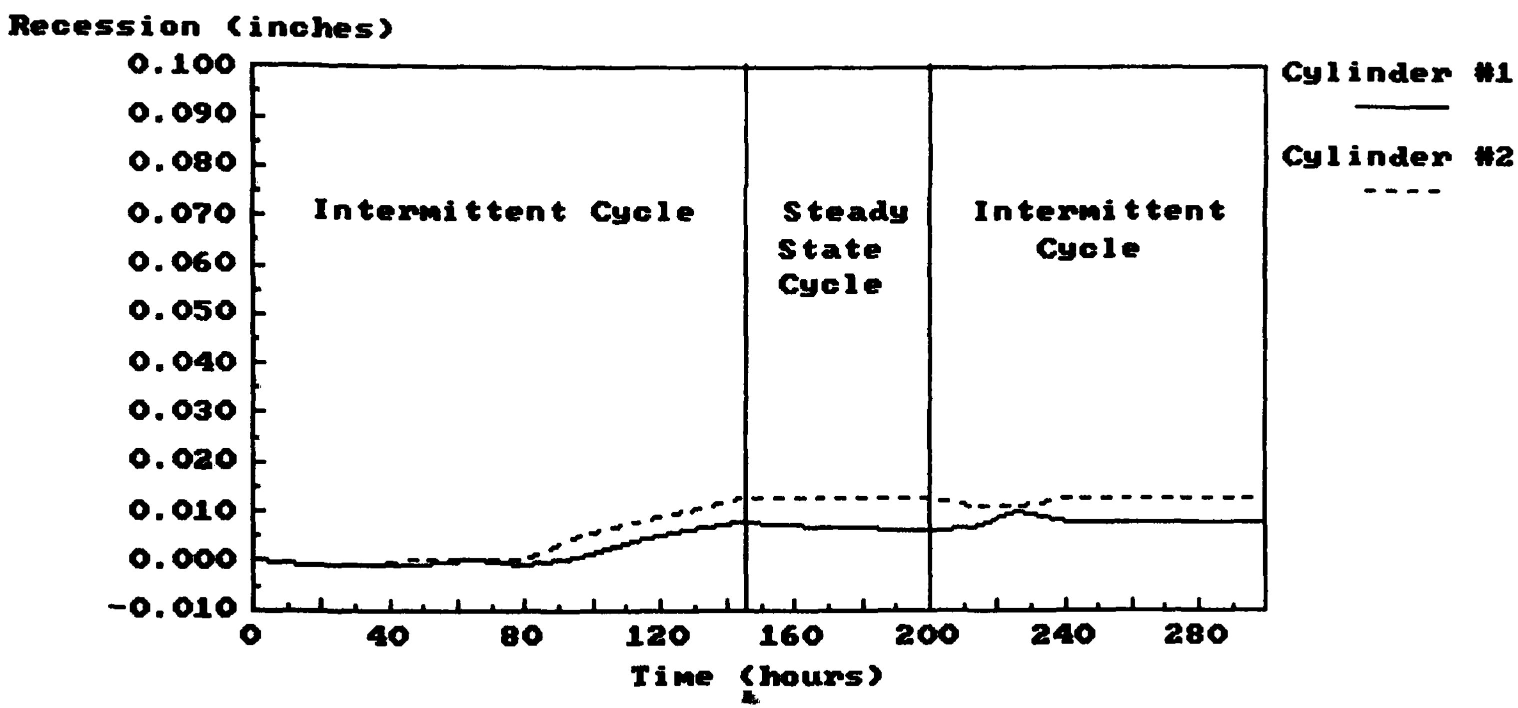
Exhaust Valve Seat Recession
John Deere B, unleaded fuel, run 1
cast iron valve seats



See text for description of duty cycle

Figure 2

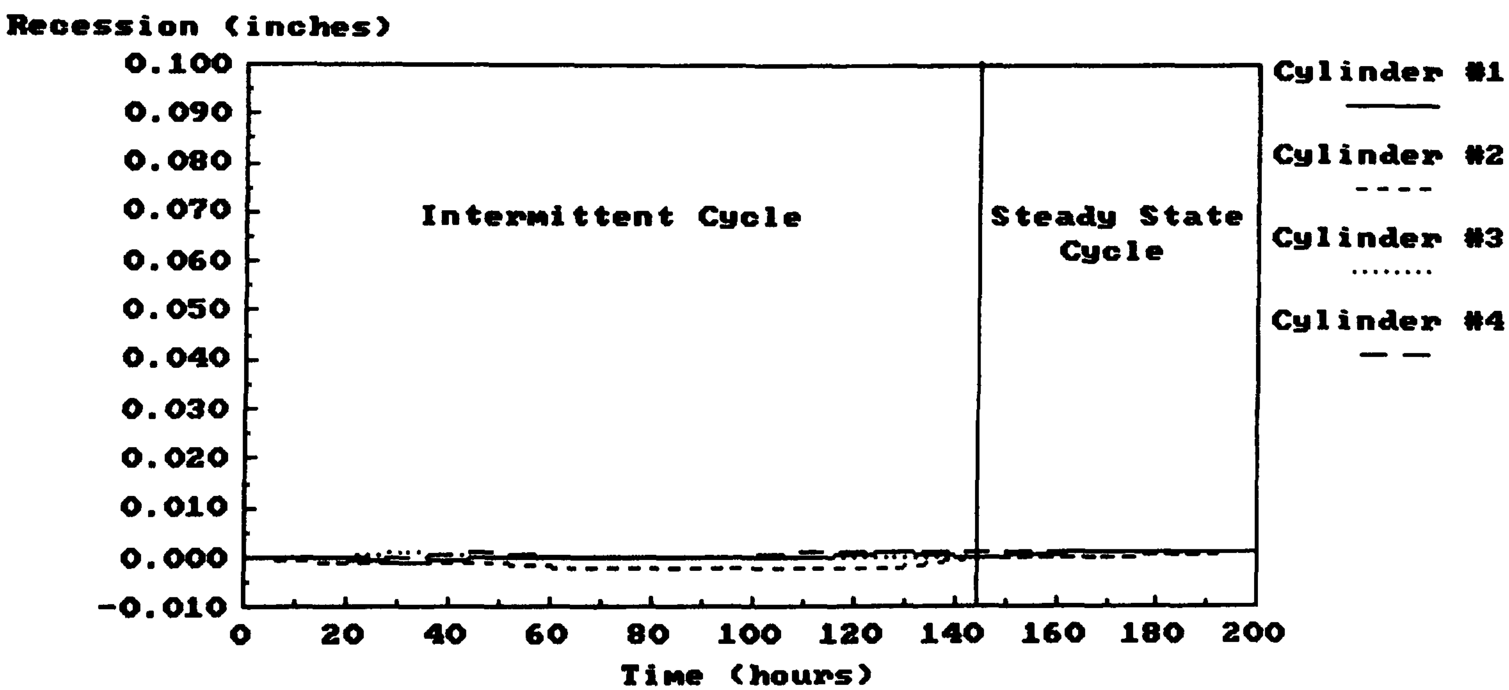
Exhaust Valve Seat Recession
John Deere B, unleaded fuel, run 2
cast iron valve seats



See text for description of duty cycle

Figure 3

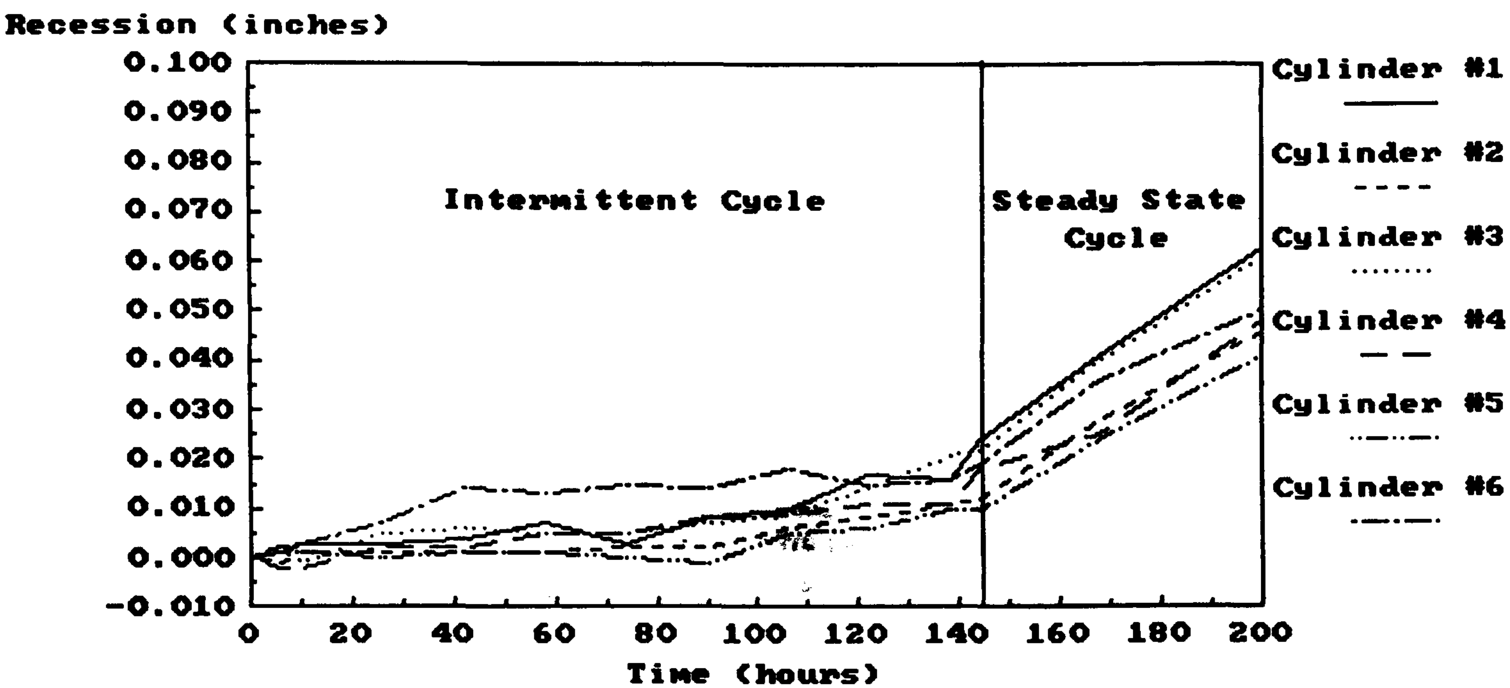
Exhaust Valve Seat Recession
Farmall H, unleaded fuel
cast iron valve seats



See text for description of duty cycle

Figure 4

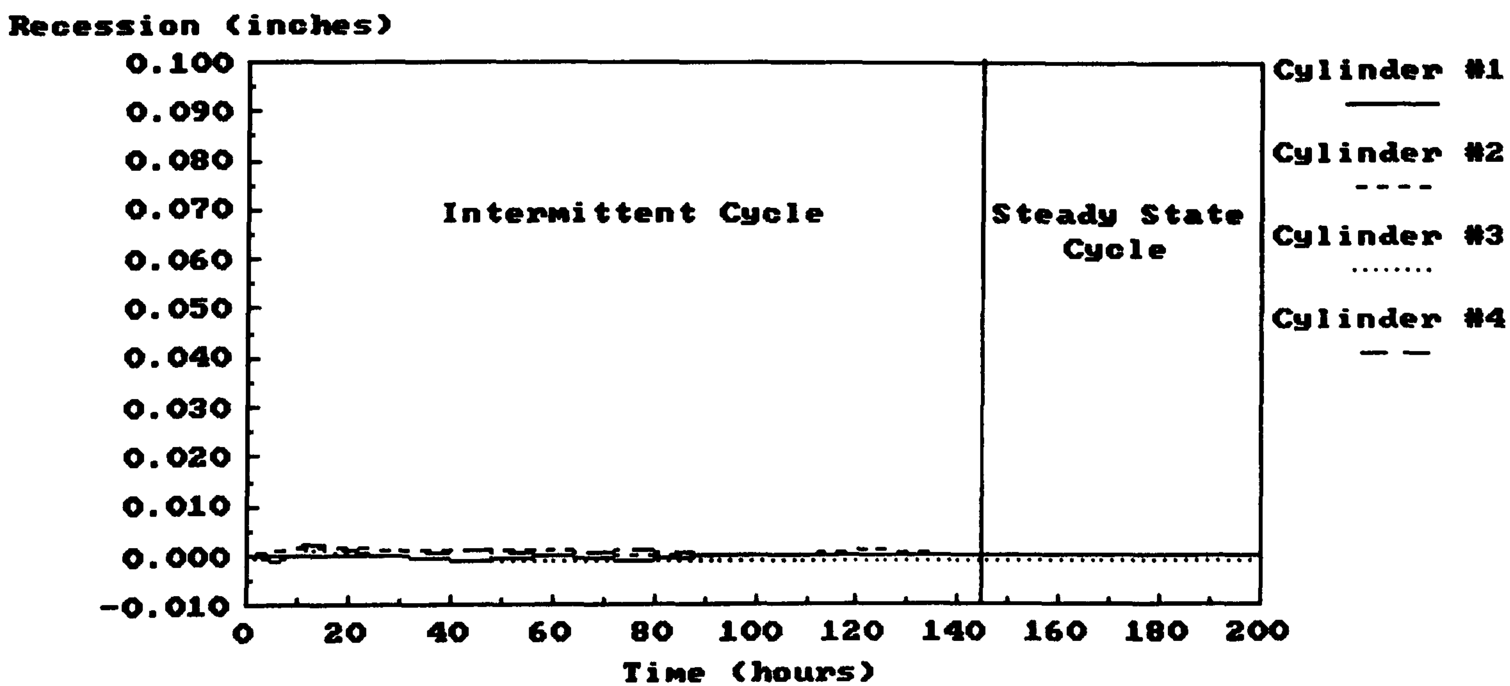
Exhaust Valve Seat Recession
John Deere 303 CID, unleaded fuel
cast iron valve seats



See text for description of duty cycle

Figure 5

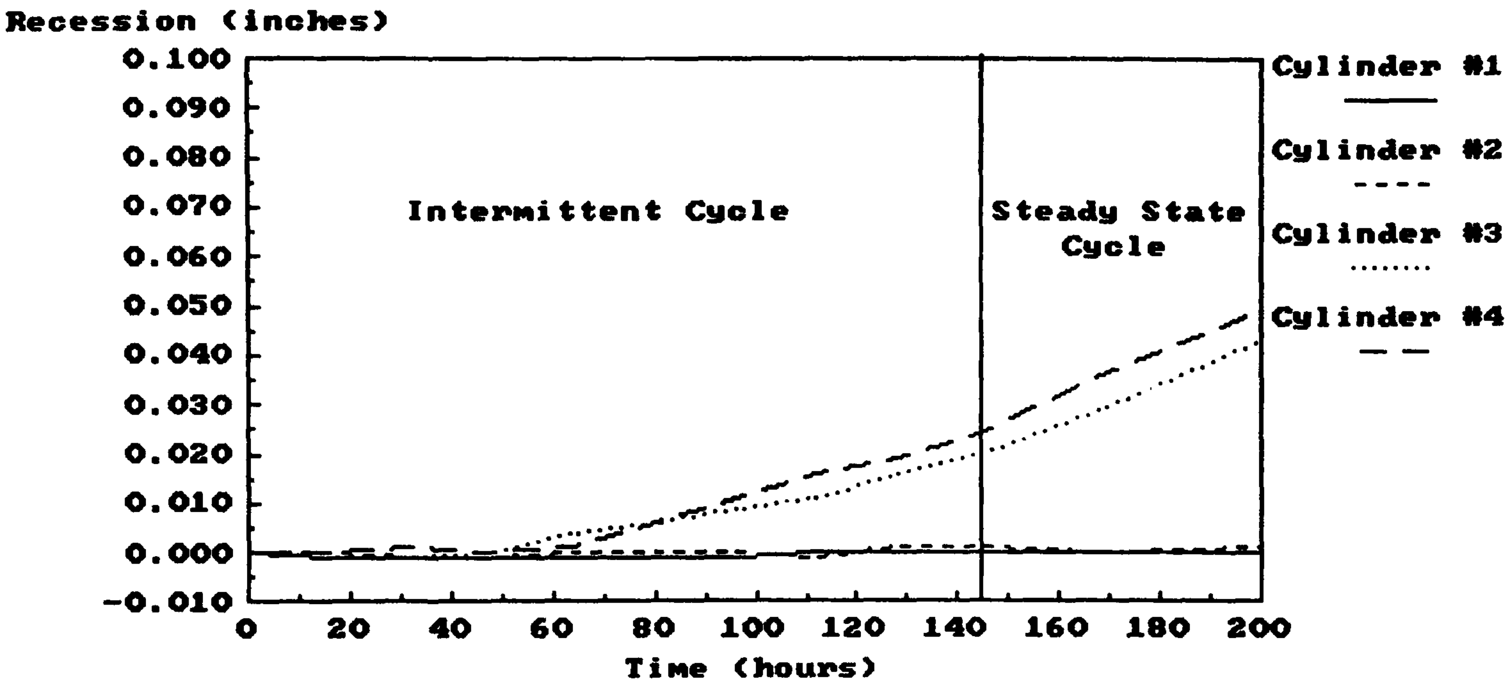
Exhaust Valve Seat Recession
IH 240, unleaded fuel, run 1
cast iron valve seats



See text for description of duty cycle

Figure 6

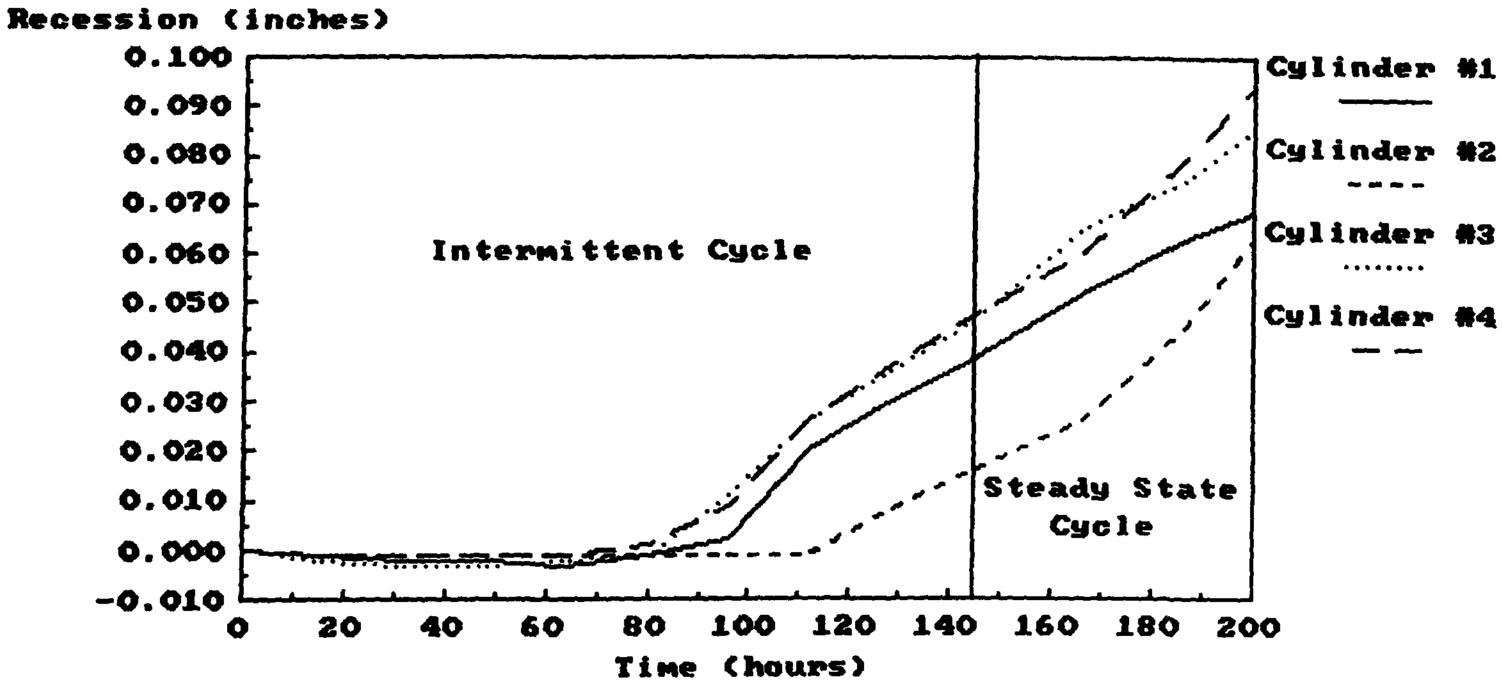
Exhaust Valve Seat Recession
IH 240, unleaded fuel, run 2
cast iron valve seats



See text for description of duty cycle

Figure 7

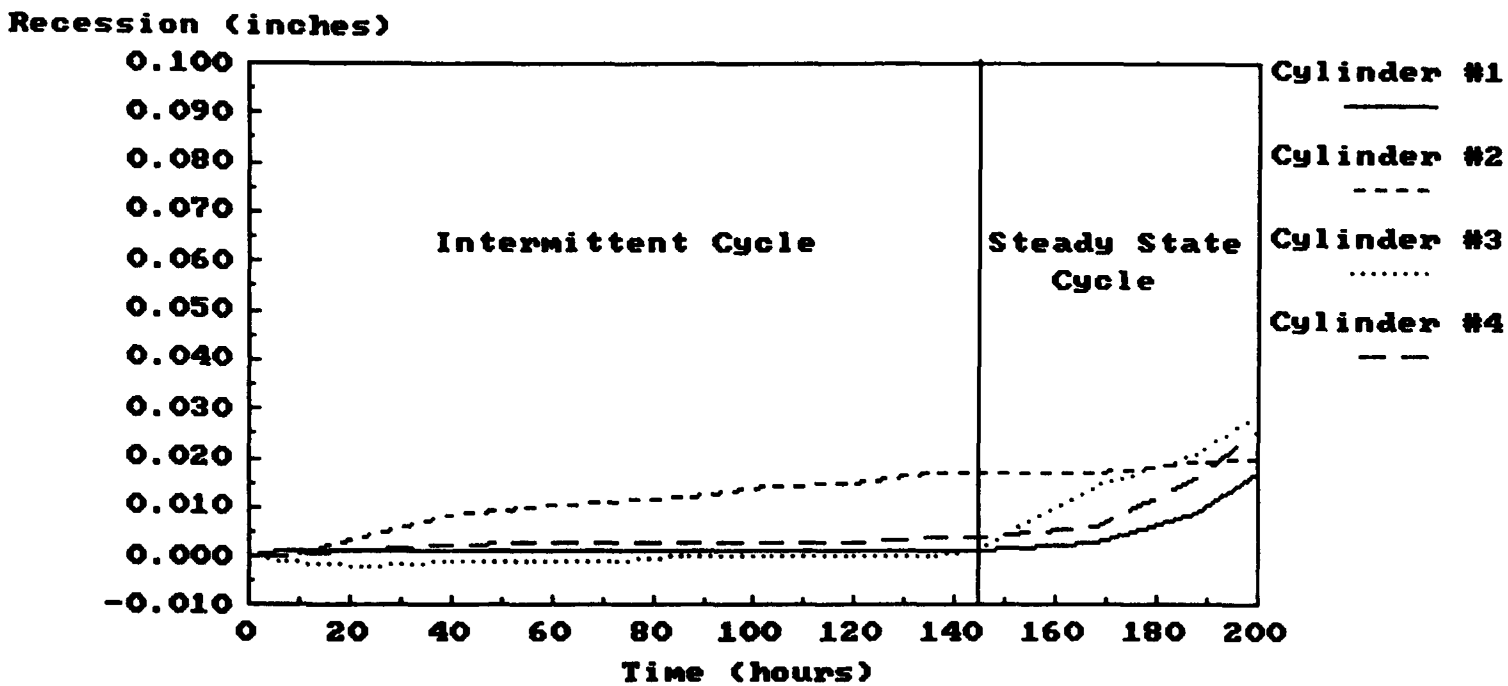
Exhaust Valve Seat Recession
IH 240, unleaded fuel, run 3
cast iron valve seat inserts



See text for description of duty cycle

Figure 8

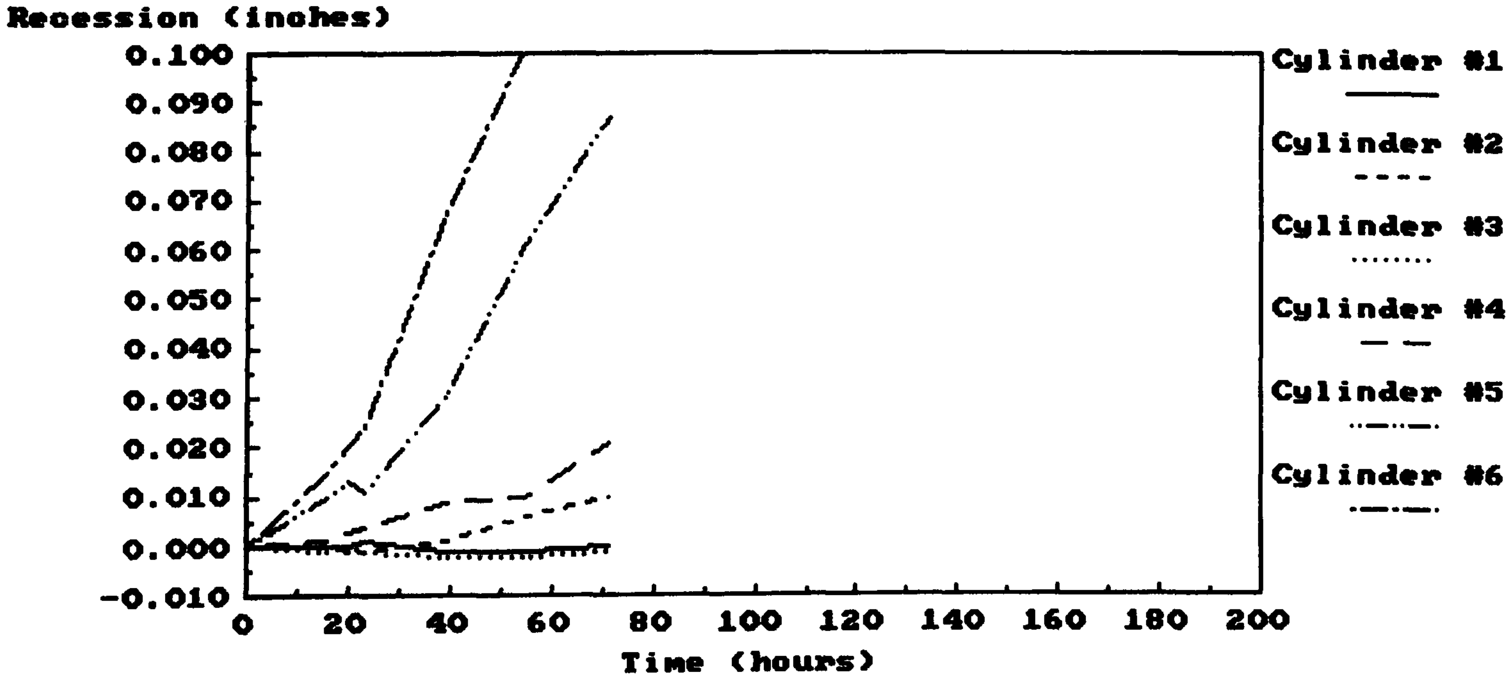
Exhaust Valve Seat Recession
Ford 8N, unleaded fuel
cast iron valve seat inserts



See text for description of duty cycle

Figure 9

Exhaust Valve Seat Recession
GM 292-A, unleaded fuel
cast iron valve seats

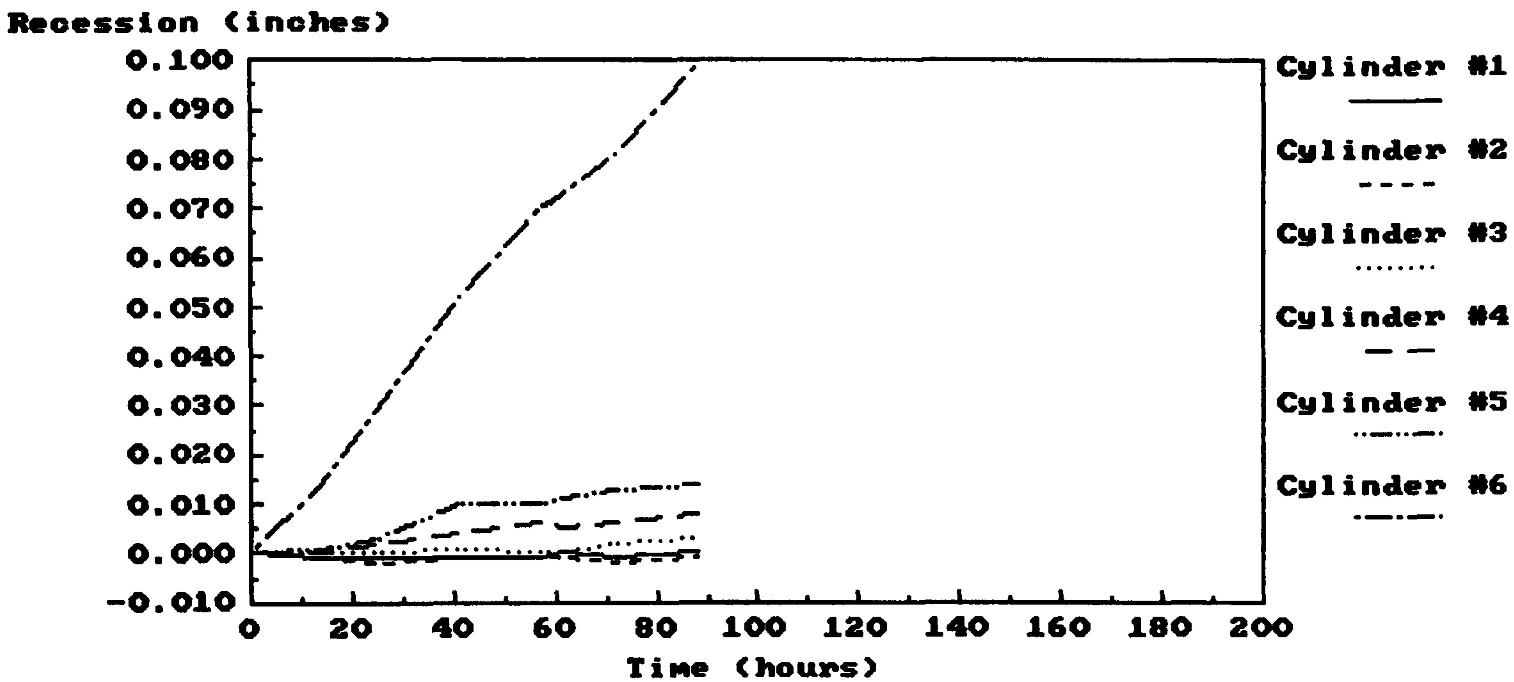


Test terminated at 71 hours due to excessive recession.
Total recession on cylinder # 6 is 0.131 inches.

See text for description of duty cycle

Figure 10

Exhaust Valve Seat Recession
GM 292-B, unleaded fuel
cast iron valve seats
lighter duty cycle

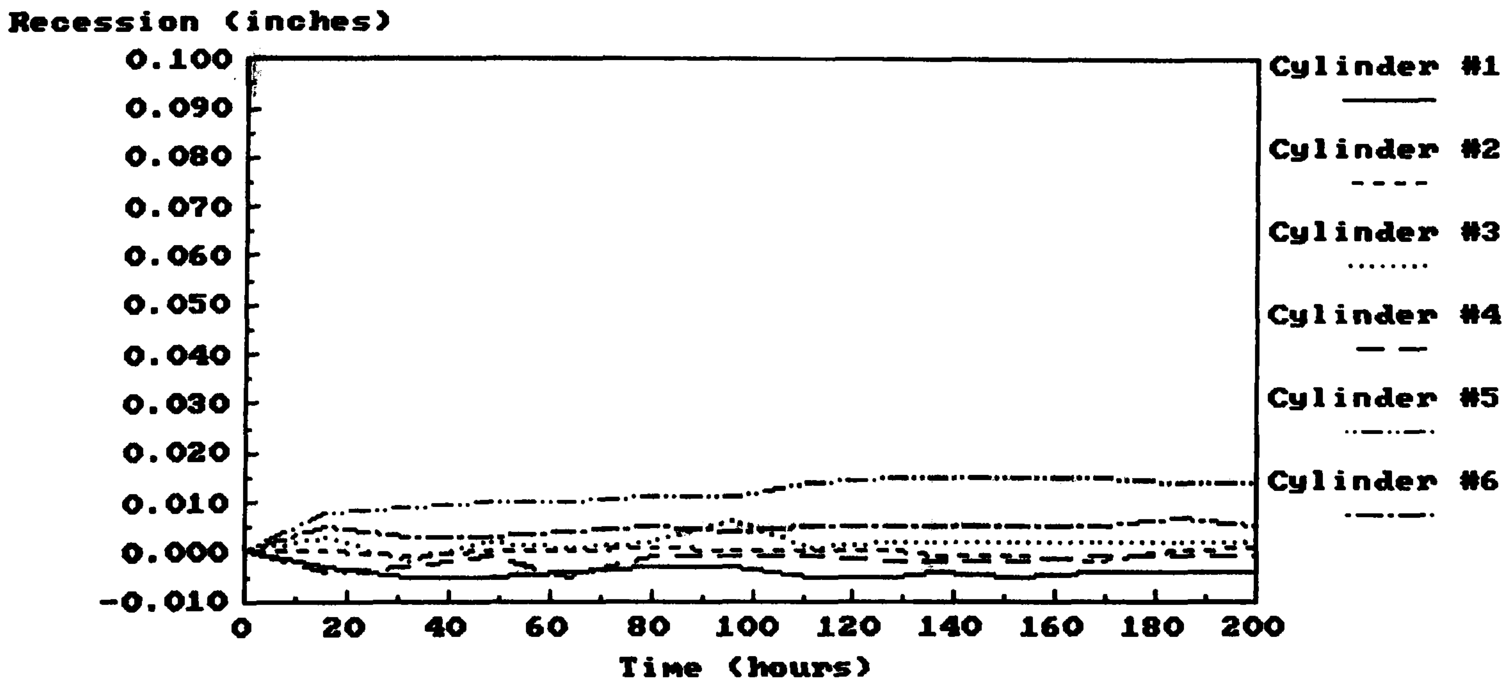


Duty cycle changed to eliminate the 3600 rpm portion of the cycle. Test terminated at 88 hours due to excessive recession. Maximum recession, 0.099 inches.

See text for description of duty cycle

Figure 11

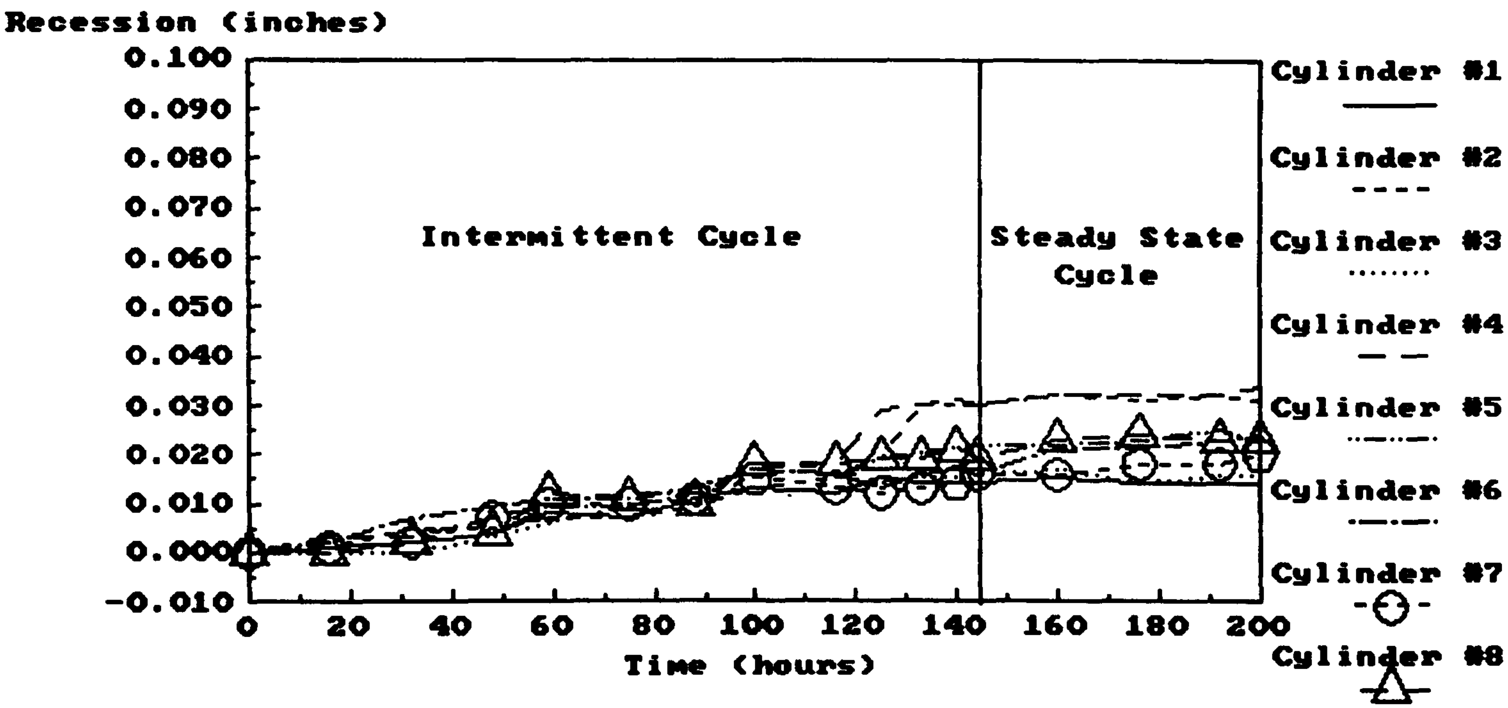
Exhaust Valve Seat Recession
GM 292-B, unleaded fuel
induction-hardened cast iron valve seats



See text for description of duty cycle

Figure 12

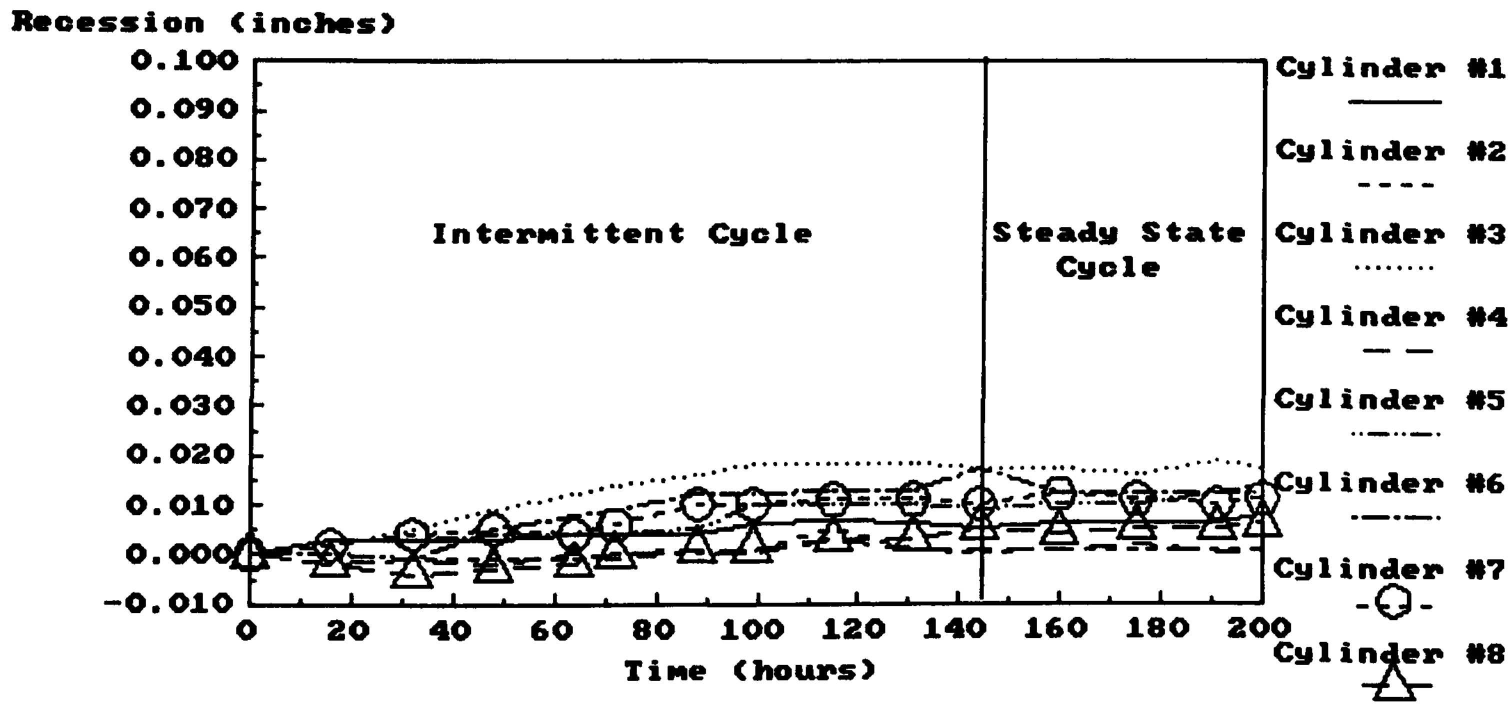
Exhaust Valve Seat Recession
GM 454, unleaded fuel
induction-hardened cast iron valve seats



See text for description of duty cycle

Figure 13

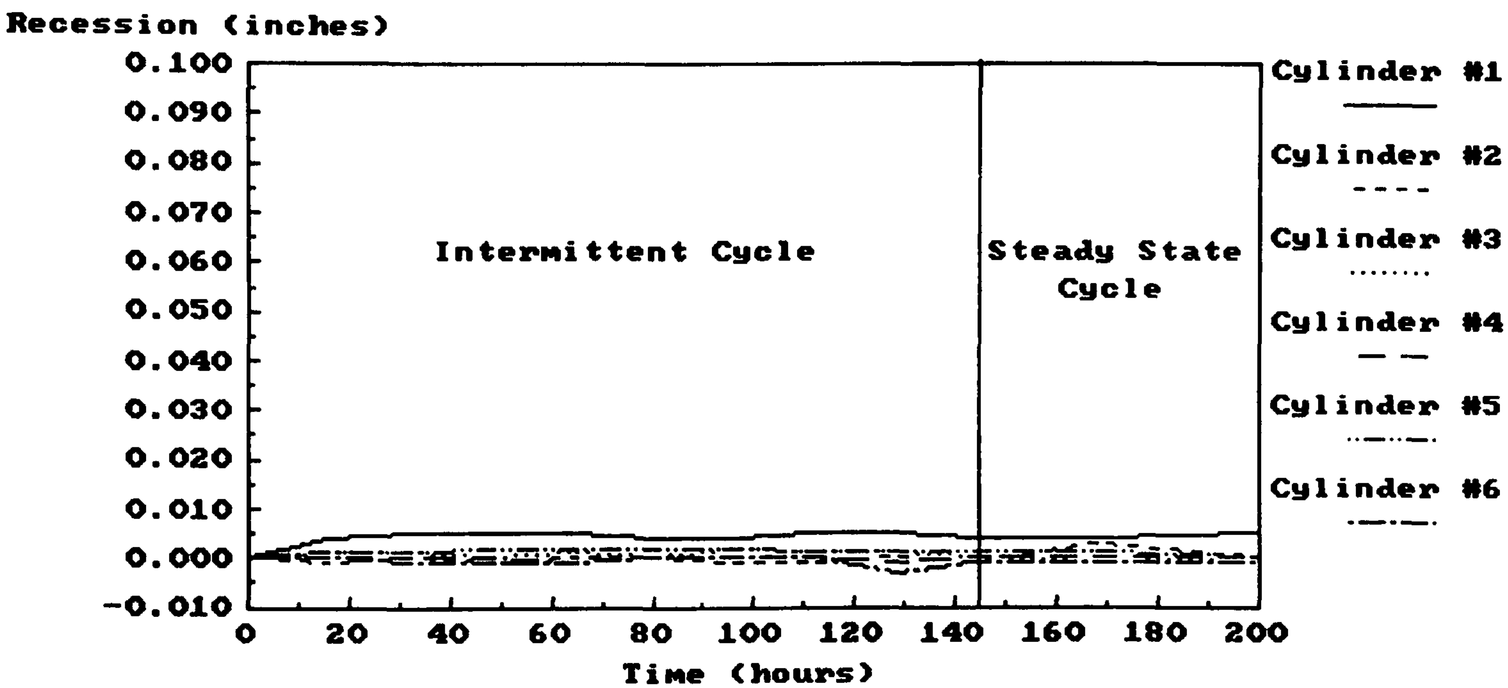
Exhaust Valve Seat Recession
GM 454, unleaded fuel
steel valve seat inserts



See text for description of duty cycle

Figure 14

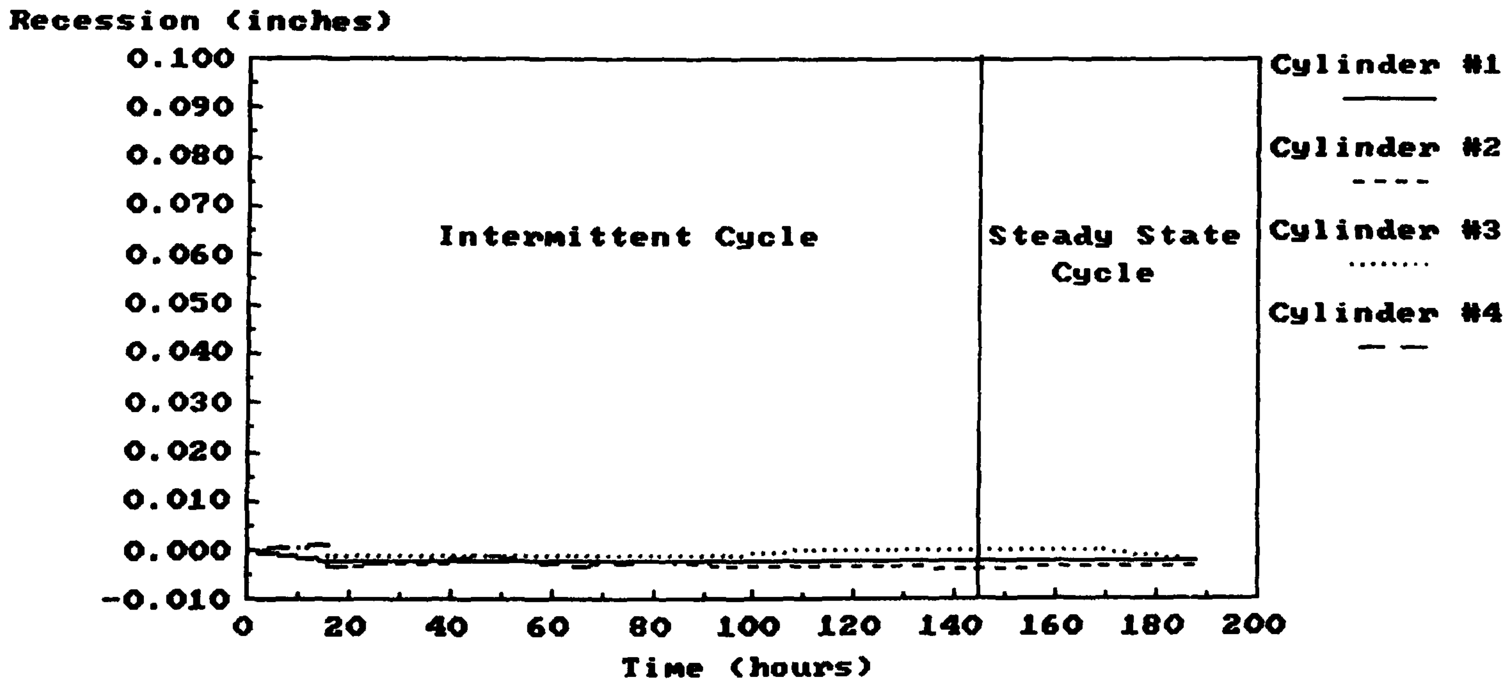
Exhaust Valve Seat Recession
John Deere 303 CID, 0.10 gplg
cast iron valve seats



See text for description of duty cycle

Figure 15

Exhaust Valve Seat Recession
IH 240, 0.10 gplg
cast iron valve seats

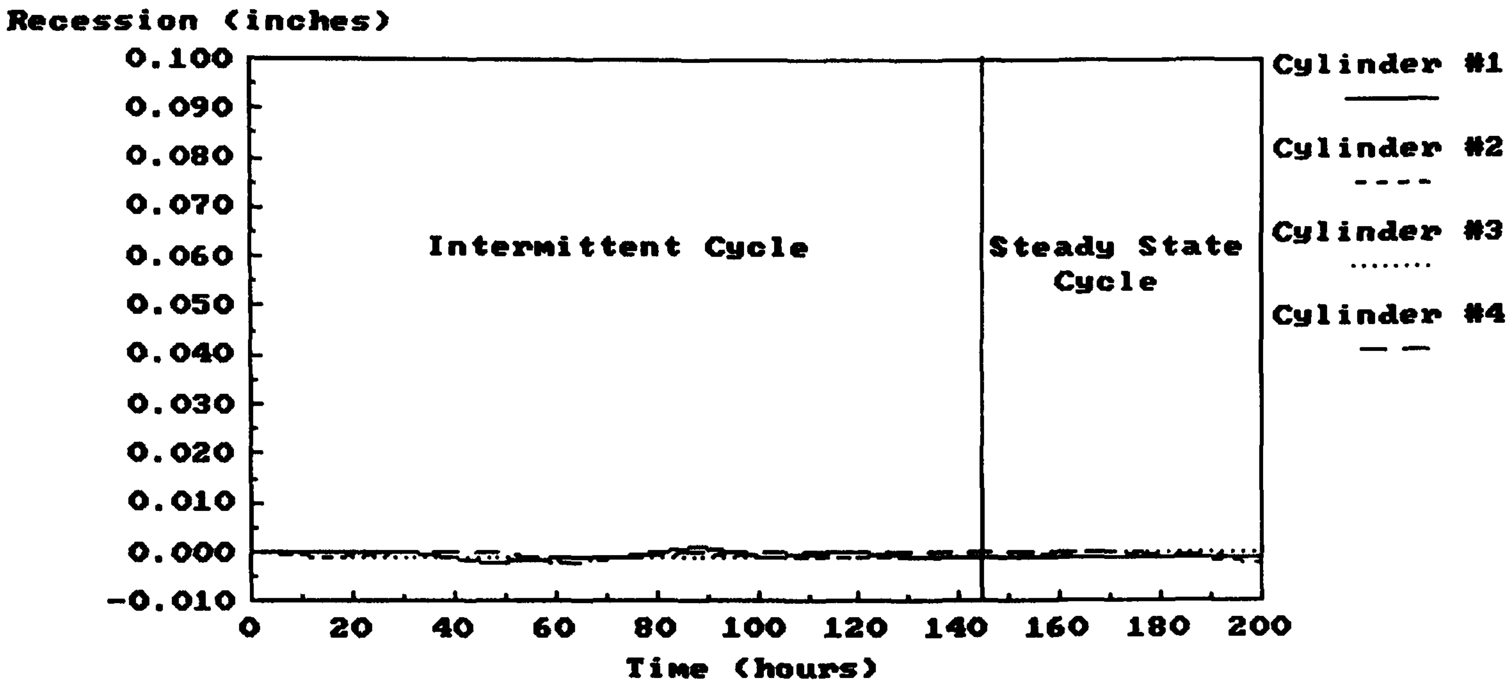


Test terminated at 188 hours due to broken crankshaft

See text for description of duty cycle

Figure 16

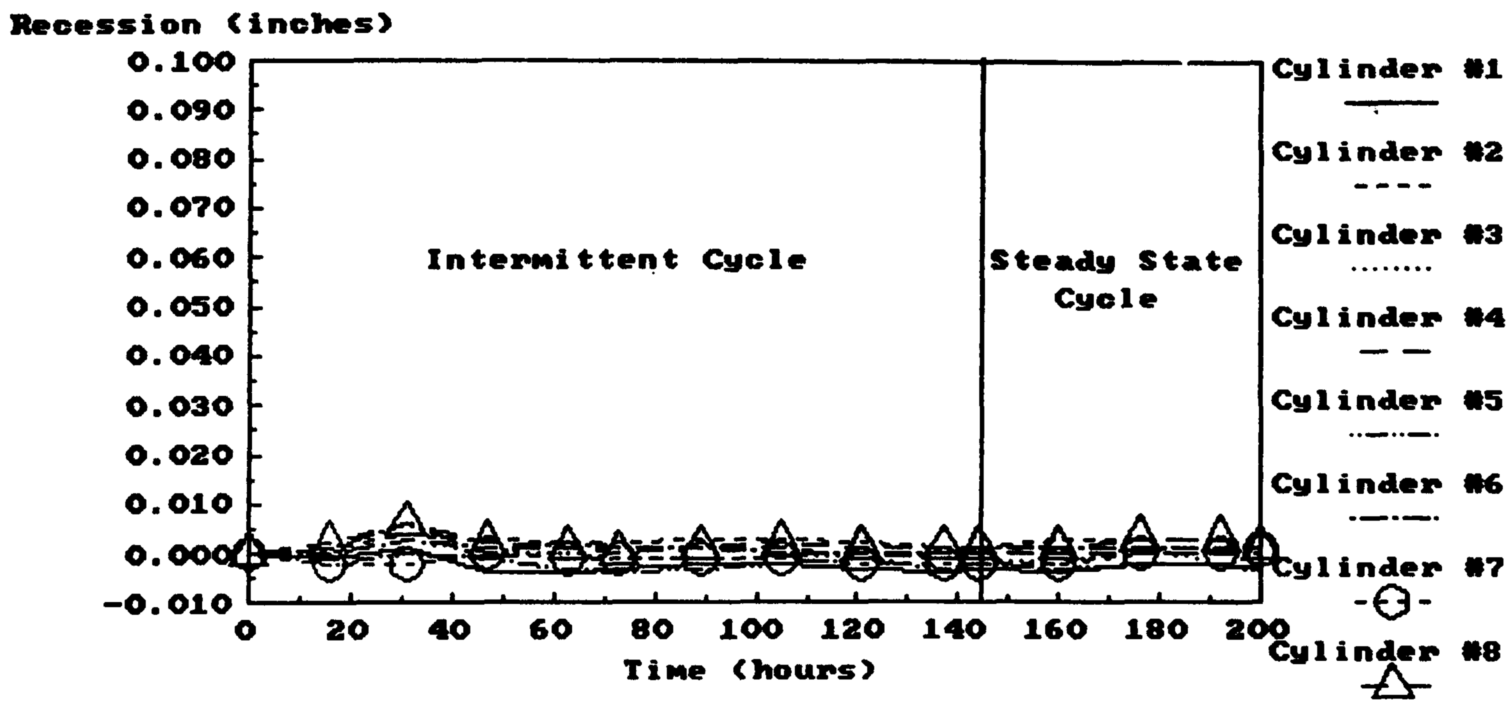
Exhaust Valve Seat Recession
IH 240, 0.10 gplg
cast iron valve seat inserts



See text for description of duty cycle

Figure 17

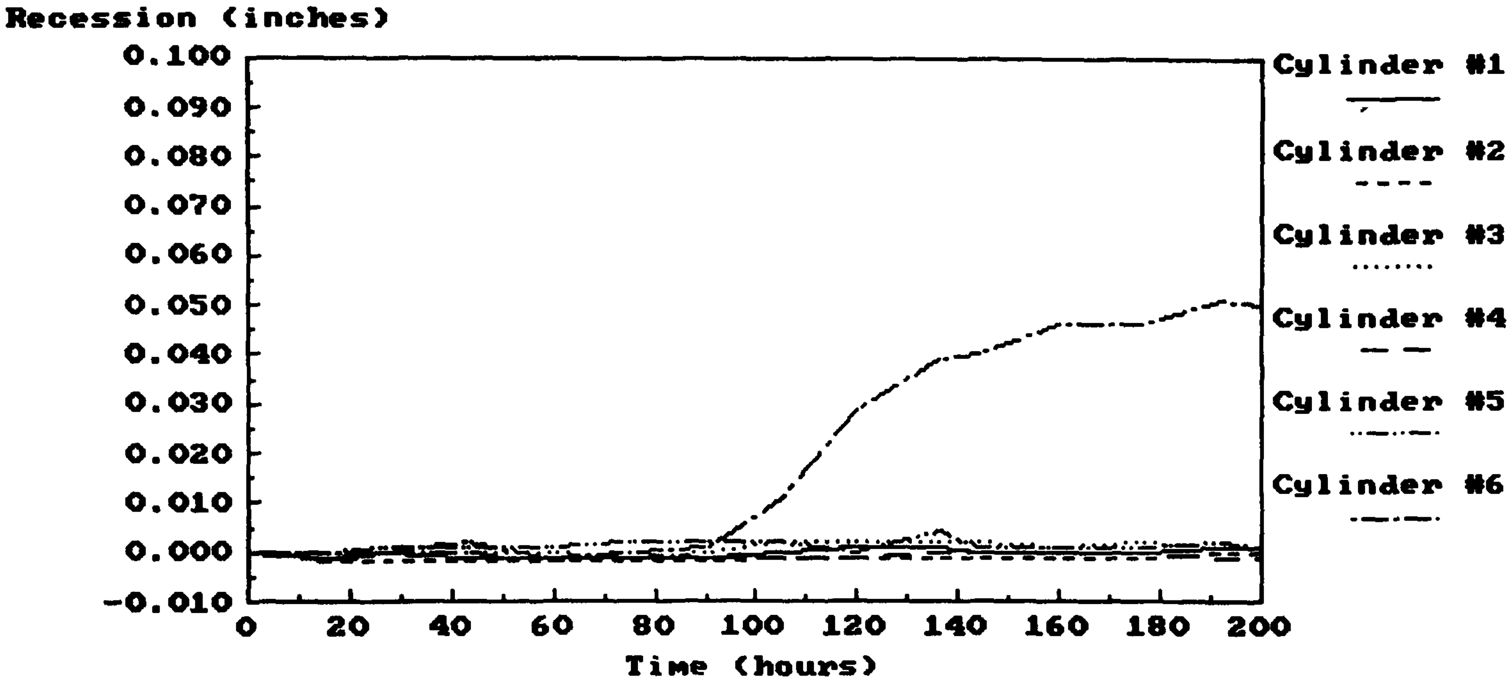
Exhaust Valve Seat Recession
GM 454, 0.10 gplg
induction-hardened cast iron valve seats



See text for description of duty cycle

Figure 18

Exhaust Valve Seat Recession
GM 292-A, 0.10 gplg, run 1
cast iron valve seats

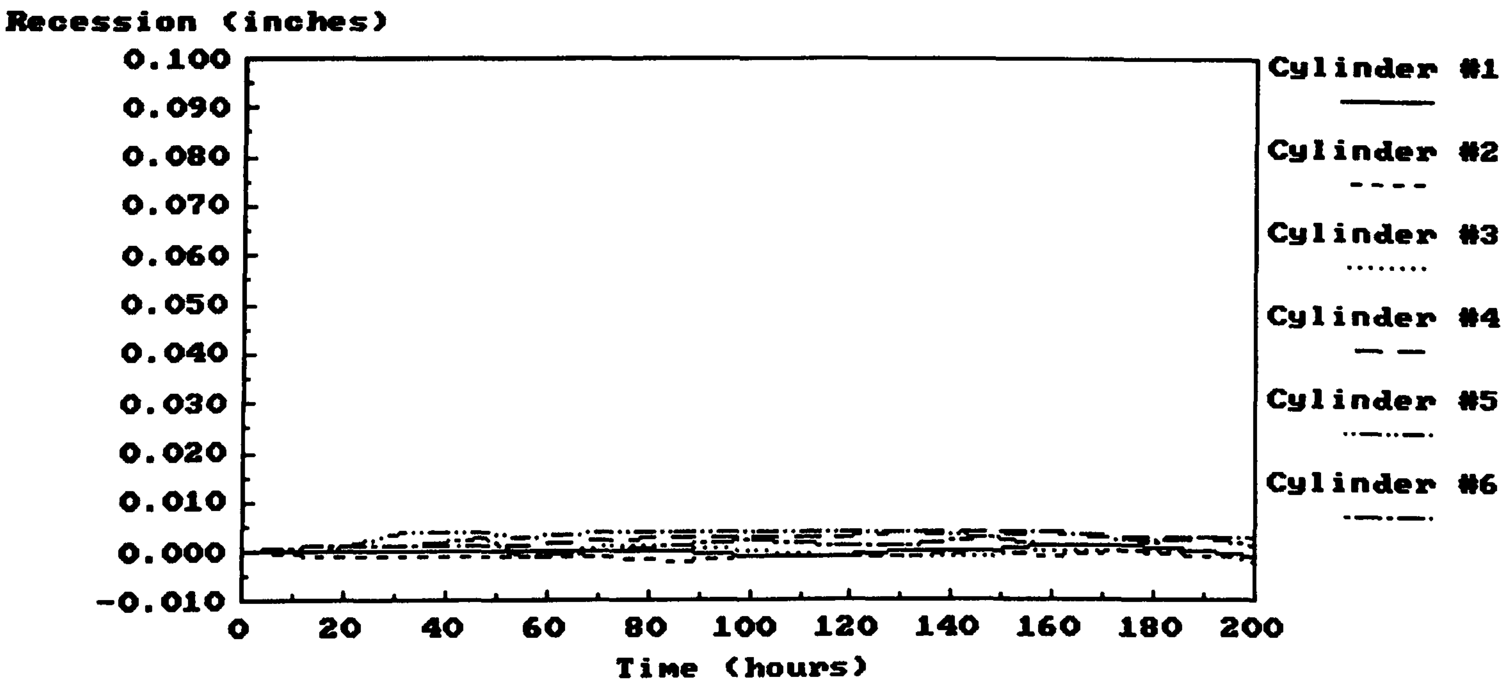


Cylinder head gasket replaced at 120 hours

See text for description of duty cycle

Figure 19

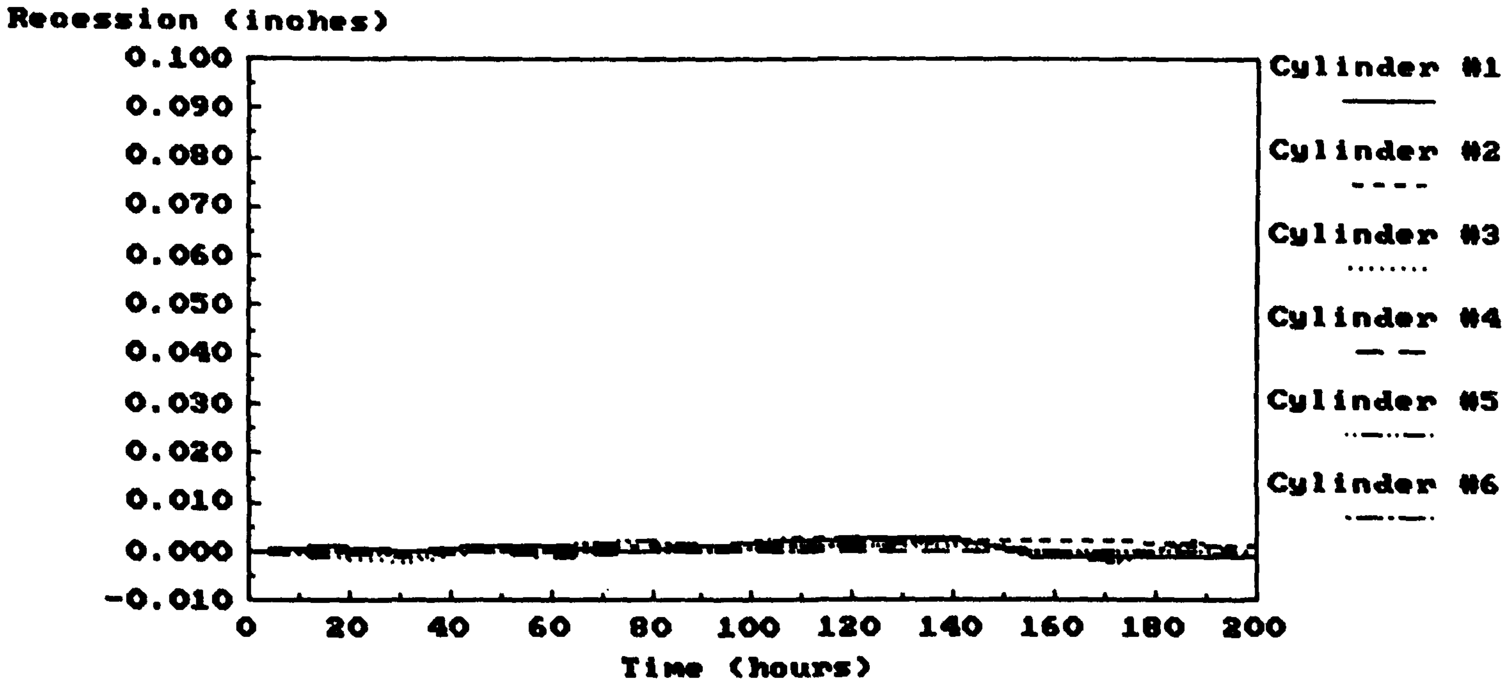
Exhaust Valve Seat Recession
GM 292-A, 0.10 gplg, run 2
cast iron valve seats



See text for description of duty cycle

Figure 20

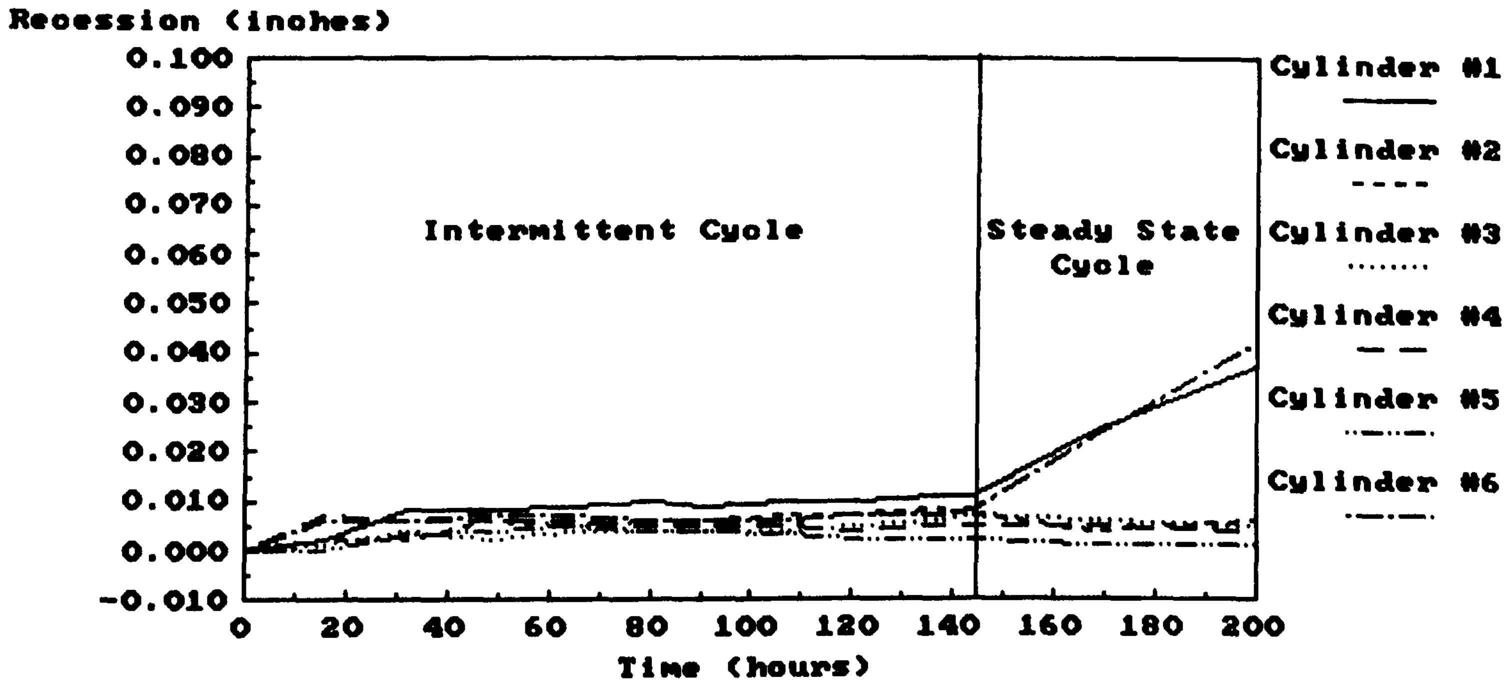
Exhaust Valve Seat Recession
GM 292-B, 0.10 gplg
cast iron valve seats



See text for description of duty cycle

Figure 21

Exhaust Valve Seat Recession
John Deere 303 CID, Lubrizol "PowerShield"
cast iron valve seats

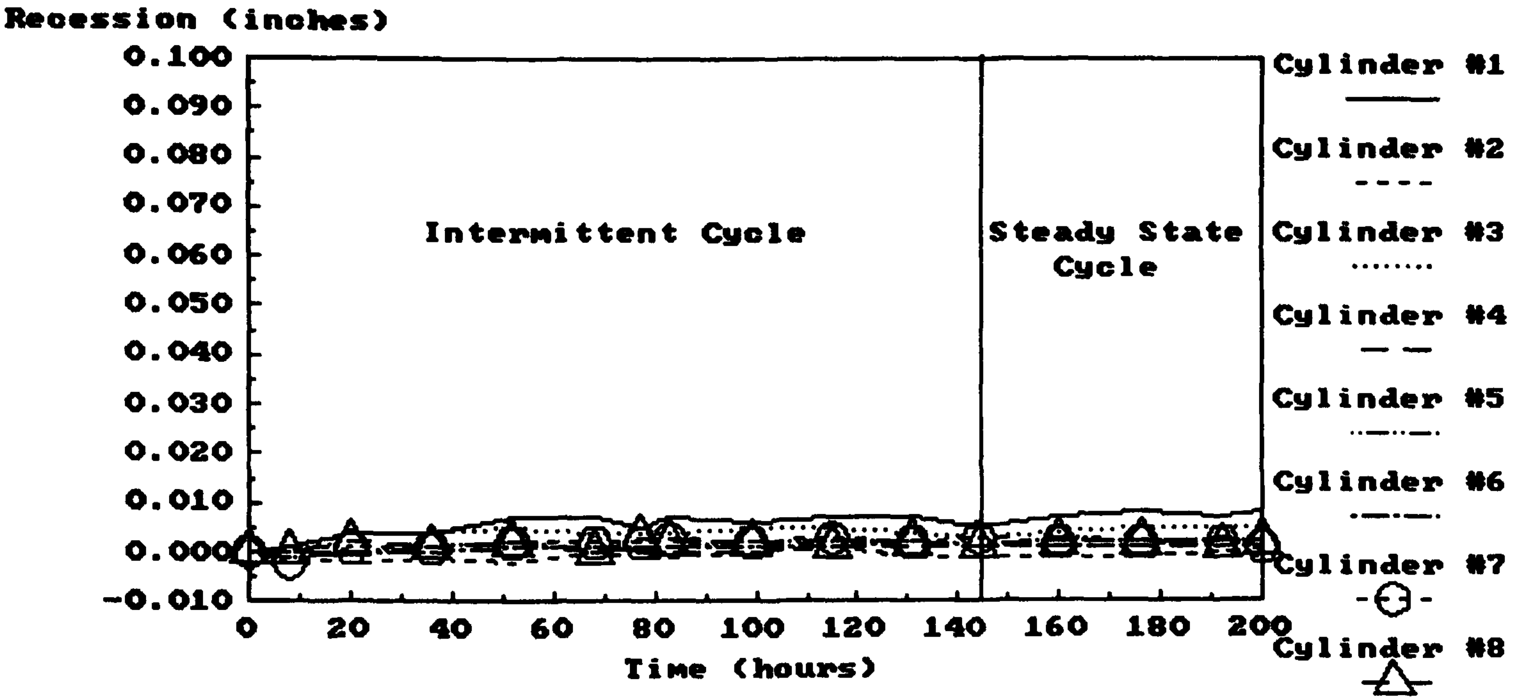


"PowerShield" additive used at 250 pounds per 1,000 barrels of gasoline

See text for description of duty cycle

Figure 22

Exhaust Valve Seat Recession
GM 454, Lubrizol "PowerShield"
induction-hardened cast iron valve seats

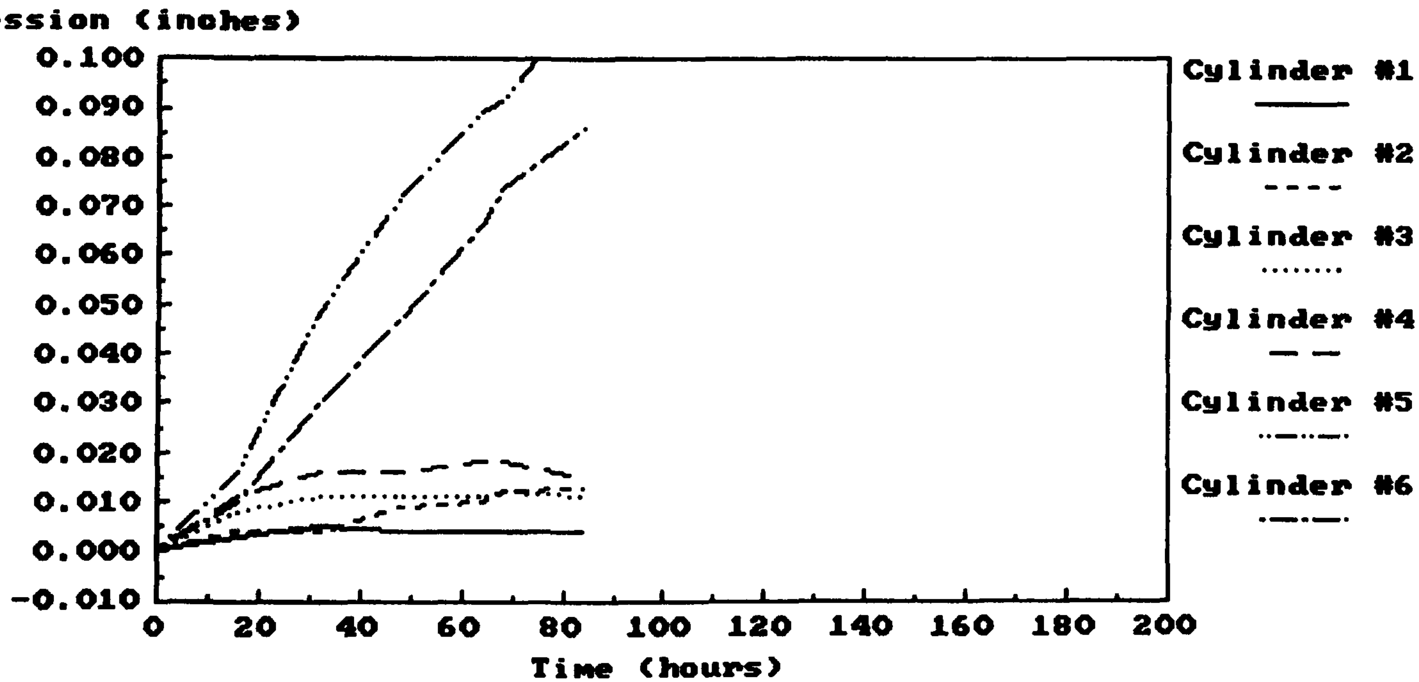


"PowerShield" additive used at 250 pounds per 1,000 barrels of gasoline

See text for description of duty cycle

Figure 23

Exhaust Valve Seat Recession
GM 292-A, Lubrizol "PowerShield"
cast iron valve seats



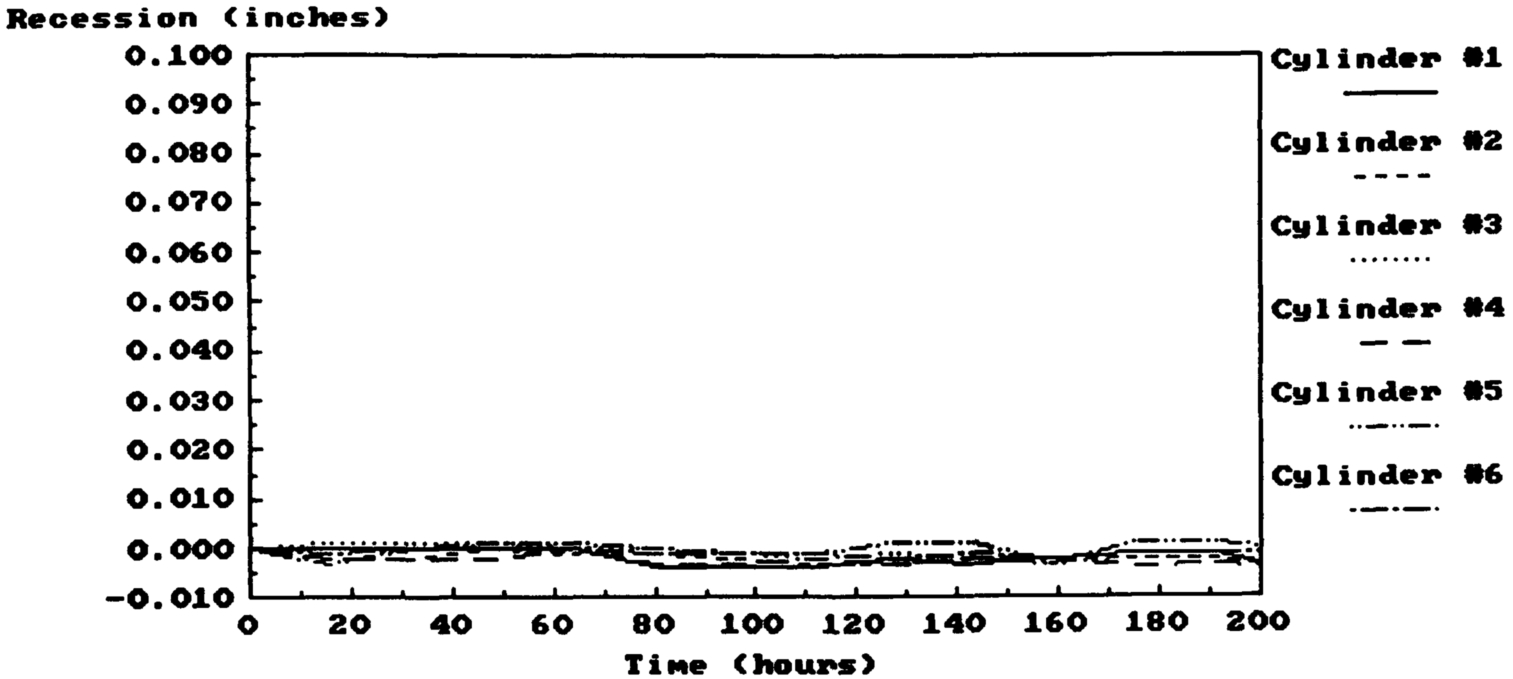
"PowerShield" additive used at 250 pounds per 1,000 barrels of gasoline

Test terminated at 84 hours due to excessive recession. Maximum recession, 0.112 inches.

See text for description of duty cycle

Figure 24

Exhaust Valve Seat Recession
GM 292-B, Lubrizol Concentrated "PowerShield"
cast iron valve seats

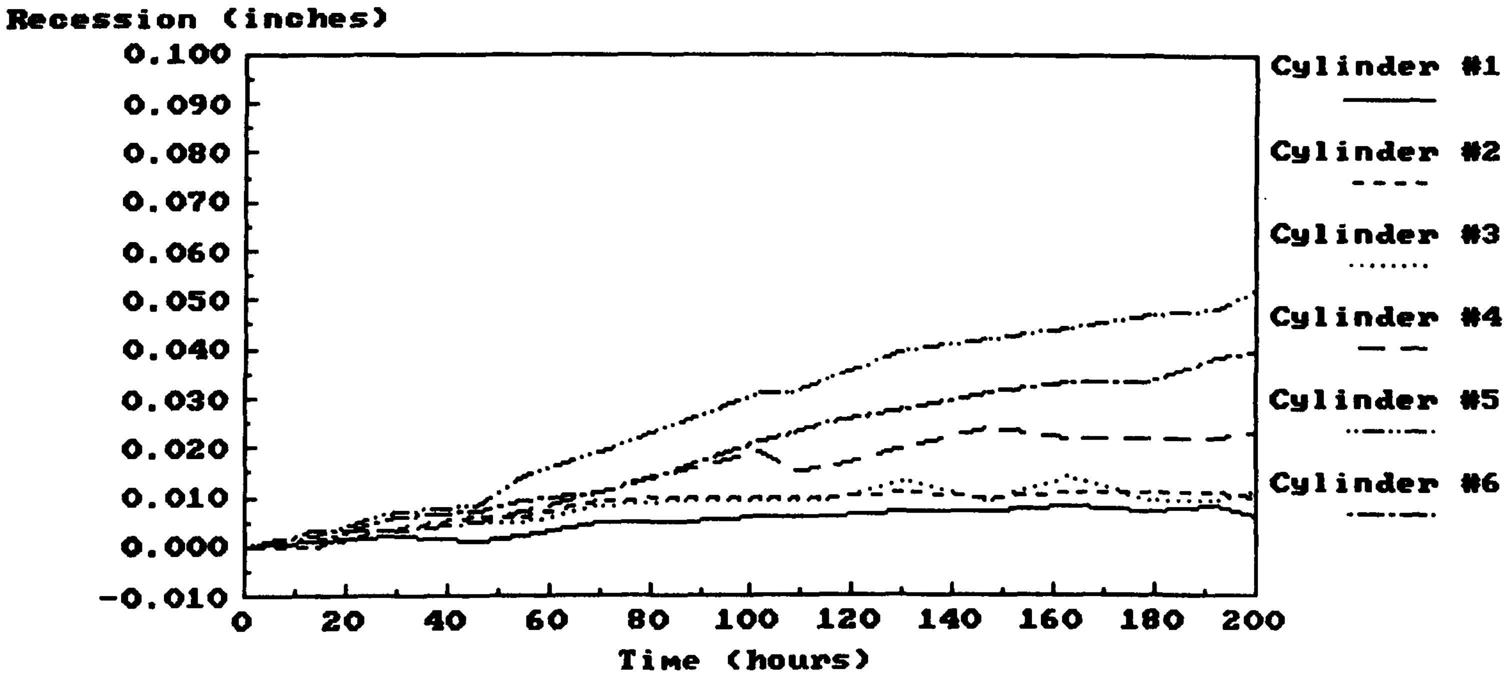


"PowerShield" additive used at 1,000 pounds per 1,000 barrels of gasoline

See text for description of duty cycle

Figure 25

Exhaust Valve Seat Recession
GM 292-A, DuPont Additive
cast iron valve seats



DuPont additive used at 200 pounds per 1,000 barrels of gasoline

See text for description of duty cycle

Appendix 2

Consultants Evaluations of Engine Testing Performed by NIPER

March 2, 1987

Mr. Richard G. Kozlowski
Director, Field Operations and Support Division
EN-397F
U. S. Environmental Protection Agency
Washington, DC 20460

Dear Mr. Kozlowski:

The purpose of this letter is to provide comments on the testing program involving agricultural engines that was conducted by the National Institute for Petroleum and Energy Research (NIPER) at Bartlesville, Oklahoma. The final report resulting from that study is entitled "Effect of Low Levels of Lead and Alternative Additives to Lead on Engines Designed to Operate on Leaded Gasoline". In order to put my comments into perspective, some background information on the overall study will be given.

Background

During the latter part of Calendar Year 1985, a proposed test plan was developed by the Environmental Protection Agency (EPA) in cooperation with the U. S. Department of Agriculture (USDA). That test plan was reviewed and commented on in December 1985 by representatives from various engine manufacturers, universities, government agencies, organizations representing the farmers and other interested parties. An EPA/USDA meeting was held in January 1986 with members of the various reviewing groups to discuss the development of the testing program. The contractor was under contract to do the work by early summer of 1986 and actual engine testing was begun in June 1986. The draft final report was delivered to EPA for review in January 1987.

Because of a variety of different equipment configurations ranging from two to eight cylinder engines, laboratory modifications were necessary to accommodate the various engines. Some engines required pressurized cooling systems, while others operated at atmospheric pressure. Some older engines used in the study had carburetor systems that were inherently poor in their ability to control air-fuel ratios. Procedures for determining valve seat hardness and recession during the accumulations had to be developed by the contractor.

Several factors unrelated to the fuels being tested, resulted in setbacks of the experimental schedule. They included: failures of dynamometer equipment; mechanical failures of engines; and an unusual amount of rainfall in the vicinity of the contractor site which flooded the laboratory.

Performance of Contractor

The contractor has done an excellent job in conducting the testing program and executing the various tasks on a reasonable time schedule, considering the short lead time for setting up the experiments and the many setbacks that were beyond the contractor's control. The quality of the data is as good as could be expected, considering the limitations on the budget and the number of engines available for testing. The methods developed for determining valve seat hardness and recession during the accumulation of hours were adequate for the purposes of the study. The valve seat recession measurements taken during the accumulation of hours were backed—up by bench inspections of the cylinder heads. The bench measurements were made before the start of the accumulation of hours on the engines and after the completion of each test by an independent certified automotive mechanic. This was an excellent method for confirming the accuracy of valve seat recession measurements because the two separate measurements were made totally independent from each other.

The testing program was well conceived with a representative cross section of engine types being incorporated into the testing. The chosen engine duty cycles were good in that they served to show valve seat recession as a function of fuel type for some engines, while other engines showed no valve seat recession with any of the fuels. In general, the contractor performed well in executing the experimental testing in a timely fashion and produced a technical report that provides useful data on the effect of gasoline lead levels and alternative additives to lead on valve seat recession in engines that were originally designed for leaded gasoline. However, at no fault of the contractor, EPA or USDA (because of budget constraints), it would have been helpful to have had more engines in the testing program. This aspect will be discussed further in the following section.

Adequacy of the Test Data

The data from the program are adequate for the purposes of the study with the exception of two areas. One area relates to the question of whether or not lead at 0.10 gram per gallon in gasoline is adequate to prevent valve seat recession in all of the engines tested. The Ford 8N engine was not tested on 0.10 gram per gallon leaded gasoline, therefore, no data are available to determine if 0.10 gram per gallon leaded gasoline would prevent valve seat recession in this engine. The GM 292 engine showed significant valve seat recession in one cylinder with 0.10 gram per gallon leaded gasoline. Because a head gasket failure occurred mid—way through the accumulation of hours on this first test, the engine was rebuilt and retested and 10 thousands of an inch recession was noted for one valve seat. A duplicate GM 292 engine was tested later in the program with no observed valve seat recession. Although a head gasket failure occurred in the first test, the engine was repaired at 120 hours and the test was continued to 200 hours. Valve seat recession continued after the head gasket replacement at 120 hours. Although the rate of valve seat recession was lower after the head gasket replacement than that just prior to the head gasket failure, there appears to be no basis for throwing out this test result. The overall results from the GM 292 engine tests for 0.10 gram per gallon leaded gasoline are mixed. Further engine testing is required to determine whether or not 0.10 gram per gallon leaded gasoline will provide adequate protection against valve seat recession in the GM 292 engine.

The second area which needs further study is alternative additives. One additive (additive "D") tested in the current program showed good results when blended at a concentration of 1,000 pounds of additive to 1,000 barrels of gasoline. However, the lubricating oil wear metals analyses for the additive "D" test showed increased concentrations of iron, chrome, sodium and molybdenum when compared to other fuel tests with the same GM 292 engine. These results indicate the need for longer term engine durability testing with the additive to determine any adverse effects on the engine such as deposit formation in the engine or increased wear. Since the additive contains sodium and possibly other metallic elements, an assessment should be made to determine if the use of the additive might result in potential degradation of air quality.

Recommendations for Future Work

Should additional engine testing be considered in the future, I suggest that additional studies be done on alternative additives as a method for preventing valve seat recession. In addition to identifying additives that successfully prevent valve seat recession, once an additive has been shown to be effective, further work would be needed to determine any detrimental effects the additives might have on the engine.

If further testing is done, I recommend that a larger number of engines be tested to account for engine-to-engine, test-to-test, and day-to-day variability. In addition, changes in uncontrolled engine variables such as air-fuel ratio may influence valve seat recession. The experimental tests just completed indicate that a larger number of engines is required to give conclusive results.

An example illustrating the need for a larger number of engines is the International Harvester 240 engine used in the current study. The first test with unleaded gasoline showed no valve seat recession. A repeat test with a slightly softer cylinder head showed exhaust valve seat recession in two cylinders. At this point, one might conclude that the softer cylinder head was responsible for the valve seat recession in the repeat test. However, subsequent inspections to determine the hardness of the cylinder head material near the individual valve seats indicated that the observed valve seat recession in the repeat test probably was not due to differences in hardness between the two cylinder heads. It was also noted that the engine's air-fuel ratio (uncontrolled variable) was significantly leaner for the repeat test which could have contributed to increased valve recession. A third test was run on this engine using unleaded gasoline with cast iron valve seat inserts which resulted in exhaust valve seat recession in all of the cylinders. In the third test, the average daily air-fuel ratio was similar to the first test. The variation in test results for a given system suggests the need for replicate testing for each engine/fuel combination in the testing program.

It is recognized that it is impractical to run every engine type in the overall population. However, once a given set of engines is selected for testing, replicate testing of each engine setup and fuel is highly desirable. In many cases, it is impractical to run enough engines and tests to provide statistically significant results. However, a compromise situation may be appropriate for providing a basis for good engineering judgments. For a test program such as the one just completed, three tests is the minimum number of replicates which would give reasonable confidence in the data. This could be done in two different ways. One way would be to repeat the same test three times on the same engine. The second way would be to run three identical engines simultaneously. Should further testing be considered in the future, I strongly recommend that replicate testing be done to increase confidence in the resulting data.

One way to reduce test–to–test and day–to–day variability, and possibly reduce the number of engine tests required to provide conclusive results, is to control air–fuel ratio. First, one would have to determine the normal operating air–fuel ratio for each operating mode and the variation of air–fuel ratio within each mode for each given engine. Then the air–fuel ratio would be controlled (by means of a special laboratory apparatus) at its "average" value throughout the accumulation of hours on each test. The air–fuel ratio would be controlled at a different value for each operating mode corresponding to the normal air–fuel ratio characteristics of the engine.

Since most of the engines tested showed a problem with valve seat recession on unleaded fuel, an assessment should be made to compare the relative cost and practicality of retrofitting cylinder heads with hardened valve seats to using alternative additives or using 0.10 gram per gallon gasoline. This assessment should take into account the total number of engines in the field, the number of engines that have potential for a valve seat recession problem, etc.

Summary

In summary, the contractor has done an excellent job in conducting the experimental work and completing the project in a reasonable time frame. The data from this program are of significant value and should be published in a form such that anyone in the public domain can obtain a copy of the report. In addition, the contractor should be encouraged to publish the results of the study in an engineering society technical paper. Should any future testing be contemplated, I recommend that additional work be done on alternative additives to lead. An assessment should be done to determine the cost and practica.ity of retrofitting cylinder heads with hardened valve seats. Also, replicate engine tests should be considered to better account for test–to–test variability.

Should there be any questions about these comments, please do not hesitate to give me a call.

Sincerely,

Ralph D. Fleming
Consultant

cc:
Jerry Allsup, NIPER
John Garbak, EPA
Gerald Grinnell, USDA

REPORT

Assessment of the testing program conducted by NIPER on selected gasoline engines.

Louis I. Leviticus
Nebraska Tractor Testing Laboratory.

March 25, 1987.

1. I want to compliment NIPER, and in particular Mr. Allsup and his staff, for a job well done under severe time constraints. The work was carried out with competence and integrity. The only criticism I have is the fact that the oil analysis was not carried out exactly as in the original plan of work.

2. One of the great limitations of this project has been the fact that not enough engines of each type could be evaluated. It is quite clear from the hardness measurements that considerable variation exists between heads. This variation may be the result of manufacturing processes or may be due to different sources for the heads or inserts used. Hence, tests of the statistical significance cannot be applied in this study.

3. Although the results obtained may be debatable from a statistical significance viewpoint, they nevertheless provide a good insight into the problems encountered when operating an engine, designed for leaded fuel use, on unleaded fuel and with additives.

4. In general, the results tend to show that the combustion chamber temperature may be a major contributor to the phenomenon of recession of valve seats below a certain critical hardness value. Higher combustion chamber temperatures can occur due to a variety of reasons:

   a. High loads.
   b. Inadequate cooling (dirty radiator, slipping belts, blocked passageways in the engine etc.).
   c. Lean fuel mixtures (High A/F ratio).
   d. Ignition problems (Timing, Fouled spark plugs).
   e. Carbon or other deposits in the combustion chamber.

5. It cannot be determined with certainty from the data what the critical seat hardness is. This would seem to depend upon the engine characteristics and, possibly, on the way the engine is used and maintained.

6. Engine speed may not be a factor by itself, but, coupled with a high load and/or a lean mixture an increase in engine speed may lead to <u>earlier</u> recession. This is a judgement call. The study was designed to simulate the operation of engines under normal conditions. It accomplishes that purpose. However, several questions remain unanswered concerning what exactly causes recession.

7. The results tend to show that at 0.1 gplg none of the engines suffered from excess recession. A definite conclusion cannot be reached however since one of the engines did show excessive recession after head gasket failure. Since the test did not examine the harshest possible operating conditions, one cannot conclude that 0.1 gplg will protect all engines under all operating conditions.

8. The data from the additive tests, limited as they were, do not warrant their recommendation, at this stage, as a replacement for lead. This conclusion is based on the following reasons:

a. It appears that there is, as yet, uncertainty about the correct cocentration of some of the additives. I may point out that it is possible that different engines might require different concentrations of an additive.

b. The recommended concentrations, for the additives tested, showed that the engines were not completely protected against recession.

c. An examination of the effect of the additives on emissions was inconclusive.

d. The oil analysis showed that when additives were used, the Sodium content usually increased drastically. The sodium is apparently introduced to the oil through the additive. Since the formulation of the additives is proprietary the composition of the compound in which sodium occurs is not known.

e. The oil and exhaust gas analysis did not include checking for sulphur compounds. Sulphur in the exhaust gases can cause damage to the engine and exhaust parts since they are mixed with Hydrocarbons and water vapor and may form acids; the sulphur compounds in the oil can cause damage in certain engines since they attack certain metal compounds. It is very difficult to determine which engines would be affected, since this depends upon:

.. Engine combustion characteristics, which can vary with engine design and operating conditions.

.. Different oils contain different additives which may react differently with sulphur compounds.

.. Metal alloys used in the engine. There are examples of manufacturers warning the users against certain oils, containing a molybdenum compound, which releases a sulphur compound in the oil. This compound then combines with water to create an acid, which attacks certain alloys used.

f. The nature of the deposits found and their long-term influence on the engine were not determined.

g. The only fuel additive combination, which did not cause recession was tested on one engine only.

9. Recommendations for future testing.

The additives should be tested and evaluated further in order to:

a. Determine the correct concentration(s) to be used.

b. Investigate whether the concentrations should differ for different engine makes.

c. Determine the composition of the exhaust gases and their influence, if any, on the various engine components.

d. Determine the influence on the composition of engine oils and the influence of the compounds on the oil quality and on alloys used in various engines.

Louis I. Leviticus
Nebraska Tractor Testing Lab

Appendix 3

Duty Cycles Used in Engine Tests

Duty cycles were developed to represent conditions normally encountered by farm tractors, combines and large trucks, and by recreational vehicles. Each engine was operated on its specified duty cycle until 200 hours were accumulated on each test fuel.

Tractors and Combines

The duty cycle for tractor and combine engines consisted of two parts--an intermittent portion covering 144 hours of operation and a steady-state portion covering 56 hours. The intermittent part is consistent with the duty cycle (SAE J708) used for many years by the Nebraska Tractor Testing Laboratory to test the performance of new tractors. The steady-state part was selected to represent the maximum continuous load that is likely to be placed on these engines, such as pumping irrigation water.

Intermittent Part--Each engine was run through six power settings with the engine speed controlled by the governor per manufacturers' specifications as follows until 144 hours were accumulated (16 hours on 8 hours off per day):

a. 85% of dynamometer torque obtained at maximum power--40 minutes

b. Zero dynamometer torque at rated rpm--40 minutes

c. 42.5% of dynamometer torque obtained at maximum power--40 minutes

d. Dynamometer torque at maximum power--40 minutes

e. 21.25% of dynamometer torque obtained at maximum power--40 minutes

f. 63.75% of dynamometer torque obtained at maximum power--40 minutes

Steady-State Part--Each engine was run at governed speed and 75 percent of maximum torque around the clock until 56 hours were accumulated. After 24 hours, the engines were shut off for 2 hours for valve seat recession measurements and service checks.

Farm Trucks

The engines were to be operated 16 hours on and 8 hours off per day on the following duty cycle until 200 hours were accumulated for each fuel.

a. 85% of maximum power (available at 3,000 rpm) at 3,000 rpm--40 minutes

b. 45% of maximum power (available at 3,000 rpm) at 3,000 rpm--40 minutes

c. 45% of maximum power (available at 2,500 rpm) at 2,500 rpm--40 minutes

d. 25% of maximum power (available at 2,000 rpm) at 2,000 rpm--40 minutes

e. 85% of maximum power (available at 3,600 rpm) at 3,600 rpm--40 minutes

Recreational Vehicles

The recreational vehicle test called for the engine to be on 16 hours and off 8 hours per day until 200 hours were accumulated for each fuel. The engine was operated in both intermittent and steady-state modes.

Intermittent Part--The engine was operated in six speed and power settings as follows until 144 hours were accumulated:

a. 85% of maximum power (available at 3,000 rpm) at 3,000 rpm--40 minutes

b. 45% of maximum power (available at 2,000 rpm) at 2,000 rpm--40 minutes

c. 85% of maximum power (available at 3,600 rpm) at 3,600 rpm--40 minutes

d. 45% of maximum power (available at 2,500 rpm) at 2,500 rpm--40 minutes

e. 45% of maximum power (available at 3,000 rpm) at 3,000 rpm--40 minutes

f. 85% of maximum power (available at 2,500 rpm) at 2,500 rpm--40 minutes

Steady-State Part--During the steady-state part of the cycle, the engine was run at a setting that produced 100 horsepower (52 percent of maximum power) at 3,000 rpm until 56 hours were accumulated.

Appendix 4

Engines Tested

1. John Deere "B" tractor; 2-cylinder I-head engine; rated at 24 horsepower at 1,250 revolutions per minute (rpm); 4 11/16" x 5 1/2" bore and stroke, 190.4 cubic inch displacement (CID). The engine was originally equipped with ordinary cast iron cylinder heads with a hardness of 9-25 on the Rockwell C scale. The tractor was manufactured between the 1930s and 1952. Similar tractors were manufactured until about 1960.
2. Farmall "H" tractor; 4 cylinder I-head engine; rated at 24 horsepower at 1,650 rpm; 3 3/8 x 4 1/4" bore and stroke. The engine was originally equipped with "special gray iron" valve seat inserts having a hardness of 26-36 on the Rockwell C scale. The tractor was manufactured between the 1930s and 1953. Similar tractors were built until about 1958.
3. For "8N" tractor; 4-cylinder L-head engine; rated at 23 horesepower at 2,000 rpm; 3 3/16" x 3 3/4" bore and stroke, 119.7 CID. The engine was originally equipped with valve seat inserts having a hardness of 39-43 on the Rockwell C scale. The tractor was manufactured between 1947 and 1952.
4. International Harvester 240 tractor; 4 cylinders; rated at 27 horsepower at 2,000 rpm; 3 1/8" x 4" bore and strokes, 122.7 CID. The engine was originally equipped with an ordinary cast iron cylinder head with a hardness of 12-23 on the Rockwell C scale. The tractor was manufactured

between 1958 and 1962. Similar tractors were built until 1978.

5. John Deere 95 303 CID 6-cylinder combine engine; rated at 80 horsepower at 2,500 rpm. The engine was originally equipped with ordinary cast iron cylinder heads with a hardness of 9-25 on the Rockwell C scale. The engine was manufactured between about 1960 and 1974. A 4-cylinder version of this engine also was used in combines and tractors, and a 3-cylinder version was used in tractors.
6. Pre-1974 Chevrolet 292 CID 6-cylinder truck engine; rated at 115 horsepower at 4,000 rpm. Prior to 1974, the engine was equipped with ordinary cast iron cylinder heads. The engine is still in production but now has induction-hardened cast iron exhaust valve seats. The engine also has been used in combines and other agricultural equipment.
7. Pre-1984 General Motors 454 CID 8-cylinder recreational vehicle engine; rated at 210 horsepower at 4,000 rpm. The engine has always been manufactured with induction-hardened exhaust valve seats.

Appendix 5

Farm Engine-Use Survey Form

Form Approved
O.M.B. Number 2060-0137
Expiration Date 1/31/87

Additional information about gasoline-powered farm equipment used on your operation is needed by the USDA's Office of Energy to develop fuel policies related to lead content in gasoline.

17a. Did you use any **GASOLINE-POWERED** tractors, combines, or trucks *(larger than 1 ton capacity)* on your operation last year?

Office Use
700

[ ] **YES** [ ] **NO** - *Go to Item 18.*

17b. What **GASOLINE-POWERED** tractors, combines, and trucks did you use on this operation during 1985?
(DO NOT INCLUDE DIESEL POWERED EQUIPMENT.)

Gasoline Tractors Used 20 or More Hours During 1985, Beginning With the One Used Most							**Percentage of Time Used During 1985 2/**				
Tractor	**Manufacturer**	**Office Use**	**Year of Manufacture 1/**	**PTO Horsepower**	**Year Engine Last Overhauled**	**Total Hours Used in 1985**	**Pumping Irrigation Water %**	**Other Hard Uses %**	**Medium Uses %**	**Light Uses %**	
# 1		701	702	703	704	705	706	707	708	709	100
# 2		710	711	712	713	714	715	716	717	718	100
# 3		719	720	721	722	723	724	725	726	727	100
Others					728 Number	729	730	731	732	733	100

Gasoline Combines and Cornpickers Used During 1985, Beginning With the One Used Most						
Combine/ Cornpicker	**Manufacturer**	**Office Use**	**Year of Manufacture 1/**	**Rated Horsepower**	**Year Engine Last Overhauled**	**Total Acres Harvested in 1985**
# 1		734	735	736	737	738
# 2		739	740	741	742	743
Others					744 Number	745

Gasoline Trucks Larger than 1 Ton Capacity Used During 1985, Beginning With the One Used Most							
Truck	**Manufacturer**	**Office Use**	**Year of Manufacture 1/**	**Engine Size (cu. in.)**	**Year Engine Last Overhauled**	**Total Miles Driven in 1985**	**Rated Capacity (tons)**
# 1		746	747	748	749	750	751 . _ _
# 2		752	753	754	755	756	757 . _ _
# 3		758	759	760	761	762	763 . _ _
Others					764 Number	765	

1/ For rented, leased, or borrowed equipment, enter "98" for year of manufacture and report only manufacturer name, total hours and percent of time used, and acres harvested or miles driven in 1985

*2/ **Other Hard Use:** Plowing, Disking, and other high RPM, heavy engine loads*
***Medium Use:** Baling with PTO, chopping silage, rotary mowing, and other high RPM, moderate engine loads.*
***Light Use:** Harrowing, planting, cultivating, raking, hauling, spreading manure, and other low to medium RPM, light engine loads*

18. Do you own any diesel-powered tractors?

[ ] **NO** [ ] **YES** - How many?

Number
766

Appendix 6

How to Order Additional Documents Referred to in this Report

The following documents, referred to in this report, are available in EPA docket Number EN-87-03. Copies may be obtained by writing to Control Docket Section (LE-131A), Environmental Protection Agency Gallery 1, West Tower, 401 M Street, S.W., Washington, D.C. 20460. Telephone (202) 382-7548. The docket may be inspected between 8 a.m. and 4 p.m. on weekdays. As provided in 40 CFR Part 2, a reasonable fee may be charged for photocopying.

1. Effects of Low Levels of Lead and Alternative Additives to Lead on Engines Designed to Operate on Leaded Gasoline, Final Report. Report by the National Institute for Petroleum and Energy Research (NIPER) on results of engine tests performed for this study (193+ pages).
2. Statements of work covering work performed by NIPER.
   A. Effects of Low Levels of Lead and Alternative Additives to Lead on Engines Designed to Operate on Leaded Gasoline. Covers tests of leaded and unleaded gasoline performed during fiscal year 1986 (10 pages).
   B. Study of the Effects on Leaded Engines of Alternative Additives to Lead. Covers tests of non-lead additives performed during fiscal year 1987 (12 pages).
3. Quality Assurance Project Plan for Engine Testing Work Performed by NIPER (23 pages).

4. Interviewers Manual for Gasoline-Powered Farm Equipment Survey. Survey conducted by the National Agricultural Statistics Service, USDA during July 1986 (7 pages).

5. Survey Protocol and Quality Assurance Plan for Field Measurement of Exhaust Valve Seats in Gasoline-Powered Tractors. Survey conducted by the Radian Corporation during September 1986 (84 pages).

United States
Environmental Protection
Agency

Office of Mobile Sources
Washington, D.C. 20460

March 1987

EPA

EFFECT OF LOW LEVELS OF LEAD AND ALTERNATIVE ADDITIVES TO LEAD ON ENGINES DESIGNED TO OPERATE ON LEADED GASOLINE

Report No. B06725-2
(Proposal No. 86-86B)
March 1987

FINAL REPORT

EFFECT OF LOW LEVELS OF LEAD AND ALTERNATIVE ADDITIVES TO LEAD ON ENGINES DESIGNED TO OPERATE ON LEADED GASOLINE

By
Jerry R. Allsup

Work Performed for
U.S. Environmental Protection Agency
Under Contract No. 68-02-4355

EXECUTIVE SUMMARY

A series of tests was conducted to determine effects of using leaded, low lead, unleaded fuels, and fuel additives on valve seat recession in engine designed for leaded fuels.

A total of eight engines: four tractor engines, one combine engine, two light-duty truck/combine engines, and one heavy truck engine were tested with various combinations of fuels, valve seat hardness, and duty cycles.

Results showed none of six engines tested on 1.2 gm/gal leaded fuel to have problems with valve seat recession.

Using unleaded fuel, two low-speed tractor engines did not have problems with valve seat recession. All other engines tested with unleaded fuel, including induction-hardened heads, steel valve seat inserts, cast iron heads, and cast iron valve seat inserts resulted in valve seat recession. Induction hardening and use of steel valve seat inserts greatly reduced but did not necessarily prevent valve seat recession. Reduction in severity of the engine duty cycle reduced the rate of valve seat recession slightly. Engine failure in as little as 100 hours is likely with some engines.

Tests with 0.10 gm/gal lead in fuel essentially eliminated valve seat recession using the specified duty cycles.

Tests with alternative fuel additives showed that valve seat recession was significantly reduced by the use of moderate amounts of additive, and was eliminated by larger amounts of additive. Combustion chamber deposits were increased by the use of large amounts of additives. More work is needed to evaluate long-term effects.

TABLE OF CONTENTS

TABLE OF CONTENTS--CONTINUED

TABLES AND ILLUSTRATIONS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

APPENDIX A

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

Table | Page

APPENDIX B

TABLE OF CONTENTS (CONTINUED)

APPENDIX C

EFFECT OF LOW LEVELS OF LEAD AND ALTERNATIVE ADDITIVES TO LEAD ON ENGINES DESIGNED TO OPERATE ON LEADED GASOLINE

By

Jerry R. Allsup

ABSTRACT

This report describes testing operations to determine the effect of using leaded gasoline, low-lead gasoline, unleaded gasoline, and gasoline with additives in engines designed for leaded gasoline. Four tractor engines, one combine engine, two light-duty farm truck engines, and one heavy-duty truck engine were tested using leaded fuel (1.2 gm/gal), unleaded fuel, and low-lead fuel (0.10 gm/gal). Results show the medium and higher speed engines experienced valve seat recession using unleaded fuel, while lower speed engines did not show valve seat recession using the unleaded fuel. No substantial valve seat recession occurred using the 1.2 or 0.10 gm/gal leaded fuel. Fuel additives were found to have some potential with unleaded fuel in reducing valve seat recession, although unresolved questions remain.

ACKNOWLEDGMENT

We wish to acknowledge the technical and administrative assistance of Mr. John Garbak, U.S. Environmental Protection Agency, and to Dr. Gerald Grinnell, U.S. Department of Agriculture, in providing technical direction and assistance to the program. Further, we wish to acknowledge the technical assistance provided by consultants Dr. Ralph D. Fleming, EFE Consulting Services, and Dr. Louis Leviticus, Nebraska Tractor Test Laboratory.

INTRODUCTION

The testing program was designed to evaluate the effects that various levels of lead in gasoline will have on engines designed to operate on leaded fuel. In addition, the program was designed to determine if alternative fuel additives had potential for reducing valve seat recession. Specifically, the testing measured valve seat recession while operating engines on a fuel with varying amounts of lead or other fuel additives. Eight test engines were procured, and rebuilt if necessary, and accumulated about 200 hours on each of the fuels in that engine. Valve seat recession was determined by measuring valve stem height or valve lash periodically during the testing and by an internal inspection of the cylinder head and the valve train assembly before and after each test fuel.

The valve train parameters measured before and after the fuel tests included valve seat angle, valve seat recession, valve height, valve tulip diameter, valve guide diameter, valve stem diameter, valve spring height, valve spring force--normal, and valve spring force--compressed.

TEST PARAMETERS AND CONDITIONS

Duty Cycle

1. Tractor and Combine Duty Cycle - The duty cycle was patterned after the SAEJ-708 Agricultural Tractor Test Code and consisted of six power settings with engine speed controlled by the governor per manufacturer's specification. The engine was operated at each mode for a period of 40 minutes in the following order (four hours for a complete cycle):

   a. Eighty-five percent of dynamometer torque obtained at maximum power.

   b. Zero dynamometer torque at rated rpm.

   c. One-half of 85 percent of dynamometer torque obtained at maximum power.

   d. Dynamometer torque at maximum power.

   e. One-quarter of 85 percent of dynamometer torque obtained at maximum power.

   f. Three-quarters of 85 percent of dynamometer torque obtained at maximum power.

   g. Repeat this cycle until 144 hours has been reached. (The cycle was run 16 hours on, 8 hours off.)

   h. Steady-state duty cycle for tractors and combine engines - At the conclusion of the 144-hour cycle above, the tractor and combine engines were run at governed speed at 75 percent of dynamometer torque obtained at maximum power for 56 hours continuously.

2. A farm truck speed/load cycle was used to simulate heavy and medium hauling at highway speeds (85 and 45 percent maximum power at 3,000 rpm)

as well as medium and low speed (2,500 rpm at 45 percent power, and 2,000 rpm at 25 percent power). Also included is a high-speed condition of 3,600 rpm at 85 percent power. This cycle was repeated until 200 hours was accumulated at 16 hours per day on and 8 hours off. The farm truck cycle was as follows:

a. 85% maximum power (available at 3,000 rpm) at 3,000 rpm - 40 minutes.

b. 45% maximum power (available at 3,000 rpm) at 3,000 rpm - 40 minutes.

c. 45% maximum power (available at 2,500 rpm) at 2,500 rpm - 40 minutes.

d. 25% maximum power (available at 2,000 rpm) at 2,000 rpm - 40 minutes.

e. 85% maximum power (available at 3,600 rpm) at 3,600 rpm - 40 minutes.

3. Recreational Vehicle Cycle: The recreational vehicle (RV) speed/load cycle simulates extended time at highway road load conditions required to transport a relatively large RV at highway speeds. The cycle also includes lower speed urban-type driving and near maximum speed/load conditions. The cycle is repeated until 144 hours is reached at 16 hours per day. Following 144 hours, a 16-hour per day steady-state mode of 100 hp at 3,000 rpm is followed until a total of 200 hours was accumulated.

a. 85% maximum power (available at 3,000 rpm) at 3,000 rpm - 40 minutes.

b. 45% maximum power (available at 2,000 rpm) at 2,000 rpm - 40 minutes.

c. 85% maximum power (available at 3,600 rpm) at 3,600 rpm - 40 minutes.

d. 45% maximum power (available at 2,500 rpm) at 2,500 rpm - 40 minutes.

e. 45% maximum power (available at 3,000 rpm) at 3,000 rpm - 40 minutes.

f. 85% maximum power (available at 2,500 rpm) at 2,500 rpm - 40 minutes.

g. After 144 hours, 100 hp at 3,000 rpm for 56 hours at 16 hours per day.

The design of the program was to operate the engines for 16 hours per day, five days per week. Occasional engine/dynamometer system problems affected the scheduled tests (discussed in the results section of this report). During the 56-hour continuous duty cycle (for tractor and combine engines) the engines were shut down for approximately two hours at the 24-hour point for recession measurements and service checks.

The speed/load conditions for the various test engines are listed in table 1.

TABLE 1. - Summary of speed/load conditions for engine duty cycle

	Mode						
	1	2	3	4	5	6	56-hour
			John Deere "B"				
RPM	1260	1370	1300	1250	1300	1275	1275
Torque, ft/lb	86	0	43	max	21	64	76
			Ford 8N				
RPM	2050	2200	2100	2000	2150	2100	2100
Torque, ft/lb	56	0	28	max	14	42	50
			IH-240				
RPM	2050	2200	2100	2000	2150	2100	2100
Torque, ft/lb	73	0	37	max	18	54	64
			Farmall "H"				
RPM*	1700	1800	1750	1650	1750	1725	1725
Torque, ft/lb	85	0	43	max	21	64	75
			John Deere 303				
RPM*	2600	2750	2700	2500	2700	2650	2650
Torque, ft/lb	143	0	71	max	36	107	126
			GM 292				
RPM	3000	3000	2500	2000	3600	NA	NA
Torque, ft/lb	168	89	92	53	149	NA	NA
			GM 454				
RPM	3000	2000	3600	2500	3000	2500	3000
Torque, ft/lb	285	145	258	149	151	282	175

*RPM listed for the tractor engines is nominal except for 0 load and max load due to engine governor controlling rpm.

Measurement of Recession

1. Measurement of valve seat recession was made at the conclusion of each 16-hour cycle. If technical problems occurred, valve seat recession measurements were made at earlier intervals.

2. Standard measures of engine performance including coolant temperature, exhaust temperature, power, engine rpm, oil temperature and pressure, intake air temperature, barometric pressure, and air-fuel (A/F) ratio were continuously monitored and recorded at 4-minute intervals. Engine compression was measured at the start and end of each fuel test sequence. Undiluted carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbon (HC), and oxide of nitrogen (NO_x) emissions were determined at the test modes specified earlier at 16-hour increments.

3. Valve lash was readjusted at each measurement interval to prevent failure so that testing could be continued.

4. Other effects these test fuels may have on engines were observed and measured (i.e., intake and exhaust valve deposits, valve train wear, etc.) by an automotive machine shop operated by a certified engine rebuilder under contract to NIPER. The qualifications of the rebuilder were examined in detail by two independent consultants: Dr. R. D. Fleming, EFE Consulting Services; and Dr. L. Leviticus, Nebraska Tractor Test Laboratory.

<u>Other Test Parameters</u>

1. The cooling system used during the test program for the tractor and combine engines is a centralized cooling system capable of maintaining engine temperature of 205° F ± 5°. A pressurized cooling system was used for the GM-292 and GM-454 engines to maintain engine coolant temperature of 230° F.

2. Ambient engine intake air temperature was controlled to 85° F ± 5°.

3. Humidity was not controlled, but measurements were taken at the start of each accumulation cycle.

4. Engine oil was changed at 100-hour intervals and after each test (but not exceeding manufacturer's specifications) and make-up oil added daily as required. Used engine oil was analyzed for wear metals using a qualified commercial facility.

5. Oil temperature was monitored continuously.

6. Exhaust back pressure was determined on each engine/mode condition at the start and end of each fuel test to ensure consistent back pressure.

ENGINES

The test engines selected were as follows:

1. John Deere "B" tractor, 190.4-CID, 1,250 rpm, 24 hp, representative of many of the 2-cylinder engines built by John Deere before 1960. The engine had a compression ratio of 4.7:1. The tractor was built with cast iron cylinder heads having a hardness of HRC 9-HRC 25.

   The John Deere "B" engine was rebuilt prior to testing with a new engine block and new original engine manufacturer (OEM) pistons and rings. The crankshaft and camshaft were checked by a certified engine rebuilder and found to be in tolerance for OEM specifications. The "B" engine crankshaft housing is an intergal part of the tractor frame; therefore, the engine could not be removed from the tractor. Instead, an adaptor was fabricated to accept power output from the flywheel side of the tractor to a water brake dynamometer, thus allowing the engine to be tested while mounted in the tractor. Instead of using the OEM radiator and gravity flow coolant system, an external electrically driven water pump with a capacity of about 4 gal/min was used to recirculate cooling water through the engine and cooling tower reservoir. The coolant temperature was maintained at 205° F.

   The John Deere "B" engine did not use valve rotators for its exhaust or intake valves.

   After rebuilding, the John Deere "B" was "broken in" using 1.2 gm/gal leaded test fuel following OEM recommendations as follows:

   5 minutes - no load - low idle
   5 minutes - no load - high idle
   5 minutes - 1/4-load - governed rpm
   10 minutes - 1/2-load - governed rpm
   10 minutes - 3/4-load - governed rpm
   10 minutes - full load - governed rpm

2. Farmall "H" tractor, 4-cylinder, 152-CID, 24 hp engine rated at 1,650 rpm. The Farmall "H" has a compression ratio of 5.9:1.

   The "H" engine was rebuilt with new OEM cylinder liners, pistons, and rings. In addition, the crankshaft was dressed by a certified engine rebuilder to meet OEM specifications due to lack of availability of new OEM equipment. Valve seat inserts of a cast iron variety were used in the original head assembly. Several cast iron inserts from three manufacturers were measured for hardness with variations in the range of Rockwell HRC 14 to HRC 20. An average value of HRC 17 or HRB 97 was selected such that the inserts used were of average quality and of similar hardness. The "H" did not use valve rotators for the exhaust and intake valves.

The OEM recommended break-in schedule for the Farmall "H" tractor used prior to testing and with the 1.2 gm/gal leaded fuel is as follows:

30 minutes - 1/2 rated power - 825 rpm
30 minutes - 3/4 rated power - 1,240 rpm
30 minutes - 3/4 rated power - 1,650 rpm
Retorque head - readjust valves
60 minutes - 3/4 rated power - 1,650 rpm

3. Ford 8N tractor, 4-cylinder, 120-CID, rated at 23 hp at 2,000 rpm.

The Ford 8N is an "L" head or valve-in-block design with a compression ratio of 6.7:1. The engine was rebuilt to factory "new" tolerances by a major Ford tractor facility. The engine was tested with cast iron valve seat inserts. The Ford 8N has valve rotators on the exhaust valves but not on the intake valves.

After rebuilding, the engine was broken in using OEM recommendations as follows:

30 minutes - 1/2 rated load - 1,000 rpm
30 minutes - 3/4 rated load - 1,500 rpm
30 minutes - 3/4 rated load - 2,000 rpm
Retorque head - adjust valves
60 minutes - 3/4 rated load - 2,000 rpm

The engine was broken in using unleaded fuel, which was the only fuel tested in this engine. The fuel used for break-in on all engines was the fuel to be tested during the next fuel test.

4. International Harvester Farmall 240 tractor, 123-CID, rated at 27 hp at 2,000 rpm, representative of most IH engines less than 150-CID sold until 1979. The IH 240 had a compression ratio of 6.8:1.

The IH-240 engine was rebuilt prior to testing with new OEM cylinder liners, pistons, and rings. An original crankshaft and camshaft were measured and found to be within OEM specifications and installed. The IH-240 engine used valve rotators for the exhaust valves only. The engine was broken in using the 1.2 gm/gal leaded test fuel prior to testing. The following break-in schedule for the IH-240 was followed as recommended by the manufacturer:

30 minutes - 1/2 rated load - 1,000 rpm
30 minutes - 3/4 rated load - 1,500 rpm
30 minutes - 3/4 rated load - 2,000 rpm
Retorque head - adjust valves
60 minutes - 3/4 rated load - 2,000 rpm

5. John Deere 303, 6-cylinder, 303-CID combine engine rated at 80 hp at 2,500 rpm, representative of engines used in tractors, combines, and other equipment between 1960 to 1974. The John Deere 303 had a compression ratio of 7.6:1.

   The 303 engine was rebuilt with new OEM cylinder liners, pistons, and rings. The crankshaft and camshaft were checked for wear and balance by a certified engine rebuilder and found to be within OEM tolerance and used for testing. The 303 engine used valve rotators only on the exhaust valves.

   The John Deere 303 was broken in prior to testing using the 1.2 gm/gal leaded test fuel on the following OEM recommended "break-in" schedule:

   5 minutes - no load - 800 rpm
   5 minutes - no load - 2,000 rpm
   5 minutes - 1/4 load - 2,200 rpm
   10 minutes - 3/4 load - 2,200 rpm
   10 minutes - full load - 2,300 rpm

6. Two GM-292 6-cylinder, 292-CID engines rated at 120 hp at 4,000 rpm representative of pre-1974 engines used in light trucks and agricultural equipment. The two engines designated as GM-292 "A" and GM-292 "B", with a compression ratio of 8.0:1, were procured from General Motors (GM). New

carburetor, intake manifold, exhaust manifold, and electrical system were used representative of pre-1974 engine adjustments. The GM-292 engine used valve rotators for exhaust valves only.

Induction-hardened engine heads were used on 1974 and later model productions. New OEM engine heads without induction hardening were obtained from GM for this test. The GM-292 engines were installed on a test stand using a pressurized closed cooling system with a water-cooled external heat exchanger in order to operate at 225° to 230° F as required to simulate actual operation.

The break-in procedure used for the GM-292 and recommended by the manufacturer is shown below.

The test fuel used for break-in contained 1.2 gm/gal lead.

RPM	Time	Torque, ft/lb
1,000	30 minutes	58
Change oil/filter		
1,600	2 hrs., 55 min.	61
Idle	5 minutes	-
2,600	1 hrs., 55 min.	80
Idle	5 minutes	-
3,200	2 hrs., 55 min.	90
Idle	5 minutes	-
3,600	2 hrs., 55 min.	96
Idle	5 minutes	-
4,000	15 minutes	WOT*
Idle	5 minutes	-
4,000	15 minutes	WOT
Idle	5 minutes	-
4,000	15 minutes	WOT
Idle	5 minutes	-
4,200	15 minutes	WOT
Idle	5 minutes	-
4,200	15 minutes	WOT
Idle	5 minutes	-
4,200	15 minutes	WOT
Idle	5 minutes	-
Change oil/filter		

*Wide Open Throttle

Following engine break-in, the head was removed and new OEM heads were installed for testing.

6. GM-454 heavy truck engine, 8-cylinder, 454-CID rated at 210 hp at 4,000 rpm. The GM-454 engine had a compression ratio of 9.1:1. The GM-454 engine has induction-hardened valve seats and represents a 1982 model vintage production engine. The GM-454 was procured as a new OEM "short" block. Other OEM equipment including engine heads, intake and exhaust assemblies, and complete valve assemblies were procured and installed on the engine to represent OEM production. The GM-454 engine used valve rotators only on the exhaust valves.

This engine was installed using a pressurized cooling system with water-to-water heat exchanger which operated at 225° to 230° F.

The break-in procedure for the GM-454 engine recommended by the manufacturer is shown below.

The fuel used for break-in contained 1.2 gm/gal lead.

RPM	Time	Torque, ft/lb
1,000	30 minutes	103
Change oil/filter		
1,600	2 hrs., 55 min.	110
Idle	5 minutes	-
2,600	2 hrs., 55 min.	144
Idle	5 minutes	-
3,200	2 hrs., 55 min.	162
Idle	5 minutes	-
3,600	2 hrs., 55 min.	173
Idle	5 minutes	-
4,000	15 minutes	WOT*
Idle	5 minutes	-
4,000	15 minutes	WOT
Idle	5 minutes	-
4,000	15 minutes	WOT
Idle	5 minutes	-
4,200	15 minutes	WOT
Idle	5 minutes	-
4,200	15 minutes	WOT
Idle	5 minutes	-
4,200	15 minutes	WOT
Idle	5 minutes	-
Change oil/filter		

*Wide Open Throttle

Following engine break-in, the engine heads were removed, and new OEM heads were installed for testing.

After each engine completed a test with a fuel or additive, the engine head was removed and another installed for a new test. A minor break-in was conducted after a new test head was installed. This consisted of 10 minutes at each test mode of test cycle followed by engine shutdown, retorquing the heads, and obtaining the first data point (0 hours).

FUEL AND ADDITIVES

Commercial-grade unleaded-regular fuel was procured from the Sun Oil Refinery in Tulsa, Oklahoma, in a single batch of sufficient quantity to operate the entire planned test program. The test fuel was tested for lead tolerance by the NIPER Fuels Chemistry section. The lead was reported to be undetectable at .0008 gm/gal detection limit. This fuel was used as "unleaded" fuel and also served as base fuel for all other test fuels.

Tetraethyl lead motor mix, composed of 61.49 weight-percent tetraethyl lead, 17.86 weight-percent ethylene dibromide, and 18.81 weight-percent ethylene dichloride, with the remainder kerosene and dye stabilizers, was added to unleaded fuel on board a tank truck and delivered to the test site. Subsequent analyses of the fuel by the NIPER Fuels Processing Laboratory showed 1.2 ±.1 gm/gal lead with the target being 1.1 gm/gal. This fuel was used and reported as 1.2 gm/gal.

The tetraethyl lead motor mix was used also to blend a batch of low lead fuel in a similar procedure with a target of 0.10 gm/gal. Fuel analysis by a commercial laboratory, NIPER, EPA, and Phillips Petroleum Company showed a range of 0.09 to 0.13 gm/gal lead in the fuel. This fuel is described as low lead fuel or 0.10 gm/gal lead.

Compositional analysis of the unleaded fuel is shown in table 2. Physical properties test data of the fuel are shown in table 3.

The octane of only the base fuel was measured.

TABLE 2. - Fuel compositional analysis

Volume Percent Summation by Carbon Number and Compound Class

Carbon No.	Paraffins Normal	Paraffins Iso	Naphthenes	Olefins	Aromatics	Total
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	0.10	0.00	0.00	0.01	0.00	0.11
4	4.04	1.32	0.00	2.68	0.00	8.04
5	7.50	8.10	0.21	4.64	0.00	20.46
6	3.45	9.46	1.41	3.84	0.48	18.64
7	1.91	5.13	1.29	2.81	4.39	15.54
8	0.83	5.35	1.25	0.33	10.06	17.82
9	0.26	2.95	0.01	0.00	8.80	12.01
10	0.16	0.88	0.00	0.00	5.06	6.10
11	0.18	0.04	0.00	0.00	0.83	1.05
12	0.11	0.00	0.00	0.00	0.12	0.24
Total	18.53	33.23	4.17	14.31	29.75	100.00

Average Molecular Weight = 91.70
Average Density = .730
Average Carbon Number = 6.59
H/C Ratio = 1.88

TABLE 3. - Fuel inspection data

Distillation, D 86 % Evaporated	
IBP	90° F
5	114
10	128
15	139
20	149
30	173
40	200
50	230
60	261
70	287
80	310
90	345
95	370
EP	411

Research Octane No. 91.7
Motor Octane No. 81.3

Fuel Additive "A"

Fuel additive "A" was a supplied by The Lubrizol Corporation. The additive, a variation of the "Powershield" product, was blended with unleaded gasoline at a level of 250 pounds of additive per 1,000 barrels of fuel (250 PTB). Fuel samples were analyzed by the U.S. Environmental Protection Agency (EPA) facility at Ann Arbor, Michigan, and by The Lubrizol Corporation prior to testing to ensure the proper concentration of additive was used. The fuel blending procedure consisted of measuring an amount necessary at the NIPER laboratory for each individual fuel compartment of the fuel transport truck. The additive was then introduced to the transport truck compartment as the compartment was being filled with base fuel. The transport then was driven approximately 25 miles to the test facility and the fuel was transferred to a storage tank. From the storage tank the test fuel was delivered directly to the test engines.

Fuel Additive "B"

Fuel additive "B" was a commercial product supplied by The Lubrizol Corporation with a trade name "Powershield." The product was blended with unleaded gasoline at a level of 250 PTB. Fuel samples were collected and analyzed at the EPA facility at Ann Arbor, Michigan, and at The Lubrizol Corporation confirming the product was properly mixed prior to testing.

Fuel Additive "C"

Fuel additive "C" was a product supplied by E. I. du Pont de Nemours and Company, Inc., of Wilmington, Delaware, labeled as "DM-A4." The product was blended at a level of 200 PTB. Fuel sample analysis from the EPA and E. I. du Pont Company prior to testing confirmed the additive was properly blended.

Fuel Additive "D"

Fuel additive "D" was a commercial product supplied by The Lubrizol Corporation with a trade name of "Powershield." The product was blended with unleaded gasoline at a level of 1,000 PTB. Fuel sample analysis from the EPA and The Lubrizol Corporation prior to testing confirmed the fuel product was properly blended.

Lube Oil Analysis

Phillips Trop-Artic SAE-30 lube oil was used in all the tractor and combine engines, and Phillips Trop-Artic SAE-10-40 was used in the GM engines during this test series.

The oil and filter were changed at 100-hour intervals during the tests with the engine always beginning the test with new oil.

The oil wear metals analysis was performed by a major Caterpillar equipment dealer in the local area.

EXHAUST EMISSIONS AND AIR-FUEL RATIO

Exhaust emissions were measured at regular intervals during the 200-hour test. The gaseous emissions, CO, CO_2, HC, NO_x, and unconverted oxygen in the undiluted exhaust were measured. Air-fuel (A/F) ratio was calculated from the exhaust gas composition. The exhaust emission and air-fuel ratio data are discussed in the text and presented in tabular form in appendix A. Emissions were measured at the midpoint of the daily 16-hour engine cycle on each mode and for each engine on a daily basis, thus providing comparative data on the status of the engines.

Considerable variation in emissions and A/F with engine type and duty cycle is inherent in the engine design. This variation is normal for proper engine operation.

The exhaust emission data presented herein are summarized in two ways. First, the emissions for a single mode for all of the test days the engine operated on a specific fuel are averaged and presented as "mode average." In addition, the standard deviation is included as a "variability index" of the emissions during each specific mode during the complete fuel test. Thus, a large standard deviation indicates the engine did not closely repeat itself during day-to-day operation, and conversely a small standard deviation indicates good repeatability of a mode on a daily basis.

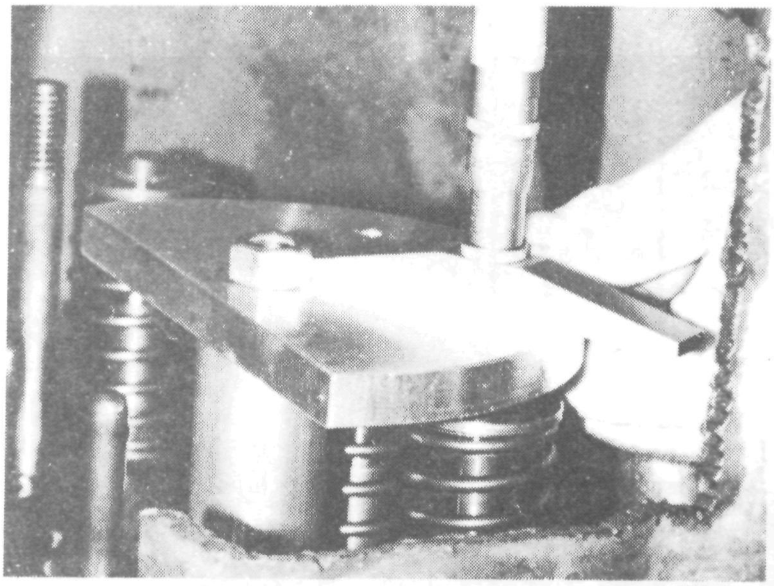
Secondly, in order to provide a summary of emissions on a day-to-day basis, the emissions are presented on a "daily average" basis. The daily average simply represents a numerical average of all modes for each day. The standard deviation is not useful here because it is recognized at the outset that significant variability between modes exists due to characteristics of the engine; however, the variability is adequately demonstrated in the "mode average." The "daily average" presented herein is useful only in noting overall trends of emissions and A/F. The "daily average" cannot identify which mode or modes vary nor which ones remained constant. If the "daily average" remains constant, the probability is that all modes remained constant.

Further, it must be recognized that the majority of these test engines were built when precise carburetion for emission controls was not required. Therefore, the emission data should be useful only in examining trends or as an additional diagnostic in understanding exhaust valve seat recession.

VALVE SEAT RECESSION

John Deere "B"

Valve seat measurement on the John Deere "B" tractor engine was made using a jig made at NIPER (figure 1). This measurement required removal of the rocker arm assemblies and attaching the jig via the rocker arm stud directly to the machined head surface. Two holes drilled in the jig directly over the intake and exhaust valves allowed direct measurement from the surface of the jig (secured rigidly to the head) to the top of the valves.



JD B

FIGURE 1. - Recession measurement jig--John Deere "B" engine.

Farmall "H"

Valve seat recession measurements were made on the Farmall "H" tractor engine using a jig made from aluminum which rested on each side of the valve covers' machined surface area with a flat plate across the top of the head just over the valve train assembly. The plate across the top was machined such that one surface was 6° from horizontal which made the measurement directly perpendicular to the direction of travel of the intake valve. This resulted in measurements directly in the line of travel and eliminated errors due to the angles included. The measurement jig is shown in figure 2. The angle of the exhaust valve was also 6° in order to accomplish the goal described above.

After valve lash had been adjusted and with the feeler gauge inserted between the rocker and valve stem, the recession measurement was made using a depth micrometer to measure the distance from the angled surface of the jig resting on the machined head surface to the top of the rocker assembly in contact with the valve.

Farmall H

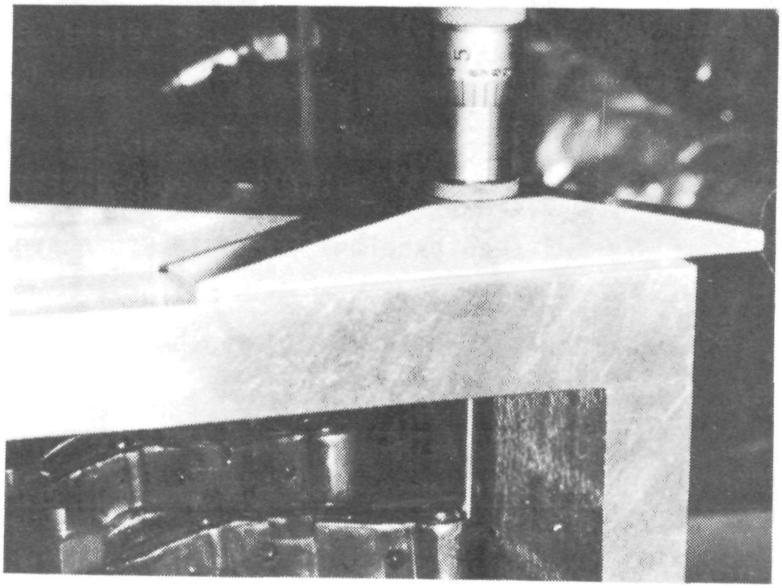


FIGURE 2. - Recession measurement jig--Farmall "H" engine.

Ford 8N

Valve seat measurement on the Ford 8N was made measuring the valve lash using a feeler gauge. The "valve-in-block" design required removing the intake/exhaust assembly to gain access to the valve inspection ports. The procedure was simply to determine the lash using a feeler gauge and compare the reading to the previous measurement and reset the valve lash to the proper setting.

At the start and end of the test, the engine was disassembled and the distance from the flat machined engine block surface to the face of the valve installed in the block was measured using a micrometer. The valve seat recession was calculated from these measurements.

IH-240

Valve seat recession measurements on the IH-240 engine were made using a jig consisting of a stainless steel machined cylinder with a slot along the length, allowing the cylinder to be placed over the valve and valve spring with the rocker assembly attached (figure 3). The jig rests on the machined head surface near the valve, and measurements are made from the top of the jig to the top of the rocker arm resting directly on the valve. During actual measurement, valve lash was set to specifications using a feeler gauge inserted between the rocker and valve and measured from top of cylinder to top of rocker arm assembly using a dial depth gauge. The engine was manually rotated to get maximum compression of either the exhaust or intake valve while measuring the companion valve to accurately repeat the lash and recession measurement.

GM-292

Valve seat recession measurements were accomplished for the GM-292 engine using a jig consisting of a machined cylinder with a slot along the length similar to that used on the IH-240 engine (figure 3). The jig was placed over the valve and valve spring and allowed to rest on the machined head surface near the valve spring area. The distance from the top of the jig to the top of the rocker arm assembly in contact with the valve was measured using a depth dial indicator.

IHC 240

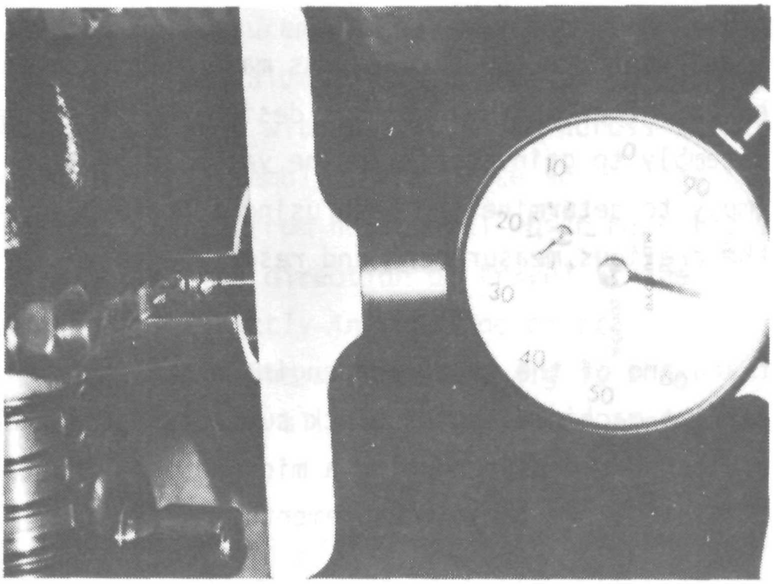


FIGURE 3. - Recession measurement jig--International Harvester 240.

The engine was rotated by hand to top dead center (TDC) on the compression stroke (cylinder No. 1), after which intake valves 1, 2, and 4 and exhaust valves 1, 3, and 5 were measured. The remaining valves were measured at after rotating the engine 360°.

John Deere-303

Valve seat recession measurements were made for the John Deere 303 engine using a system similar to the IH-240 and GM-292 by constructing a jig consisting of a stainless steel cylinder machined with a slot the length of the cylinder. The jig was placed over the valve and valve spring and allowed to rest on a machined head surface near the valve. Valve lash was adjusted in accordance with manufacturer specifications. With the feeler gauge inserted, the measurement from the top of the rocker arm resting on the valve to the top of the jig was made to represent the change in valve height relative to the engine head. Intake valves 1, 2, and 4 and exhaust valves 1, 3, and 5 were measured with the engine at TDC on the compression stroke of cylinder No. 1. The engine was rotated exactly 360° and the remaining valves adjusted and recession measured. This was done to ensure accurate measurements without camshaft imperfections influencing measurements.

GM-454

Valve seat recession measurements on the GM-454 engine were difficult due to the design of the valves in the head. From the surface of the head, the exhaust and intake valves are not vertical with respect to the head but are offset at an angle measured both lengthwise and crosswise to the head. Measured in a plane along the engine head (front to rear), the intake and exhaust valves are offset 5° from horizontal. Measured in a plane across the engine head, the intake valves are offset 10° and exhaust valves 15° from horizontal. Therefore, in order to get a direct vertical measurement, it was necessary to design a suitable jig. The jig consisted of a rotating cylinder held parallel to the engine head by appropriate braces resting on the mach[illegible] valve cover surface. The rotating cylinder had two flat surfaces machined onto the cylinder such that one of the surfaces was perpendicular to the angle of the exhaust valve and the other surface perpendicular to the intake valve. Holes were drilled through the machined surfaces to allow direct measurement from the surface of the cylinder, through the cylinder, and directly to the top of the rocker arm assembly. Alignment of mating marks on the jig and head surface was used to assure repeatable measurements. Figure 4 shows the jig assembly used to measure valve seat recession on the GM-454.

GM 454

FIGURE 4. - Recession measurement jig--GM-454 engine.

The heads for the GM-454 engine used for these tests were induction hardened. Induction hardening typically consists of heating only the valve seat area with electrical coils followed by rapid quenching. The hardened area covers only a small portion around the valve seat area. The induction-hardened valve seat area of the head is reported by the OEM manufacturer to be approximately HRC 55.

VALVE TRAIN INSPECTION/RECESSION MEASUREMENT

A measure of pertinent valve train components and a measure of valve seat recession were made off site at an automotive machine shop under the direction of a certified engine rebuilder independent of the NIPER facility.

A brief description of the techniques used follows.

Valve Seat Angle

Valve seat angle was determined using a valve seat surfacing machine with a precision grinding stone.

Valve Seat Recession

A Fowler gauge was used to measure valve seat recession. A Fowler gauge is a device that slips over the valve, rests on the valve spring surface and measures the distance from the valve spring surface to the valve tip. A sketch of the device is presented in figure 5. The apparent valve seat recession is the difference between starting and ending measurements. The actual valve seat recession is the apparent valve seat recession corrected for any change in valve height during the test. The valve and valve seat are wiped clean with a cloth prior to measuring, but are not vigorously cleaned.

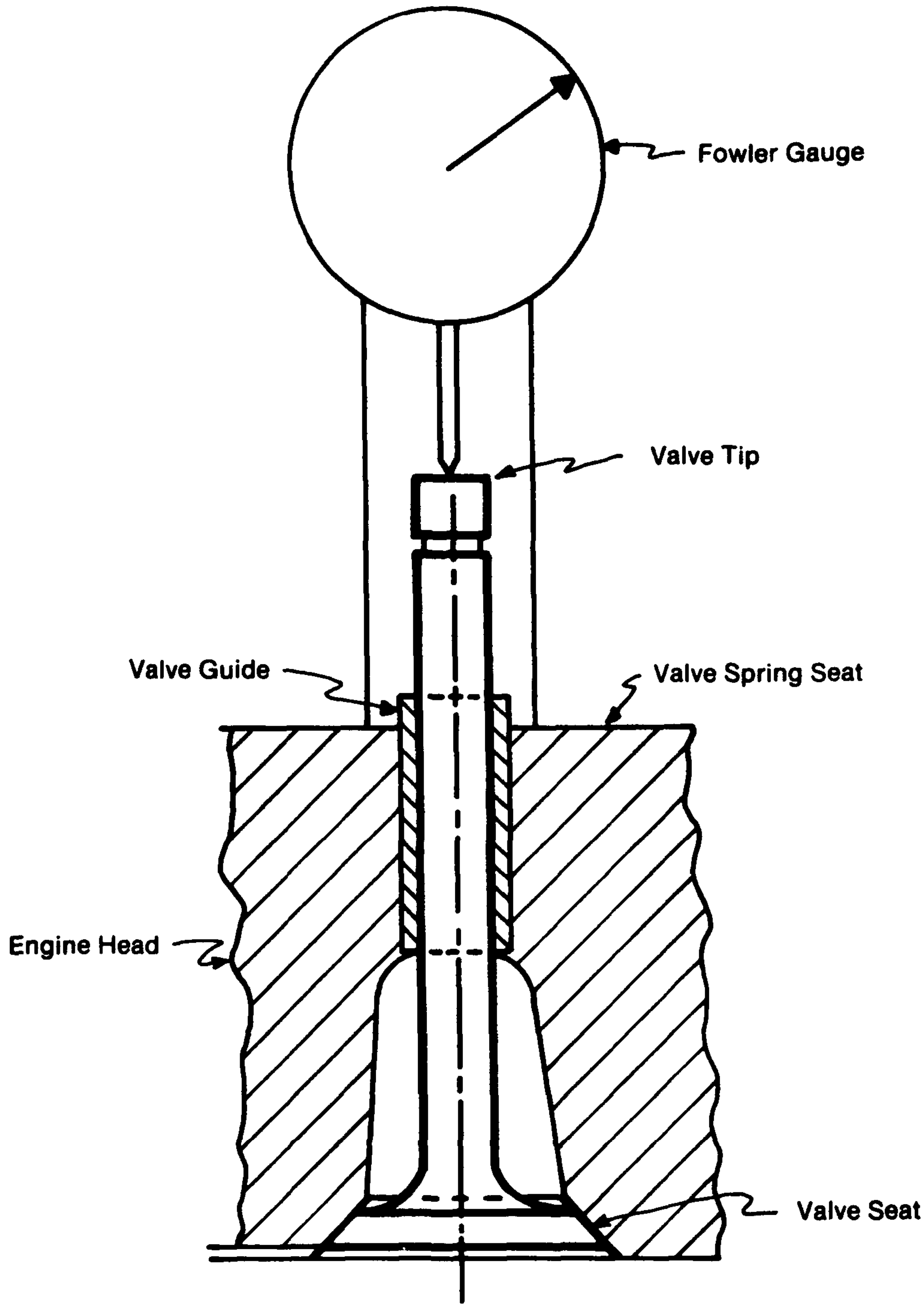


FIGURE 5. - Fowler gauge used for measurement of valve seat recession.

Valve Height

Valve height is the overall length of the valve and is measured using a height gauge. Prior to testing a small dimple is placed in the center of the valve face. The valve tip is placed on a granite block in a vertical position; the height gauge also on the granite block measures the distance from the dimple on the valve face to the surface of the block. The dimple area on the valve face is cleaned of deposits prior to measuring valve height.

Valve Tulip Diameter

The valve tulip is the widest part of the valve, and its diameter is measured with a micrometer.

Valve Guide Diameter

The valve guide diameter is measured with a valve guide dial bore gauge, a device specifically designed for this purpose and commonly used at automotive machine shops.

Valve Stem Diameter

The valve stem diameter is measured at the area of travel of the valve stem inside the valve guide. The valve stem is measured using a micrometer.

Valve Spring Height

The valve spring height is measured, after the valve spring is installed, from the head surface to the top of the valve spring using a snap gauge.

Valve Spring Force--Normal

The valve spring is removed from the engine head and compressed to the exact height value recorded as "Valve Spring Height" and the spring force measured.

Valve Spring Force Compressed

After measuring the valve spring force (normal) the valve spring is compressed to a distance equal to the camshaft lift and the spring force measured.

RESULTS AND DISCUSSION

LEADED FUEL

John Deere "B" Engine

The engine head was tested for hardness at two points and found to be 17.7 HRC and 19.5 HRC (Rockwell hardness on the "C" scale), which is roughly equivalent to 95.5 HRB and 97.5 HRB (Rockwell hardness on the "B" scale).

Exhaust valve seat recession measurements presented in table 4 ranged ±.003 inch from start to finish, thus indicating no exhaust valve seat recession using the 1.2 gm/gal fuel.

Intake valve measurements showed an apparent .005 inch change at the 97-hour test point. However, data before and after this point suggest no significant trends. The valve train inspection data (table B-1 in appendix B) show a slight negative recession in all valves which can indicate deposit build-up on the valve seats. Further, the inspection data do not confirm the observed change in intake valve No. 2 at the 97-hour point.

The A/F for all modes for the John Deere "B" tractor test using 1.2 gm/gal leaded fuel ranged from 12.7 to 14.1 over the six test modes (table A-1 in appendix A). Significant daily variation was also noted (table A-2) on day three when the average A/F leaned from about 12.4 to almost 15.9 and then dropped to 10.5 on the fourth day. The A/F also leaned on day six to 17.7 and dropped to a more typical condition of about 11.5 on the next day. While significant A/F variations occurred, no significant exhaust valve seat recession was noted using the leaded fuel.

TABLE 4. - Effect of accumulated engine hours on valve seat recession--
John Deere "B" engine--1.2 gm/gal lead--average hardness HRB 96.5

	Valve Seat Recession, inches/1000										
Hours Accumulated	17	33	49	65	81	97	113	129	144	200	*
Intake 1	0	-1	-1	2	-1	1	1	3	4	3	-1
2	0	3	3	2	2	7	8	10	10	8	-2
Exhaust 1	2	2	1	-2	-2	0	-1	-1	-1	-3	0
2	-1	-1	-1	-1	-1	2	0	-1	-2	-1	-1

*Measurement based upon engine disassembly and inspection.

Farmall "H" Engine

Several intake and exhaust cast iron inserts were tested for hardness, and inserts of median values were selected. The inserts selected for the 1.2 gm/gal fuel tests are as follows:

Intake	1 - HRC 16.5	Exhaust	1 - HRC 16.2
	2 - HRC 16.5		2 - HRC 17.1
	3 - HRC 16.6		3 - HRC 17.0
	4 - HRC 16.9		4 - HRC 17.5

The average hardness value of HRC 16.8 is roughly equivalent to HRB 95.

Valve seat inserts for these series of tests were installed using the interference fit method. With this method, the valve seat insert is .005 inch larger in diameter than the hole in which the insert is to be installed. The insert (designed with chamfered edges) is then pressed into the engine head assembly.

Valve seat recession measurements for the Farmall "H" using fuel with 1.2 gm/gal are presented in table 5.

Data show that, at the 58-hour point, valve seat recession apparently increased in cylinder No. 1 exhaust valve but remained constant after that point, as well as before. This coincides with a point when a compression check indicated somewhat lower compression in this cylinder compared to the other. It is postulated that the valve seat insert had moved slightly while in the head. The test was continued while closely monitoring the engine condition. During the remainder of the test, little change was noted, thus suggesting that the observed effect was not, in fact, valve seat recession but due to another factor.

TABLE 5. - Effect of accumulated engine hours on valve seat recession--Farmall "H" engine, 1.2 gm/gal lead--average insert hardness HRB 95

Hours Accumulated		Valve Seat Recession, inches/1000													
		15	30	37	42	58	73	87	104	120	136	144	168	200	*
Intake	1	0	-3	0	1	1	1	2	1	3	2	2	2	2	-1
	2	2	6	2	-1	1	2	2	2	3	2	3	0	3	0
	3	1	3	1	2	1	-1	-1	0	-1	1	2	2	1	-5
	4	0	-2	0	0	-1	0	0	0	0	-1	-2	-2	-3	-2
Exhaust	1	8	8	8	9	37	39	32	30	31	30	30	31	30	0
	2	2	2	4	5	4	2	4	4	4	4	4	6	4	-5
	3	2	2	2	3	4	2	1	1	3	1	1	2	3	-5
	4	2	2	2	2	3	2	1	2	2	2	3	2	2	-3

*Measurement based upon engine disassembly and inspection.

Comparison of valve train inspection data (table B-2) before and after testing suggests no valve seat recession within a range of .005 inch. The inconsistency of exhaust valve No. 1 noted in the "running" measurements was not apparent in the valve train inspection. Valve guide wear of about .0006 inch was consistent for both intake and exhaust valves. The valve properties were essentially unaffected. The valve spring force was reduced about 10 percent due to the aging of the springs during the 200-hour test.

The A/F variation between modes for the Farmall "H" using leaded fuel ranged from 11.5 to 12.9 (table A-3), while the daily A/F variation ranged from 10.0 to 14.2 (table A-4). There appears to be no consistent trend toward enleanment or enrichment in the daily A/F variations noted.

International Harvester 240 Engine

Table 6 presents valve seat recession measurements for the IH-240 engine and shows no exhaust valve seat recession using the leaded fuel. The data tend to indicate valve seat recession of No. 1 intake valve. However, if a new baseline were taken after only three hours of operation, no recession would be indicated. It is assumed that the valve was not seated well on the initial reading. The head was measured for hardness at three places and found to be HRC 17.5, HRC 20.7, and HRC 16.5 measured on the Rockwell "C" scale. Subsequent measurements showed HRB 92, HRB 93, and HRB 93 when measured on the Rockwell "B" scale.

TABLE 6. - Effect of accumulated engine hours on valve seat recession--
IH-240 engine--1.2 gm/gal lead--average hardness HRB 92.7

	Valve Seat Recession, inches/1000													
Hours Accumulated	3	18	34	39	54	69	84	99	114	128	144	168	200	*
Intake														
1	4	4	5	7	3	3	5	5	4	6	5	5	5	-1
2	-2	-1	-1	0	0	-1	0	0	-1	1	0	0	0	-1
3	-2	-1	-2	0	-1	-2	-2	-1	-1	0	-1	-1	0	2
4	0	-2	0	1	1	0	-1	-1	0	0	0	0	-1	2
Exhaust														
1	-2	-2	0	3	0	0	-1	0	-1	1	0	0	-1	2
2	0	0	0	1	1	0	1	1	1	1	1	0	0	3
3	-1	-1	0	1	0	0	0	-1	-1	0	-1	0	-1	2
4	-1	-2	-2	0	-2	-2	-2	-2	-2	-2	-3	-3	-3	3

*Measurement based upon engine disassembly and inspection.

Comparison of valve train inspection data (table B-3) before and after the 200-hour test suggests no valve seat recession outside a range of .004 inch. A .003-inch change in valve height was noted in exhaust valve measurements. This could have been due to an early problem with the lack of lubricant transferred to the valve train in the first test cycle due to an undetected restriction of the oil line. The restriction was detected and repaired after about six hours of engine operation. Valve guide wear appeared to be normal except for intake valve No. 3 which had about .0143-inch wear. The valve spring force reduction due to the test also appeared to be consistent.

The A/F variation between modes was large for the IH-240 engine operating on the leaded fuel, with modes 1 and 4 operating at A/F of 13.9 and mode 2 operating at 11.1 (table A-5). However, daily operation was consistent with an average A/F ranging from 12.2 to 12.9 (table A-6).

GM-292 "A" Engine

The hardness of the head was measured and found to be HRB 91. The construction of the head was such that accurate readings could only be obtained at one spot near the rear of the engine. The data presented in table 7 suggest no trend toward valve seat recession during the 200-hour period using leaded fuel. Valve seat recession data show greater variability than noted in the other engines, with up to .008-inch recession noted.

TABLE 7. - Effect of accumulated engine hours on valve seat recession--
GM-292 "A" engine, 1.2 gm/gal leaded fuel--average hardness HRB 91

Hours Accumulated		Valve Seat Recession, inches/1000														
		6	16	32	48	63	79	95	111	122	138	154	170	186	200	*
Intake	1	-	2	-1	-2	0	-2	1	-1	-1	-2	0	2	2	2	2
	2	-	-	-	-	1	1	2	2	1	2	2	2	3	3	2
	3	-	3	5	5	4	5	3	3	5	4	5	6	4	5	3
	4	-	1	0	2	2	1	2	4	4	4	3	3	2	2	2
	5	-	3	0	1	0	0	0	10	9	8	8	9	7	7	3
	6	-	2	0	0	-2	-4	-5	0	-4	-4	-4	-3	-3	-2	0
Exhaust	1	-2	0	0	-1	0	0	0	-1	-1	-1	-1	0	-1	0	-3
	2	-1	-2	-2	-2	0	0	-3	1	1	0	-1	-2	-2	-1	-5
	3	-5	-3	-3	-1	-1	-1	3	6	6	6	6	6	6	6	2
	4	-3	-2	-1	-1	-1	0	-1	-3	0	-2	-3	-3	-2	-2	-4
	5	7	9	7	6	7	7	6	6	6	7	6	5	7	8	2
	6	0	0	0	0	0	3	0	2	2	2	2	1	1	1	-5

*Measurement based upon engine disassembly and inspection.

After the engine had accumulated some 16 hours, variability was reduced to only ±.003 inch which was similar to the range noted in the other tests. Intake valve 5 changed by about .010 inch during one period at 111 hours, but measurements remained stable both before and after that point. This suggested that valve seat recession was not the cause but the result of other factors.

Comparison of the valve train inspection data at the start and end of testing (table B-4) shows no valve seat change in excess of .003 inch. The variability of the "running" measurements on valve seat recession was on the order of .008 inch. Measurements of valve height of the exhaust valves appeared to indicate that the valve "stretched" during the 200-hour test. While the valve spring forces on this engine are significantly greater than the other engines (which would tend to "stretch" the valve) the mechanism of valve elongation is not understood, but is duly noted. Valve guide diameter changes in the range of .003 to .0006 inch were the norm. Exhaust valve guide No. 6 increased by .0018 inch during the 200-hour test.

A/F variations between the five test modes with the GM-292 engine operating on leaded gasoline ranged from 11.9 at the highest speed/power condition to 14.5 at the 45 percent power conditions (table A-7). Daily variations in the averaged A/F ranged from 12.9 to 14.1 (table A-8).

<u>John Deere 303 Engine</u>

The new OEM engine head was measured for hardness and found to be HRC 20.7, HRC 20.2, and HRC 19.5 which approximates HRB 101, HRB 101, and HRB 100 if measured on the Rockwell "B" scale.

Measurements presented in table 8 showed no valve seat recession and, with the exception of questionable measurements taken at the 101-hour point, the variability was generally ±.003 inch for all valves during the 200-hour cycle. Examination of the valve train inspection data before and after testing with 1.2 gm/gal leaded fuel (table B-5) shows no valve seat recession outside a variation of about .003 inch. Other variables measured show no unusual effects.

The A/F variation between the six modes for the John Deere 303 engine using leaded fuel ranged from 11.7 to 13.3 (table A-9). In addition, the daily A/F variation of the averaged modes ranged only from 12.3 to 13.4 (table A-10).

TABLE 8. - Effect of accumulated engine hours on valve seat recession--
John Deere-303 engine, 1.2 gm/gal lead--average hardness HRB 100

Hours Accumulated	Valve Seat Recession, inches/1000										
	28	44	58	70	85	101	116	132	146	200	*
Intake											
1	0	0	-2	-1	-1	0	-1	-1	-1	-2	1
2	0	0	-1	0	0	1	-1	0	0	-1	-1
3	0	2	1	1	6	7	2	3	3	3	1
4	0	0	-1	-4	0	2	0	0	-1	-1	-1
5	0	-1	1	1	2	6	-1	1	0	0	0
6	0	4	1	0	3	8	3	1	1	1	0
Exhaust											
1	0	0	-1	0	0	7	0	0	-1	-1	0
2	0	0	-1	1	1	5	-1	1	1	1	-1
3	0	0	1	0	2	4	0	-1	-1	1	1
4	0	1	0	2	3	8	3	3	3	3	1
5	0	0	-1	4	0	5	0	0	-2	0	1
6	0	-1	0	6	1	5	1	2	1	1	0

*Measurement based upon engine disassembly and inspection.

GM-454 Engine

Measurements presented in table 9 show significant variability in valve seat recession. The cause of the variability is undefined. Subsequent tests using a different measurement technique that showed better repeatability suggest two probable factors. First, the difficulty of jig repositioning and alignment considering the two angles for the intake and two other angles for the exhaust valves may have been the major factor. The second factor, however, may have been the hydraulic valve lifters not releasing all the oil pressure as the engine was rotated by hand during the measurement process. Attempts to eliminate these variables were made during subsequent tests.

Recession measurement variability of ±.019 inch was recorded, which may be excessive for detecting slight trends. Closer inspection of the data showed no obvious trends toward recession. In fact, the negative recession values indicate the possibility of head warpage or other factors at work in addition to those discussed above.

TABLE 9. - Effect of accumulated engine hours on valve seat recession--GM-454 engine, 1.2 gm/gal leaded fuel--induction-hardened seats

Hours Accumulated	Valve Seat Recession, inches/1000														
	15	32	41	56	73	89	104	120	136	144	152	168	184	200	*
Intake															
1	13	2	1	6	4	2	1	2	4	2	2	0	3	-1	1
2	16	11	9	9	9	5	1	2	5	5	6	6	2	2	-1
3	15	26	18	5	9	12	13	11	12	13	10	9	15	9	-1
4	16	-8	-7	-5	-8	-4	-8	-5	-4	-5	-4	-6	-1	-8	-2
5	19	19	17	20	17	10	12	14	17	17	17	17	18	16	3
6	7	7	7	7	12	6	5	9	12	9	9	8	13	8	-2
7	13	14	10	8	10	5	5	6	13	14	13	13	12	12	2
8	40	16	15	14	17	21	13	19	21	20	21	16	22	14	1
Exhaust															
1	-1	0	-5	-10	-12	-9	-10	-13	-11	-11	-12	-14	-16	-19	5
2	-5	-7	0	2	-6	-8	-5	-10	-7	-7	-10	-11	-16	-15	2
3	0	0	-2	-10	-12	-13	-9	-16	-7	-10	-11	-12	-16	-18	6
4	4	1	6	3	-2	-2	0	-7	0	-1	-1	-7	-8	-10	0
5	3	3	2	0	-10	-7	-3	-12	-6	-7	-8	-8	-11	-12	2
6	6	1	7	10	-3	1	0	1	0	-1	-5	-6	-2	-6	2
7	-4	-4	-7	-8	-8	-10	-13	-17	-14	-14	-17	-18	-18	-19	2
8	4	4	7	4	-3	2	6	-1	1	3	-1	-3	-4	-5	2

*Measurement based upon engine disassembly and inspection.

NOTE: See text for discussion of measurement difficulties and limitations.

Valve seat inspection data for the GM-454 engine using 1.2 gm/gal lead (table B-6) show no valve seat recession in excess of .006 inch. Recession data variability is greater than noted on most other engines.

Valve guide wear was a nominal .0005 inch and relatively consistent for all valves. Consistent valve "stretch" was not noted on this engine even though the valve spring pressures were greater than with the other engines tested. Possible differences in valve construction or composition could affect this issue. Other parameters measured show only slight variations due to normal wear.

The A/F variations over the six modes for tests with the GM-454 engine using leaded fuel showed significant variability between modes ranging from A/F of 12.9 at 3,600 rpm, 85 percent power to 15.2 at 2,000 rpm at 45 percent power (table A-11). The daily A/F average data showed good A/F repeatability ranging from 13.6 to 14.3 A/F (table A-12).

UNLEADED FUEL

John Deere "B" Engine

A new head was installed on the engine with a hardness measured at three places of HRB 93, HRB 92, HRB 91.5.

Exhaust valve seat recession measurements, presented in table 10, show a .011-inch recession in one cylinder after 200 hours and no recession in the other intake or exhaust valves. Detailed examination of the valve train assembly suggested possible misalignment problems due to the rocker arm striking the valve stem on the side rather than the center of the valve stem.

The test was repeated after a new head was installed and the rocker arm assembly realigned properly to strike the valve in the center of the stem area. The hardness of the head was measured at three places and found to be HRB 92.5, HRB 92.5, and HRB 93. The valve seat recession data for the repeat test using unleaded fuel (presented in table 11) showed .006- and .013-inch recession in exhaust valves after 200 hours of operation. The engine test was continued for an additional 100 hours of operation (6-mode cycle) to determine if the slight amount of recession noted represented a consistent trend. The additional 100 hours of operation resulted in a total recession of only .008 and .013 inch in the exhaust valve seats, suggesting that valve seat recession is minimal with this engine.

Post inspection of the valve train assembly for the original test using unleaded fuel (table B-7) showed a .009-inch recession in one exhaust valve compared to .013 inch measured during engine operation. Further examination of the right-hand exhaust valve guide showed .0035-inch wear at the bottom of the guide, and the top of guide showed .0005-inch wear. This wear pattern is an indication of the rocker arm pulling the valve stem toward the rocker shaft each time the valve opens. This would explain the elongated guide and the irregular valve seat wear.

Inspection of the valve stem end showed scuffing on the edges of stem tip, further indicating irregular rocker arm tip contact.

Inspection of the rocker arm shaft and rocker arm tip also suggested excessive wear.

TABLE 10. - Effect of accumulated engine hours on valve seat recession--
John Deere "B" engine--unleaded fuel--average hardness HRB 92.2

	Valve Seat Recession, inches/1000												
Hours Accumulated	16	32	48	64	80	96	112	128	144	168	195	200	*
Intake 1	1	0	0	-1	0	-1	0	1	0	1	1	0	1
2	-1	0	-1	0	-1	1	-1	0	-1	0	0	0	0
Exhaust 1	0	0	0	0	-1	1	0	0	-1	-1	-1	-1	0
2	-1	-1	-1	0	0	0	1	1	-1	4	11	11	9

*Measurement based upon engine disassembly and inspection.

TABLE 11. - Effect of accumulated engine hours on valve seat recession--
John Deere "B" engine--unleaded fuel repeat test--average hardness HRB 92.7

Hours Accumulated	Valve Seat Recession, inches/1000																		
	16	32	48	64	80	96	112	128	144	168	200	213	226	242	258	274	290	300	*
Intake 1	0	0	0	0	0	0	0	0	0	0	-1	-1	-2	0	-1	-1	-1	-1	0
2	-1	-1	-1	-1	-2	-2	-2	-1	-1	-2	-2	-2	-1	-2	-2	-2	-2	-2	-2
Exhaust 1	-1	-1	-1	0	-1	1	4	6	8	7	6	7	10	8	8	8	8	8	9
2	-1	-1	0	0	0	5	8	10	13	13	13	11	11	13	13	13	13	13	14

*Measurement based upon engine disassembly and inspection.

Additional inspection of the head used previously with leaded fuel showed a similar wear pattern of .001 guide wear at the bottom of the guide, and .0001 was found at the top. The guide was elongated at the same place as the unleaded test head, only not as severe. The valve seat had a build-up of lead deposit which indicated signs of the same irregular valve seat, but wear was not measurable.

Post-inspection of the valve train assembly in the unleaded repeat test (300-hour) (table B-8) showed no irregularities within the valve guide assembly as was noted during the original 200-hour test using unleaded fuel.

The A/F during the original unleaded fuel test with the John Deere "B" engine was somewhat "richer" but much more consistent compared to the leaded fuel test with the A/F varying between modes from about 10.7 to 11.3 (table A-13). Further, daily variations were much more limited ranging only between A/F of 10.2 to 11.2 for the test duration (table A-14). The A/F during the repeat unleaded fuel test (tables 15 and 16) showed the average A/F was 10.1 to 10.4 during the first four days, then ranged from 12 to 13.3 for the remainder of the test. The 56-hour mode operated at 13.1 A/F.

Farmall "H" Engine

Data for the unleaded fuel tests, presented in table 12, show no tendency toward valve seat recession in any of the cylinders. The values of the hardness of the valve seat inserts used are as follows:

Intake 1 - HRB 95.5	Exhaust 1 - HRB 95.5
2 - HRB 95.5	2 - HRB 95.0
3 - HRB 95.2	3 - HRB 95.5
4 - HRB 96.4	4 - HRB 95.0

The valve train inspection data (table B-9) showed no valve seat recession. Further, all valve guide and stem diameters, as well as valve height, were unusually repeatable and consistent from start to end of test.

Tests with the unleaded fuel in the Farmall "H" showed greater A/F variations between modes with A/F ranging from 10.5 to 15.9 (table A-17). However, the daily A/F variations were more consistent ranging from 12.6 to 13.1 (table A-18).

Again, no valve seat recession was noted during either of the tests with the Farmall "H" engine.

TABLE 12. - Effect of accumulated engine hours on valve seat recession--
Farmall "H" - unleaded fuel - average insert hardness HRB 95.5

Hours Accumulated		Valve Seat Recession, inches/1000											
		16	32	48	64	80	96	112	128	144	168	200	*
Intake	1	0	0	-1	-1	0	0	0	0	0	0	-1	-3
	2	0	0	0	1	2	2	1	1	1	1	0	-3
	3	0	-1	0	0	0	0	1	1	1	1	0	-4
	4	0	-1	0	1	1	1	0	-1	-1	-1	1	-4
Exhaust	1	0	-1	0	0	0	0	0	1	0	1	1	-4
	2	-1	-1	-1	-2	-2	-2	-2	-2	0	0	1	-3
	3	0	1	0	0	0	0	0	0	0	0	1	-2
	4	0	0	1	0	0	0	1	1	1	1	1	-4

*Measurement based upon engine disassembly and inspection.

Ford 8N

The Ford 8N engine was tested using cast iron valve seat inserts with a hardness of Rockwell HRB 96.5. The data (table 13) showed that valve seat recession occurred in one exhaust valve after about 40 hours and continued at a slow rate during the remainder of the test to about .020-inch seat recession total. The other exhaust valve seats remained generally unchanged until the start of the 56-hour steady state mode when they began to recede rapidly. The test resulted in all of the exhaust valve seats receding from .017 to .029 inch. The intake valve seats were essentially unchanged during the test.

The valve train inspection data (table B-10) also suggested no change in the intake valve seats but .017 to .030 inch recession of exhaust valve seats. The other parameters measured showed only nominal changes during the test.

Examination of the emission and air-fuel data (table A-19) showed variations in A/F of 11.6 to 13.9 of the various modes, with the 56-hour mode operating at 12.7 to 13.1 A/F. The daily variations (table A-20) showed a relatively consistent A/F average of 11.7 to 12.9 during the days the engine was operated. The NO_x instrument was inoperable during this series of tests; therefore, no data are presented.

TABLE 13. - Effect of accumulated engine hours on valve seat recession--
Ford 8N--unleaded fuel--HRB 97 valve seat inserts

		Valve Seat Recession, inches/1000													
Hours Accumulated		7	23	39	55	71	87	103	119	135	144	168	188	200	*
Intake	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0
	2	-2	-4	-4	-3	-4	-4	-4	-4	-4	-4	-4	-4	-4	-1
	3	-2	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-1
	4	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-2
Exhaust	1	1	1	1	1	1	1	1	1	1	1	3	9	17	17
	2	0	4	8	10	11	12	14	15	17	17	17	19	20	21
	3	-1	-2	-1	-1	-1	0	0	0	0	1	14	21	29	30
	4	0	1	2	3	3	3	3	3	4	4	6	16	26	25

*Measurement based upon engine disassembly and inspection.

IH-240 Engine

This engine was tested three times on unleaded fuel. Table 14 presents data for the first test. The data showed no trend toward recession with a range of measurements generally agreeing to ±.001 inch. Subsequent examination of the hardness of the head used for this test showed the head to be harder (measured in two places - HRB 97, HRB 98) compared to the four other engine heads acquired for testing (HRB 92 to HRB 94). It was therefore decided to repeat the test with a "softer" engine head.

The data for the second test with unleaded fuel are presented in table 15. The data from this test showed exhaust valve seat recession of almost .050 inch in two cylinders and no recession in the other cylinders. The hardness of this head was measured in three places and found to be HRB 93, HRB 92, and HRB 93. In order to determine if the hardness of the two cylinders showing recession was different than the other cylinders, the entire engine head was sectioned, allowing access to the valve seats for individual cylinder hardness measurements. The sectioning process allowed determining the material hardness perpendicular to direction of valve travel on the sectioned surface of the head. This measurement was made approximately 1/16 inch immediately below the valve seat surface. The hardness of the four valve seats of the head used in the first unleaded test was HRB 97, and no recession was noted.

TABLE 14. - Effect of accumulated engine hours on valve seat recession--
IH-240 engine--unleaded fuel--average hardness HRB 97.5

	Valve Seat Recession, inches/1000													
Hours Accumulated	6	12	28	44	60	76	92	108	124	140	144	168	200	*
Intake														
1	1	0	1	0	0	0	0	0	0	0	0	0	0	-4
2	-1	0	0	1	0	0	-1	-1	-1	-1	0	-1	-1	-3
3	-1	-2	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-2
4	2	1	-1	1	1	0	-1	-1	-1	-1	-1	-1	-1	-2
Exhaust														
1	0	0	0	-1	0	-1	0	0	0	0	0	0	0	-5
2	1	2	1	1	1	0	0	0	1	0	0	0	0	-3
3	-1	1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-5
4	-1	2	0	1	0	1	0	0	0	0	0	0	0	-5

*Measurement based upon engine disassembly and inspection.

TABLE 15. - Effect of accumulated engine hours on valve seat recession--
IH-240 engine--unleaded fuel--repeat test--average hardness HRB 92.7

	Valve Seat Recession, inches/1000											
Hours Accumulated	16	32	48	64	80	96	112	128	144	168	200	*
Intake												
1	-1	-1	-1	-2	-2	-2	-2	-1	-1	-1	0	-2
2	-1	0	-1	0	0	0	-2	-1	0	0	0	-4
3	0	0	0	0	0	0	0	0	0	0	0	-4
4	0	0	0	0	0	-1	0	0	0	-1	0	-4
Exhaust												
1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	-2
2	0	-1	-1	0	0	0	-1	1	1	0	1	-1
3	-1	-1	0	4	6	9	11	16	20	29	43	38
4	0	1	0	1	6	11	16	19	24	36	49	47

*Measurement based upon engine disassembly and inspection.

Hardness of the four valve seats of the head used in the repeat unleaded test was HRB 96, HRB 97, HRB 95, and HRB 96.5 for valve seats 1 through 4, averaging 96.1. Valve seats Nos. 3 and 4 received about .050-inch recession, while valve seats Nos. 1 and 2 received no recession suggesting factors other than valve seat hardness were responsible for the recession.

Valve train inspection data for the two tests with unleaded fuels (tables B-11 and B-12) confirm no valve seat recession in the first test. In the second test, .038-inch recession in cylinder No. 3 and .047-inch recession in cylinder No. 4 were noted. Valve spring force was consistent for both tests. During the first test, valve guide wear of .0022 inch in exhaust valve No. 3 was outside the norm of about .0007 inch; however, no valve seat recession was noted. During the second test, valve guide wear of .0019 inch was noted in cylinder No. 4, which had the greatest recession. This suggests that excessive valve guide wear is not consistently associated with valve seat recession.

The A/F variation between modes for the first test with unleaded fuel ranged from 10.7 to 13.4 (table A-21). Daily operation was unusually consistent and ranged from an A/F of 12.0 to 12.8 (table A-22). Again, no recession was noted during this test.

The A/F for the repeat test with unleaded fuel operated at leaner A/F conditions than in the first test. The A/F variation between modes ranged from 13.3 to 15.2 (table A-23), while the daily variation ranged from 12.8 to 16.1 with the A/F becoming leaner as the testing progressed (table A-24). This suggests that A/F enleanment, which can increase combustion temperature, may be a factor in the valve seat recession noted during these tests.

In an effort to further understand why some cylinders showed valve seat recession and others did not, even though many variables were constant (e.g., valve seat hardness, speed, load, engine temperature, etc.), a test was conducted to measure the A/F in individual cylinders. The IH-240 engine was outfitted with three sampling probes inserted in the exhaust manifold with the sample probe intake as close to the exhaust valves as practical. The exhausts for cylinder Nos. 2 and 3 pass through a common port and were sampled as one. The engine was then operated at the six test modes and the three exhaust ports sampled individually during the 6-mode test. The exhaust was sampled for approximately 10 minutes at each test condition. It is recognized that considerable exhaust mixing from all cylinders occurs due to the exhaust pulsations and that exact definition of cylinder A/F would require complete isolation of all exhaust ports. However, sampling in the exhaust ports as described above will provide an "estimate" for information on trends and serve as an indicator of amount of variation from the norm.

The cylinder-to-cylinder A/F (estimates) represent data from a single test and are shown in table 16. These data show the A/F in cylinder No. 4 is not significantly different than cylinder No. 1, except for mode 6 which represents only 65 percent power. Thus, in this case, the data do not support the hypothesis that the A/F ratio is generally higher in the cylinders that showed the most valve seat recession.

Exhaust valve seat inserts with hardness of Rockwell HRB 96 to HRB 97 averaging HRB 96.3 were used for the third test of unleaded fuel with the IH-240.

TABLE 16. - Air-fuel distribution, IH-240

Mode	Cylinder 1	Cylinder 2/3	Cylinder 4
1	14.3	13.9	14.0
2	11.8	11.7	11.9
3	12.8	12.6	12.9
4	14.6	13.8	14.4
5	12.2	12.1	12.1
6	13.5	13.4	14.0

The valve seat recession data (table 17) showed no recession until about 100 hours, after which each exhaust valve seat began receding at a substantial rate. At the end of the modal operation the valve seats had receded about .040 inch. During the following steady-state 56-hour mode recession was approximately doubled. Valve seat recession was much greater than observed when the engine was operated without valve seat inserts.

The valve train inspection (table B-13) also showed valve seat recession from .058 to .085 inch, and showed no change in valve height or valve stem diameter. However, the valve guide diameter from exhaust cylinders 3 and 4 showed significant wear.

TABLE 17. - Effect of accumulated engine hours on valve seat recession--
IH-240 engine--unleaded fuel--valve seat insert hardness HRB 96.3

Hours Accumulated		Valve Seat Recession, inches/1000												
		16	32	48	64	80	96	112	128	144	166	186	200	*
Intake	1	0	1	1	1	1	1	0	0	0	0	0	0	-3
	2	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-2	-3
	3	0	0	0	0	0	-1	-1	0	0	0	-1	-1	0
	4	0	0	0	-1	-1	-1	-1	-1	-1	-1	-2	-2	-1
Exhaust	1	-1	-2	-2	-3	-1	2	20	30	38	52	63	68	63
	2	-1	-1	-1	-1	-1	-1	-1	8	16	26	45	63	58
	3	-2	-3	-3	-2	-1	11	26	36	46	65	75	85	77
	4	-1	-1	-1	-1	1	9	26	37	47	60	79	94	85

*Measurement based upon engine disassembly and inspection.

The A/F and emission data (tables A-25 and A-26) showed consistent daily A/F mixtures during the test ranging only from 12.3 to 13.3. The variation between modes ranged from 11.6 to 13.7. The modes with the leaner A/F (1, 4, and 6) also are the modes with the highest engine load factor.

GM-292 "A" Engine

The GM-292 "A" engine was the first of two GM-292 engines tested in the program. Tests with unleaded fuel using a new head of hardness HRB 88.8 showed a large amount of valve seat recession that would probably have led to catastrophic engine failure if not terminated early. The data are shown in table 18. Approximately 0.125 inch of valve seat recession was noted in one cylinder after 71 hours of engine operation. It is interesting to note that even though valve seats in cylinders 5 and 6 had receded substantially, cylinder No. 4 showed a moderate (approximately .020 inch) recession, and the remaining cylinders showed little or no recession.

TABLE 18. - Effect of accumulated engine hours on valve seat recession--GM-292 "A" engine--unleaded fuel average hardness HRB 88.8

Hours Accumulated		Valve Seat Recession, inches/1000						
		16	20	23	39	55	71	*
Intake	1	0	3	2	1	2	1	0
	2	-3	-3	-2	-2	-2	-4	-4
	3	1	1	4	3	2	1	-5
	4	-1	-2	-2	-2	-2	-2	-5
	5	-1	-1	-1	0	1	0	-4
	6	-1	-1	-1	-1	-6	-3	2
Exhaust	1	0	0	1	-1	-1	0	-5
	2	0	-1	-1	1	6	10	1
	3	-1	0	-1	-2	-2	-1	-4
	4	1	3	4	9	10	21	16
	5	10	13	11	30	61	87	90
	6	15	20	24	67	103	131	121

*Measurement based upon engine disassembly and inspection.

In order to understand the reason for recession in selected cylinders, this engine head was sectioned to allow access for hardness measurements of Ohe individual exhaust valve seats. The sectioning process allowed hardness measurements to be made immediately below the valve seat surface on a cross section of the valve seat surface perpendicular to the direction of valve travel. The hardness of the individual exhaust valve seats was HRB 93.5, HRB 91.0, HRB 89.5, HRB 90.0, HRB 90.5, and HRB 91.0, respectively, for cylinders No. 1 through No. 6. Again, it should be noted that while cylinder Nos. 1 and 3 had no recession, cylinders No. 2 and 4 had about .015 inch recession, and cylinders No. 5 and 6 showed about .100 inch recession. The data suggest that effects other than material hardness were responsible for valve seat recession for this engine.

Inspection of the valve train data before and after the test with unleaded fuel (table B-14) confirms the "running" measurements of valve seat recession in that three cylinders had no recession, one had recession of .016 inch, and two cylinders had recession of .090 and .121 inches. Further examination of valve guide wear (exhaust) showed .0016- and .0015-inch wear in the two cylinders with no valve seat recession and .0022 inch in the cylinder with the most wear. However, the cylinder with .090-inch recession showed essentially no valve guide wear. Valve spring force was significantly lower in cylinders 5 and 6 after the test, compared to other cylinders.

A/F variations between modes for the test (table A-27) using unleaded fuel ranged from 11.9 to 14.1 which are similar to the tests using leaded fuel. Further, the daily A/F variations noted were 12.9 to 13.4 (table A-28) which are also similar to the leaded test. In spite of the similarities in A/F, the unleaded tests resulted in high valve seat recession, whereas the leaded test resulted in no recession.

In an effort to further understand why some cylinders received valve seat recession and others did not (even though many variables were consistent; e.g., valve seat hardness, speed, load, engine temperature, etc.), selected tests were conducted to measure the A/F in individual cylinders. The engine was outfitted with six sampling probes inserted in the exhaust manifold with the sample probe intake as close to the exhaust valves as practicable. The engine was then operated at the five test modes, and the exhaust ports were sampled individually. It is recognized that considerable exhaust mixing from all cylinders occurs due to the exhaust pulsations and that exact definition of cylinder A/F would require complete isolation of all exhaust ports. However, sampling in the exhaust ports as described above will provide an "estimate" for information on trends and serve as an indicator of the amount of variation from the norm.

The cylinder-to-cylinder A/F (estimates) represent data from a single test and are shown in table 19.

TABLE 19. - Air-fuel ratio of individual cylinders

Mode Speed/Load	1	2	3	4	5	6
1 (3,000 RPM/85%)	10.6	10.7	12.2	13.3	13.8	14.1
2 (3,000 RPM/45%)	14.4	14.3	14.7	14.3	14.1	14.2
3 (2,500 RPM/45%)	14.4	13.9	14.7	14.6	13.6	13.8
4 (2,000 RPM/25%)	13.6	13.6	13.9	13.6	12.7	13.0
5 (3,600 RPM/85%)	10.3	10.5	11.7	12.8	13.2	13.4

The data suggest that during the severe duty conditions of modes 1 and 5, the A/F distribution is askewed, in that cylinders 4, 5, and 6 are much leaner than other cylinders; and cylinders 4, 5, and 6 encountered exhaust valve seat recession of .016, .090, and .121 inches, repectively. The leaner A/F mixtures would result in higher cylinder temperatures which could increase valve seat recession at the high speed/load condition. It is interesting to note that during the lighter duty cycles, in which valve seat recession is expected to be less severe, the A/F distribution levels out so that only slight differences are apparent. It could be postulated from this data (and the material hardness data presented earlier) that valve seat recession may be influenced by A/F. The degree of A/F influence (if any) is unknown without further testing under controlled A/F conditions.

GM-292 "B" Engine

A second GM-292 engine designated as GM-292 "B" was tested with unleaded fuel and using an induction-hardened head. Induction hardening only included the valve seat area and is reported by the manufacturer to be approximately HRC 55 hardness. The valve seat recession data (table 20) showed exhaust valve seat No. 5 to recede some .014 inch, while the other valve seats changed less than .005 inch.

The valve train inspection data (table B-15) showed cylinders 1, 3, 4, 5, and 6 to have valve seat recession of about .010 inches, while cylinder No. 2 received only .003 inch. The valve train inspection data also showed valve height decreasing by about .005 inch on most valves.

The A/F and emissions data (table A-29 and A-30) showed a range of A/F due to modes of 11.6 to 14.0 which is typical of other tests with this engine. The daily variation of averaged A/F ranged only from 12.8 to 13.6 which suggests no unusual perturbation of A/F occurred during the test.

The GM-292 "B" engine was also tested using unleaded fuel in a modified (reduced severity) duty cycle using a noninduction-hardened engine head. The mode No. 5, which is a high-speed/high-load condition of 85 percent power at 3,600 rpm, was dropped from the test condition leaving only a 4-mode cycle.

The test with the GM-292 "B" engine was discontinued after 88 hours due to excessive valve seat recession. The valve seat recession data (table 21) showed .099 inch recession in cylinder 6, while cylinder 5 had .014 inch.

Cylinders 1, 2, and 3 had essentially no recession. Comparative tests with the GM-292 "A" engine using the original duty cycle (discussed earlier) showed exhaust valve seat recession of about .125 inch after 71 hours in cylinder 6.

The valve train inspection data (table B-16) also showed exhaust valve seat No. 6 was recessed by .094 inch, with cylinders 1-3 showing essentially no recession. The other parameters measured showed only nominal values indicating normal wear.

The A/F and emission data (table A-31 and A-32) are presented in the appendix, but the averaged data are not directly comparable to the other tests due to elimination of one of the modes. The data do show, however, that the A/F for the remaining modes is similar to the same modes in other tests. Further, the daily variation ranges only from A/F of 12.8 to 13.3 indicating no significant changes in A/F during the test.

TABLE 20. - Effect of accumulated engine hours on valve seat recession--GM-292 "B" engine--unleaded fuel--induction hardened engine head

		Valve Seat Recession, inches/1000													
Hours Accumulated		16	32	48	64	80	96	112	128	136	152	168	184	200	*
Intake	1	0	-1	-1	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	3
	2	-1	-1	1	1	0	-1	-1	-1	-1	-1	-1	-1	-1	6
	3	0	-2	0	0	0	0	0	-1	0	-1	-1	-1	-1	5
	4	-1	-1	0	-1	-1	-1	0	-1	0	-1	-1	0	-1	4
	5	-1	0	0	0	0	0	0	0	0	0	0	0	0	4
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Exhaust	1	-3	-5	-5	-4	-3	-3	-5	-5	-4	-5	-4	-4	-4	8
	2	0	-1	0	0	1	0	0	0	-1	-1	-2	0	1	3
	3	3	-2	2	1	2	6	2	2	2	2	2	2	2	10
	4	-4	-3	-1	-5	-1	-1	-1	-2	-2	-2	-1	-1	-1	8
	5	8	9	10	10	11	11	14	15	15	15	15	14	14	11
	6	5	3	3	4	5	4	5	5	5	5	5	7	5	11

*Measurement based upon engine disassembly and inspection.

TABLE 21. - Effect of accumulated engine hours on valve seat recession--GM-292 "B" engine--unleaded fuel--average hardness HRB 89--modified cycle

		Valve Seat Recession, inches/1000							
Hours Accumulated		14	25	41	57	61	72	88*	**
Intake	1	-1	-1	1	-1	-1	0	0	-1
	2	0	-1	-1	-1	-2	-2	-1	-1
	3	-1	-1	-1	-2	-2	-2	0	2
	4	-3	-2	-1	-2	-2	-2	-2	0
	5	-3	-3	-3	-3	-4	-4	-5	-3
	6	-1	-1	0	-1	-1	-1	1	1
Exhaust	1	-1	-1	-1	-1	0	-1	0	-1
	2	-1	-2	-1	-1	-1	-2	0	-1
	3	0	0	1	0	0	2	3	2
	4	0	2	4	6	5	6	8	6
	5	1	3	10	10	11	13	14	10
	6	14	29	52	70	73	81	99	94

*Test was terminated at 88 hours due to recession.
**Measurement based upon engine disassembly and inspection.

John Deere 303 Engine

The 200-hour test was conducted using unleaded fuel with a new engine head which measured HRB 98, HRB 99, and HRB 96 at three places. Valve seat recession data, presented in table 22, showed recession of at least .050 inch in all exhaust valves and some recession in one intake valve. The most recession occurred during the 56-hour steady-state mode beginning at 144 hours, rather than during the cyclic operation.

Valve train inspection data (table B-17) confirm exhaust valve seat recession of about .050 inch for all cylinders using the unleaded fuel for 200 hours. The apparent recession noted on No. 4 intake valve during the "running" measurements was not confirmed by the valve train inspection. The reason for this discrepancy is not clear. Valve height was increased during the 200-hour test, again the valve spring force is relatively high, but the mechanism of valve elongation is not understood. Valve guide diameters increased a consistent .0003 to .0008 inch for all cylinders except for exhaust No. 3 which increased .0015 inch. Valve stem diameters were also consistent and decreased by .0004 to .0005 inch.

All parameters measured, except valve seat depth, appeared to be normal and consistent.

The A/F variations noted for the John Deere 303 engine using unleaded fuel are very similar to the tests using leaded fuel in that the average A/F between modes ranges from 12.2 to 13.9 (table A-33). The daily average A/F ranged from 12.5 to 13.5 (table A-34).

GM-454 Engine

Two valve seat measurement jigs (one for the exhaust valve, one for the intake valve) were used for this series of tests to eliminate measurement variability due to jig realignment and to accommodate both the exhaust and intake valves. Exhaust valve seat recession in the GM-454 engine using unleaded fuel ranged from about .015 to .035 inch for the 200-hour test. The data are presented in table 23. The recession is consistent among all exhaust valves. It should be noted again that this engine test series used new OEM induction-hardened heads.

TABLE 22. - Effect of accumulated engine hours on valve seat recession--
John Deere-303 engine--unleaded fuel--average hardness HRB 97.7

Hours Accumulated	Valve Seat Recession, inches/1000													
	6	10	26	42	58	74	90	106	122	138	144	168	200	*
Intake														
1	-1	0	0	0	0	1	0	0	0	6	0	0	-1	-4
2	-1	0	-1	-1	-1	-1	-1	-2	-2	-1	-1	0	0	-2
3	0	1	0	0	0	1	0	0	0	1	1	1	0	-3
4	-1	1	1	2	1	1	1	0	6	7	14	15	15	-4
5	0	0	-1	0	0	0	0	0	0	0	0	0	0	-3
6	-1	-1	-1	0	-1	-1	-1	-1	1	0	0	-1	-1	0
Exhaust														
1	1	3	3	4	7	3	8	10	17	16	24	41	63	56
2	-1	1	1	1	1	2	2	6	8	11	12	28	46	41
3	1	-1	5	6	5	5	7	9	14	21	22	40	61	64
4	-2	-2	2	2	5	5	8	9	11	11	18	25	48	41
5	1	1	0	1	1	0	-1	5	6	10	10	24	41	36
6	2	3	7	14	13	15	14	18	15	16	19	36	50	43

*Measurement based upon engine disassembly and inspection.

TABLE 23. - Effect of accumulated engine hours on valve seat recession--
GM-454 engine--unleaded fuel--induction-hardened head

		Valve Seat Recession, inches/1000																
Hours Accumulated		16	32	48	59	75	88	100	116	125	133	140	144	160	176	192	200	*
Intake	1	-1	1	3	1	1	3	4	1	2	2	3	2	2	1	1	2	0
	2	-2	-4	-5	-6	-3	-3	-4	-2	-2	0	-3	1	-2	-2	0	0	1
	3	-2	-2	0	-2	-2	0	1	-1	0	0	0	0	0	-1	0	0	0
	4	0	-2	-3	-5	-1	-1	0	-1	1	2	1	0	0	1	1	0	-3
	5	0	-1	-1	0	-1	-1	0	-1	2	-1	1	0	2	0	0	1	0
	6	-1	-2	2	2	4	4	3	3	6	5	5	6	6	6	6	6	-2
	7	-4	-4	-1	-1	-2	-4	-4	-3	1	-4	-2	-3	-2	-2	-1	-1	0
	8	-1	-4	2	1	3	3	3	2	3	1	3	1	2	1	2	3	-1
Exhaust	1	1	2	4	8	7	11	13	12	15	14	14	14	15	14	14	14	7
	2	1	5	5	7	7	9	13	15	19	30	30	30	32	31	32	31	26
	3	0	0	3	6	10	11	13	12	14	15	15	16	17	14	16	16	10
	4	3	3	7	9	12	12	17	18	29	30	31	30	32	32	32	34	32
	5	1	2	4	9	9	12	17	16	19	20	21	22	22	23	25	23	20
	6	2	7	9	11	11	13	17	16	13	16	17	16	21	21	23	24	15
	7	1	2	7	10	10	11	15	13	12	13	14	16	16	18	18	20	16
	8	0	2	4	12	11	10	18	18	19	19	21	19	23	24	23	23	22

*Measurement based upon engine disassembly and inspection.

Examination of the valve train inspection data (table B-18) confirmed relatively consistent exhaust valve seat recession ranging from .007 to .032 inch using unleaded fuel. Valve guide wear was a nominal .0004 inch for the intake valves, which exhibited no valve seat recession; however, exhaust valve guide wear ranged from .0006 to .0046 inches (cylinder No. 5). In addition, there are no correlations of valve seat recession with valve guide or valve stem wear.

Tests with the unleaded fuel showed A/F variations between modes to be relatively narrow, compared to the leaded fuel test, ranging from A/F of 12.8 to 13.9 (table A-35). The daily A/F average of all modes showed consistent A/F of 12.7 to 14.3 (table A-36). These were slightly richer than the tests with leaded fuel. However, operation during the 56-hour mode averaged 14.6 for the unleaded test compared to an average of about 14.1 for the leaded test.

The GM-454 engine was also tested using unleaded fuel with valve seat inserts. The valve seat inserts are for "moderate duty" based upon SAE-J610b recommended practice. The inserts (J-LOY, X-B) contained 1.5 percent carbon, 20 percent chromium, 1.3 percent nickel, 1.25 percent silicon, and the remainder cast iron. The hardness of the inserts used was tested and found to be an average of HRC 42.0. Standard exhaust valves were used for the test as recommended by the valve seat manufacturer.

At approximately 120 hours into the test the engine began to lose power, a compression check confirmed low compression on No. 6 cylinder. The head was removed and inspected and the problem diagnosed as collapsed piston rings. The No. 6 piston was removed and a new piston and rings installed (standard size), correcting the problem and the test continued to 200 hours.

The valve recession data (table 24) showed maximum recession of .017 inch during the 200-hour test with a range of .005 to .017 inches for the eight exhaust valves.

TABLE 24. - Effect of accumulated engine hours on valve seat recession--
GM-454 CID engine--unleaded fuel--steel exhaust valve seat

Hours Accumulated		Valve Seat Recession, inches/1000														
		16	32	48	64	72	88	99	115	131	144	160	175	191	200	*
Intake	1	-2	-3	-2	-1	0	-1	0	0	0	-1	-2	-2	-1	-1	-3
	2	2	3	3	5	5	5	5	5	5	3	4	5	9	5	-2
	3	-2	-2	-1	-1	-1	-2	-2	-2	0	-2	-2	-1	-3	-2	0
	4	0	-1	-1	0	1	2	0	0	-2	0	3	2	2	0	-3
	5	-2	-2	2	-2	-2	1	0	-1	1	1	-1	0	0	-1	-3
	6	3	4	4	5	5	4	5	6	5	7	9	7	5	4	0
	7	-2	-2	-3	0	-3	0	-4	-3	-2	-5	-2	-2	-3	-7	-4
	8	C	0	1	1	1	1	1	1	2	3	5	3	5	2	-4
Exhaust	1	3	3	3	4	4	4	6	7	6	5	6	6	6	8	6
	2	-2	-1	-1	-1	0	0	1	5	1	0	1	1	1	1	5
	3	2	5	9	12	14	16	18	18	18	17	17	16	19	17	17
	4	-2	-1	-2	0	-1	1	0	3	1	1	1	2	0	+1	4
	5	3	3	4	4	4	5	10	10	10	9	10	10	12	12	8
	6	0	-1	5	8	9	12	12	13	13	17	12	12	12	14	15
	7	2	4	5	4	6	10	10	11	11	10	12	11	10	11	8
	8	-2	-4	-3	-2	0	1	1	3	3	5	4	5	5	6	12

*Measurement based upon engine disassembly and inspection.

The valve train inspection data (table B-19) also showed a maximum recession of .017 inch and slight recession of most other exhaust valves. In addition, this test is the only test of the entire series to detect any wear of the exhaust valve itself. The ridge noted on the seat surface of the valves was ground away until the ridge was eliminated and the depth of the ridge in the valve thus measured. The depth of the ridges was found to be .004, .004, .001, .002, .001, .002, .003, and .002 inch for cylinder Nos. 1 through 8. Other aspects of the parameters measured appear to be nominal.

The A/F and emission data (tables A-37 and A-38) showed the engine to operate within a range of A/F from 12.6 to 14.0 depending upon mode, with the richer A/F associated with the high speed/load conditions.

The average day-to-day variation of A/F ranged only from 12.9 to 13.5 with the 56-hour steady state mode operating at 13.4 to 13.8 A/F.

LOW LEAD FUEL 0.10 GRAMS/GALLON

International Harvester 240 Engine

After noting wear with unleaded fuel, tests were conducted with fuel containing 0.10 gm/gal lead in the IH-240 engine. The hardness of the head used for this test was measured at three places and found to be HRB 93.5, HRB 92, and HRB 93. The data, presented in table 25, showed no valve seat recession trends in any of the valves using the 0.10 gm/gal fuel. The trend toward negative recession implies a build-up of deposits under the valve seat. Detailed examination of the engine head by a certified engine rebuilder after the tests were completed confirmed that negative numbers were due to a build-up of carbon on the valve and valve seat surface. At 188 hours of the planned 200-hour test, the engine suffered a broken crankshaft, and the test was terminated. Obviously, the failure of the crankshaft is not associated with any fuel additive, and major engine rebuilding would require a repeat test to confirm the additional 12 hours of operation. In all of the data collected from other tests, recession occurred before 188 hours or not at all.

Valve train inspection data (table B-20) of the IH-240, operating on 0.10 gm/gal leaded fuel, suggested no valve seat recession in excess of .003 inch. Valve guide diameter measurements were consistent and showed essentially no wear. The only noticeable differences observed between the start and end of the test were the consistent relaxation of spring forces of about 10 percent during the 200-hour test. New springs were used for all tests. It is assumed that the springs would age rather quickly from new and then the spring force decrease at a much slower rate.

The A/F data for test with the IH-240 engine using 0.10 gm/gal lead showed A/F variations similar to the test with leaded fuel and first test with unleaded fuel. The A/F using the 0.10 gm/gal lead ranged from A/F of 10.6 to 13.6 (table A-39) with a daily variation being extremely consistent ranging only between A/F of 12.0 and 12.3 (table A-40). No valve seat recession occurred in this test nor the other tests with leaded and unleaded fuel where the A/F was consistent.

TABLE 25. - Effect of accumulated engine hours on valve seat recession--
IH-240 engine--0.10 gm/gal lead--average hardness HRB 92.8

Hours Accumulated		Valve Seat Recession, inches/1000											
		16	32	48	64	80	95	111	127	143	168	188	*
Intake	1	-1	-2	-2	-2	-1	-3	-3	-3	-4	-4	-4	-4
	2	-1	-2	-2	-2	-2	-1	-1	-2	-2	-2	-2	3
	3	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1
	4	-1	-2	-1	-2	-2	-3	-4	-4	-4	-4	-4	3
Exhaust	1	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	1
	2	-2	-3	-2	-2	-2	-3	-3	-3	-4	-3	-3	-1
	3	1	-1	-1	-1	-1	-1	0	0	0	0	-2	1
	4	1	-3	-1	-3	-2	-2	-2	-2	-2	-2	-2	0

*Measurement based upon engine disassembly and inspection.

Tests were also conducted using the IH-240 engine with fuel containing 0.10 gm/gal lead using exhaust valve inserts made from cast iron. The hardness of the valve seat inserts was measured and found to range from HRB 96.5 to HRB 97.5 with an average hardness of HRB 97.

The valve seat recession data (table 26) showed no recession of any of the valve seats. The valve train inspection data (table B-21) confirmed that no recession occurred on any of the valve seats. The other parameters measured show only nominal wear.

The A/F and emission data (table A-41) show a A/F variability due to mode ranging from 11.2 to 13.2, with the leaner A/F associated with the higher load conditions.

The daily variation (table A-42) of the average A/F ranged only from 12.1 to 12.5 which is unusually consistent. The A/F during the 56-hour mode ranged from 12.9 to 13.1 which is consistent with previous tests with this engine.

TABLE 26. - Effect of accumulated engine hours on valve seat recession--IH-240 engine--0.10 gm/gal lead--valve seat insert hardness HRB 97

Hours Accumulated		Valve Seat Recession, inches/1000												
		15	31	47	63	73	88	102	118	134	144	168	200	*
Intake	1	1	2	0	0	0	0	1	0	0	0	0	1	0
	2	0	0	0	0	0	0	0	0	0	-1	0	-1	0
	3	0	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1
	4	-1	0	0	0	0	0	-1	-1	-1	-1	-1	-1	1
Exhaust	1	0	0	-2	-1	-1	1	-1	0	-1	-1	-1	-1	1
	2	-1	0	-2	-1	-1	0	-1	-1	-1	-1	0	-2	-1
	3	-1	-1	-1	-2	-1	-1	-1	-1	-1	-1	0	0	2
	4	0	0	0	-2	-1	0	0	0	0	0	0	-1	0

*Measurement based upon engine disassembly and inspection.

GM-292 "A" Engine

The GM-292 "A" engine was tested using 0.10 gm/gal lead added to the fuel. The data are presented in table 27. Recession occurred in cylinder No. 6 with .050 inch noted in the exhaust valve seat and some recession noted in the intake valve seat of cylinder No. 6. During the test between the 105- and 120-hour test points, the engine suffered a head gasket failure that allowed communication of gases between cylinders Nos. 5 and 6. Engine coolant was unaffected. The head gasket was replaced, and the test was continued. This time period resulted in the significant valve seat recession indicating that the head gasket failure could have perturbed the test results in cylinder No. 6. None of the other valves had any trend toward recession.

TABLE 27. - Effect of accumulated engine hours on valve seat recession--
GM-292 "A" engine--0.10 gm/gal lead--average hardness HRB 89

		Valve Seat Recession, inches/1000														
Hours Accumulated		16	27	43	59	75	91	105	120	136	144	160	176	192	200	*
Intake	1	-2	-3	-3	-3	-2	-3	-2	0	-1	-1	-1	-1	-1	-2	0
	2	-1	-2	-2	-2	-1	-1	-1	1	0	0	0	0	0	1	0
	3	-1	-3	-3	-4	-3	-3	-2	-3	-5	-1	-1	-1	-2	-2	-2
	4	0	0	1	0	1	-1	-7	0	0	1	3	2	1	1	-2
	5	-1	-1	-1	-1	-1	0	0	1	2	2	2	2	2	1	-1
	6	0	0	0	0	0	0	6	9	12	12	15	15	19	19	14
Exhaust	1	-1	0	-1	-1	-1	-1	0	1	1	0	0	0	1	1	-2
	2	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	0	0	-2
	3	0	0	0	0	-1	0	2	2	2	2	1	2	1	1	-4
	4	-2	0	0	-2	0	-1	-1	-1	0	0	0	0	-1	-1	-4
	5	0	1	1	1	2	2	2	0	4	1	1	1	2	1	-3
	6	0	0	2	-1	0	1	11	29	39	40	46	46	51	50	40

*Measurement based upon engine disassembly and inspection.

Tests with the 0.10 gm/gal lead fuel showed consistent A/F variations between modes with a range of A/F from 12.1 to 14.7 (table A-43). The daily A/F variations were unusually consistent, ranging from 13.5 to 14.1 over the 11 test days (table A-44).

The valve train inspection data (table B-22) again confirmed the "running" valve seat recession measurements in that recession was noted in only one exhaust valve. In addition, recession was also confirmed in one intake valve. Both valves on which recession was noted are on cylinder No. 6. Cylinder No. 6, as well as No. 5, on this engine indicated significant recession during previous tests with unleaded fuel.

Valve guide diameter increases of .0003 to .0005 inch over the 200-hour test were typical; however, exhaust guide No. 6 increased some .0015 inch and exhaust No. 5 increased some .0011 inch. The valve spring force in cylinder No. 6 decreased during testing somewhat more than the other cylinders. Excessive heat, if generated due to air-fuel mixture or other mechanism, would be expected to both decrease the spring constants and increase valve seat recession.

The tests were repeated using the GM-292 "A" engine with 0.10 gm/gal lead to determine if the head gasket failure reported in the previous test was indeed responsible for the apparent recession noted. The hardness of the head used for this test was Rockwell HRB 91.

The valve seat recession data (table 28) showed no recession in excess of ±.003 inch. The valve train inspection data (table B-23), however, shows 0.10 inch recession in the No. 5 cylinder, but no recession in the other cylinders. Other parameters measured show only nominal change except for slightly higher valve guide wear in cylinder Nos. 5 and 6.

The A/F and emission data (tables A-45 and A-46) showed the A/F variation between the five modes ranged from 12.7 to 13.5 compared to 12.1 to 14.7 for the previous test with 0.10 gm/gal lead. The daily averaged A/F ranged from only 12.8 to 13.4 during the 200-hour test. This compares with a range of 13.5 to 14.1 for the earlier test with 0.10 gm/gal lead.

TABLE 28. - Effect of accumulated engine hours on valve seat recession--
GM-292 "A" engine--0.10 gm/gal lead--average hardness HRB 91 (repeat)

Hours Accumulated		Valve Seat Recession, inches/1000														
		16	32	48	55	71	85	101	117	131	147	158	174	190	200	*
Intake	1	0	-1	0	0	0	0	0	0	-1	-1	-1	-1	-1	0	1
	2	0	1	1	1	1	1	1	1	1	1	1	2	1	1	-1
	3	1	0	-1	-1	-1	-1	0	0	-1	0	0	-1	-1	-2	-1
	4	1	0	-1	1	1	1	2	2	1	2	1	1	1	0	-2
	5	1	2	0	1	0	0	2	0	0	2	1	0	0	0	-1
	6	0	1	0	0	-1	0	0	1	0	1	2	1	1	0	0
Exhaust	1	0	0	0	0	0	0	-1	-1	0	0	1	1	0	-1	0
	2	-1	-1	-1	-1	-1	-2	-1	-1	-1	0	-1	0	-1	-1	0
	3	1	1	1	-1	1	1	0	-1	-1	-1	0	0	0	-2	0
	4	1	1	1	1	2	3	3	3	4	4	4	3	3	3	3
	5	0	4	4	3	4	4	4	4	4	3	4	2	3	3	9
	6	1	1	3	-1	0	1	2	1	1	3	1	1	3	1	2

*Measurement based upon engine disassembly and inspection.

GM-292 "B" Engine

An additional test was conducted using 0.10 gm/gal lead in a different GM-292 engine. The engine is designated as GM-292 "B", but is an identical product to the GM-292 "A" engine.

The head was measured for hardness and found to be Rockwell HRB 91.8.

The valve seat recession data (table 29) for this test showed no seat recession in any exhaust valve greater than ±.002 inch. No. 5 intake valve seat appeared to change (negative recession) after the first measurement was made, but remained constant throughout the remainder of the test.

The valve train inspection data (table B-24) also showed no recession in any exhaust valve seat greater than ±.002 inch. The other parameters measured in the inspection data appeared to be very consistent with only nominal changes noted in all measurements.

The A/F and emission data (tables A-47 and A-48) showed an A/F variation between the five modes of 11.6 to 13.6 compared to a variation of 12.7 to 13.4 for the last test using the GM-292 "A" engine. The higher loads are associated with the richer modes. The daily averaged A/F ranged only from 12.2 to 13.0. This is similar to the last test using the GM-292 "A" engine and operating on the 0.10 gm/gal lead fuel in which the A/F ranged from 12.8 to 13.4

John Deere 303 Engine

Due to the recession noted using the John Deere 303 engine and unleaded fuel, the test was repeated using fuel with 0.10 gm/gal lead and new engine heads which measured HRB 97. HRB 99, and HRB 92 at three different places. Valve seat recession data presented in table 30 showed no trend toward recession of any of the valves during the 200-hour test. The data suggested recession of .005 inch in one valve. However, if the initial point were taken at 16 hours, the recession would be zero. This suggests that the valves are being "re-seated," rather than observing valve seat recession.

TABLE 29. - Effect of accumulated engine hours on valve seat recession--
GM-292 "B" engine--0.10 gm/gal lead--average hardness HRB 91.8

Hours Accumulated		Valve Seat Recession, inches/1000													
		16	32	45	61	77	93	108	124	140	156	172	188	200	*
Intake	1	0	1	1	1	1	1	2	1	1	2	1	0	0	-1
	2	0	-1	0	1	0	1	2	3	3	1	1	0	0	0
	3	-1	-1	0	0	1	0	1	1	1	-1	0	-1	-1	2
	4	-1	-1	-1	0	0	1	2	1	1	-1	-1	0	-1	1
	5	0	-5	-8	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-3
	6	0	-1	-1	-1	0	-1	0	0	1	-2	-1	-1	0	1
Exhaust	1	1	0	1	1	0	1	2	3	3	-1	-1	-1	-1	1
	2	0	0	0	0	1	1	3	2	2	2	2	1	1	1
	3	-1	-2	0	0	0	0	1	1	1	0	-1	-1	0	2
	4	-1	0	0	-1	0	0	0	0	0	0	-1	-1	-1	-1
	5	0	-1	0	0	0	0	1	1	2	0	0	0	-1	0
	6	0	0	1	1	2	1	0	2	2	0	-2	2	-1	1

*Measurement based upon engine disassembly and inspection.

TABLE 30. - Effect of accumulated engine hours on valve seat recession--
John Deere engine--0.10 gm/gal lead--average hardness HRB 96.0

Hours Accumulated		Valve Seat Recession, inches/1000											
		16	32	48	64	80	96	112	128	144	168	200	*
Intake	1	0	0	-1	-1	-1	-1	-1	0	-1	-1	-1	0
	2	0	0	-1	0	0	-1	-1	-1	-1	-2	-2	0
	3	-1	-1	-1	-1	-1	0	-1	0	-1	-2	-2	0
	4	-5	-5	-3	-3	-3	-3	-3	-3	-3	-4	-4	-2
	5	0	1	0	0	0	0	0	0	-1	-1	-1	2
	6	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	0
Exhaust	1	4	5	5	5	4	4	5	5	4	4	5	4
	2	-1	0	-1	0	0	-1	-1	0	-1	3	0	0
	3	1	1	0	1	0	2	1	1	0	-1	0	0
	4	0	0	0	-1	0	0	0	-1	0	0	0	0
	5	1	1	2	2	2	2	1	1	1	1	0	0
	6	0	-1	-1	-1	0	0	0	-3	-1	-1	-1	0

*Measurement based upon engine disassembly and inspection.

GM-454 Engine

Due to the exhaust valve seat recession noted on the GM-454 engine using unleaded fuel, the engine was tested using fuel with 0.10 gm/gal lead.

At approximately 30 hours into the test, the crankshaft sheared between bearings No. 7 and 8. Rather than repair the engine, a new engine was procured, installed, and broken-in using the method described earlier except that 0.10 gm/gal fuel was used. The heads from the damaged engine with 30 hours of use were then installed on the new engine and the test continued. The data, presented in table 31, showed no recession of any of the exhaust valves using the low lead fuel. One intake valve suggested a slight trend toward recession.

Examination of the valve train inspection data for the GM-454 engine using the 0.10 gm/gal fuel (table B-26) showed no appreciable valve seat recession in excess of ±.005 inch. The recession trend noted during "running" valve seat measurements in intake valve No. 8 was not apparent in the valve train inspection. The reason for this is not clear. Valve guide diameter increases remained relatively constant increasing from .0007 to .0010 inch except for cylinder No. 7 which increased by .0020 inch.

Other parameters measured changed by only nominal amounts, thus indicating no unusual wear patterns.

The A/F variations among the six test modes for tests with 0.10 gm/gal fuel showed a range of A/F from 13.2 to 14.2 (table A-51) which was similar to tests with unleaded fuel. The daily A/F average data showed a range of A/F from 13.3 to 14.6 (table A-52) during tests with the low lead fuel. These were similar to A/F during the leaded fuel test.

The valve train inspection data for test using 0.10 gm/gal lead (table B-25) show no indications of valve seat recession or abnormal wear of any valve train measured. Valve guide diameters were generally consistent and increased from .0002 to .0005 inch, except for exhaust guide No. 2 which increased some .0012 inch. Likewise, valve stem diameters decreased from 0 to .0003 inch during the 200 hours. Valve height and valve tulip diameters were unaffected by the test.

TABLE 31. - Effect of accumulated engine hours on valve seat recession--GM-454 engine--0.10 gm/gal lead--induction-hardened seats

		Valve Seat Recession, inches/1000														
Hours Accumulated		16	31	47	63	73	89	105	121	137	144	160	176	192	200	*
Intake	1	0	1	1	0	0	0	0	1	1	1	0	0	0	0	-5
	2	-1	-2	-1	-1	0	0	0	0	0	0	0	0	0	1	1
	3	1	1	1	3	2	1	2	2	1	1	0	0	0	1	1
	4	-1	-1	0	0	1	2	4	4	1	1	1	1	1	2	1
	5	-2	-1	1	1	1	-1	1	1	1	0	0	0	0	1	5
	6	1	0	2	2	4	5	4	4	3	3	3	3	3	4	1
	7	-2	-2	-3	1	1	-1	1	1	1	1	1	1	1	2	6
	8	2	2	4	4	4	5	6	6	6	6	6	6	6	7	0
Exhaust	1	-1	1	-4	-4	-3	-2	-2	-3	-4	-3	-4	-2	-2	-3	5
	2	1	4	3	2	2	3	3	2	1	1	3	3	3	-3	1
	3	0	3	0	0	-1	-1	-1	0	-1	-1	-2	1	-2	-3	3
	4	0	3	1	1	1	1	1	-1	0	0	0	0	0	0	2
	5	-2	0	-1	-3	-4	-3	-2	-1	-3	-2	-3	-2	-2	-4	0
	6	1	6	0	2	1	1	0	0	0	1	1	1	1	1	2
	7	-2	-2	0	-1	-1	-1	-1	-2	-2	-2	-2	0	0	-1	3
	8	2	6	2	1	0	1	2	1	1	1	1	3	3	1	1

*Measurement based upon engine disassembly and inspection.

The A/F variations between modes for test with the 0.10 gm/gal lead fuel ranged from 11.7 to 12.6 (table A-49). The daily average A/F ranged from 11.9 to 12.6 (table A-50) which is slightly richer A/F compared to the tests with leaded and unleaded fuels.

Fuel Additive "A"

Fuel additive "A" was supplied by The Lubrizol Corporation and represented a variation of the Lubrizol "Powershield" additive. The additive-to-fuel level was 250 pounds additive per 1,000 barrels of fuel. The additive was mixed in a 7,000-gallon batch in a fuel tank that had stored unleaded gasoline for about six months previously. A sample of the blended fuel was tested by the supplier and approved prior to testing.

GM-292 "A" Engine

Use of the additive "A" in the GM-292 "A" engine resulted in significant valve seat recession such that the test was terminated after 64 hours with some .050- to .080-inch recession occurring in cylinder Nos. 5 and 6. In a subsequent analysis of the additive, the supplier reported that the additive package was improperly formulated when manufactured; therefore, testing of this additive was discontinued.

The valve seat recession data (table 32) showed cylinder Nos. 1, 2, and 3 with little or no valve seat recession, a slight amount of recession (0.10 inch) in cylinder No. 4, and significant recession in cylinder Nos. 5 and 6.

The valve train inspection data (table B-27) showed about .005 inch recession for all intake valve seats and exhaust seats 1 through 3, with the remaining exhaust seats following the same pattern discussed above. The valve height of the intake and exhaust valves decreased about .005 inch.

The A/F and emissions data (tables A-53 and A-54) showed a range of A/F due to modes of 12.2 to 13.8. This is similar to other tests. The daily averaged A/F ranged from 12.9 to 13.1 and is similar to earlier tests with this engine. The A/F data suggest that perturbations in A/F ratio are not responsible for the valve seat recession observed.

TABLE 32. - Effect of accumulated engine hours on valve seat recession--GM-292 "A" engine--fuel additive "A" average hardness HRB 89

		Valve Seat Recession, inches/1000				
Hours Accumulated		16	32	48	64	*
Intake	1	0	0	0	0	3
	2	0	1	0	0	4
	3	-1	-1	-1	-1	5
	4	0	0	-1	1	5
	5	-2	-2	-1	-2	5
	6	2	1	1	1	3
Exhaust	1	0	1	1	0	5
	2	-1	2	2	1	5
	3	3	3	4	3	6
	4	4	10	10	10	12
	5	8	26	40	47	49
	6	14	40	65	86	77

*Measurement based upon engine disassembly and inspection.

John Deere 303 Engine

Fuel additive "A" was tested in the John Deere 303 engine for 80 hours. The test was discontinued after NIPER was notified that the additive package was not properly formulated.

The John Deere engine head was tested for hardness and measured Rockwell HRB 95.

Valve seat recession data (table 33) showed little recession; however, the valve train inspection data (table B-28) suggested from .006- to .012-inch recession. The valve height on exhaust and intake valves was reduced about .006 inch during the test according to the inspection data as was noted during the test with the 292 "A" engine.

The A/F and emission data (table A-55 and A-56) showed a range of A/F of 11.5 to 12.6 depending upon mode. The daily variation of average A/F during the five test days ranged from 11.9 to 12.2, which is somewhat lower than when the engine was tested with unleaded gasoline.

TABLE 33. - Effect of accumulated engine hours on valve seat recession--John Deere-303 engine--fuel additive "A" average hardness HRB 95

		Valve Seat Recession, inches/1000					
Hours Accumulated		16	32	48	64	80	*
Intake	1	0	0	0	0	0	6
	2	0	0	0	0	0	6
	3	0	0	0	-1	-1	6
	4	0	0	-1	-1	-1	7
	5	0	3	5	5	5	7
	6	-1	-1	-1	0	0	8
Exhaust	1	0	1	1	3	2	7
	2	0	0	0	0	0	6
	3	0	1	4	6	6	12
	4	1	1	2	3	2	7
	5	2	0	0	2	4	8
	6	0	0	0	0	0	7

*Measurement based upon engine disassembly and inspection.

Fuel Additive "B"

Fuel additive B was a product supplied by Lubrizol Corporation with a trade name "Powershield." The additive B was blended with unleaded gasoline at a level of 250 pounds of additive per 1,000 barrels of gasoline. The fuel additive B was tested in the GM-292 "A", John Deere 303, and GM-454 engines.

GM-292 "A"

The test with the fuel additive B in the GM-292 "A" engine was conducted with an engine head of hardness Rockwell HRB 89.

The valve seat recession data for the GM-292 "A" (table 34) show a significant amount of exhaust valve seat recession of .112 and .086 inches in cylinders 5 and 6 after 84 hours of operation. The test was terminated after 84 hours. Cylinders 2 through 4 received some .011 to .015 inches recession while cylinder No. 1 was virtually unchanged. The intake valves were not affected within the range of ±.003 inches.

The valve train inspection data (table B-29) showed similar recession results to the recession data collected daily. The other engine parameters measured only slight or no change at all, which would normally be expected in the relatively short test.

The A/F and emissions data (tables A-57 and A-58) showed that the A/F variations among the five modes ranged from 12.8 to 14.2, while the daily variation of the averaged A/F ranged from 13.4 to 14.0. Comparisons of the A/F from other tests with this engine showed this A/F to be typical except that, at the richest A/F mode of 12.8, the A/F is somewhat leaner than the other tests in which the A/F ranged from 11.9 to 12.7 for the richest mode.

John Deere 303

Tests were conducted with the John Deere 303 engine using fuel additive B. The engine test used a head of Rockwell hardness HRB 95.

Valve recession data (table 35) showed little recession during the cyclic 144-hour operation. However, during the 56-hour steady-state mode, significant exhaust valve seat recession occurred in cylinders 1 and 6. Cylinders 2 through 5 appeared to have minimal recession.

TABLE 34. - Effect of accumulated engine hours on valve seat recession--
GM-292 "A" engine--fuel additive "B"--average hardness HRB 89

		Valve Seat Recession, inches/1000						
Hours Accumulated		16	32	48	64	68	84	*
Intake	1	-1	-1	-1	-1	-1	1	-1
	2	0	0	-1	-1	-1	-1	-2
	3	2	1	4	1	2	2	1
	4	1	1	0	1	1	2	0
	5	-2	-2	-3	-3	-3	-3	-2
	6	0	-1	0	1	1	0	1
Exhaust	1	3	5	4	4	4	4	2
	2	4	4	9	10	12	13	13
	3	8	11	11	11	12	11	8
	4	11	16	16	18	18	15	13
	5	16	49	72	89	92	112	109
	6	10	30	47	66	74	86	85

*Measurement based upon engine disassembly and inspection.

TABLE 35. - Effect of accumulated engine hours on valve seat recession--
John Deere 303 engine--fuel additive "B"--average hardness HRB 95

Hours Accumulated		Valve Seat Recession, inches/1000												
		16	32	48	64	80	91	107	121	137	144	168	200	*
Intake	1	-1	-2	-3	-2	-2	-1	-3	-3	-3	-3	-3	-4	2
	2	0	0	1	0	1	0	2	3	2	3	3	4	4
	3	-1	-2	0	1	1	1	0	0	0	0	0	1	5
	4	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	4
	5	-1	-1	1	1	0	1	0	0	0	0	0	0	5
	6	2	0	0	3	4	4	4	5	4	4	4	3	5
Exhaust	1	2	8	8	9	10	9	10	10	11	11	24	37	33
	2	2	2	6	5	6	6	7	7	8	7	7	6	5
	3	1	4	2	4	4	4	4	5	6	7	6	5	5
	4	7	6	6	6	5	5	5	4	5	5	5	4	5
	5	0	3	4	5	4	4	3	2	2	2	1	1	6
	6	6	6	7	7	6	6	6	7	7	8	23	42	40

*Measurement based upon engine disassembly and inspection.

The valve train inspection data (table B-30) showed similar results of .033 and .040 inches recession in cylinders 1 and 6 and .002 to .005 inches on all other valves. The valve height decreased on most valves by about .004 inch, indicating some wear on the valve tip.

The A/F and emissions data (tables A-59 and A-60) showed the engine operated at a range of A/F from 10.9 to 12.2 for the six modes. A daily variation of the averaged A/F ranged from 10.8 to 11.8. These A/F ratios are slightly richer than the A/F during other tests with this engine. For comparison, the average range A/F of all six tests conducted with this engine for the six modes is 11.7 to 12.9, while the range of average A/F for all test days is 11.9 to 12.7. During the 56-hour mode, the A/F increased to 13 which coincides with the increased valve seat recession.

GM-454

The GM 454 engine was tested using the fuel additive B. The GM 454 engine used heads with induction-hardened valve seats and completed the 200-hour test. The valve seat recession data (table 36) show cylinder No. 1 had recession of only .008 inch, while the rest of the valve seats received little or no recession.

The valve train inspection data (table B-31) again showed cylinder No. 1 to have the most recession of .009 inch with cylinder No. 3 at .008 inch; all other valve seats (intake and exhaust) were within a range .004 to .006 inch.

The valve height of all valves decreased by .005 to .006 inches during the test suggesting valve tip wear. As noted earlier, the change in valve height is corrected for determining valve seat recession from the valve train inspection data.

TABLE 36. - Effect of accumulated engine hours on valve seat recession--GM-454 engine--fuel additive "B"--induction hardened head

Hours Accumulated		Valve Seat Recession, inches/1000															
		8	20	36	52	68	77	83	99	115	131	144	160	176	192	200	*
Intake	1	0	2	2	3	3	3	2	2	2	2	2	2	5	5	5	6
	2	0	-1	-1	0	1	0	1	-1	1	1	-1	3	4	4	4	6
	3	0	1	1	1	2	1	3	4	2	2	3	4	4	4	3	4
	4	0	0	1	1	2	3	3	0	3	3	2	4	4	5	5	5
	5	-2	-2	3	0	0	0	-1	0	0	1	1	2	2	2	2	5
	6	1	1	1	2	2	2	2	1	3	2	2	3	5	5	4	6
	7	-5	-5	-3	-3	-2	-2	-1	0	-2	-3	-1	-1	-1	0	0	5
	8	1	1	0	0	0	0	1	1	2	2	2	5	7	6	6	6
Exhaust	1	1	4	4	7	7	5	7	6	7	7	5	7	8	7	8	9
	2	-1	-2	-1	-2	0	-1	-1	0	1	-1	-1	-1	-1	0	-1	5
	3	0	4	4	5	4	4	4	5	5	4	3	4	5	5	5	8
	4	-1	0	0	1	1	0	0	0	1	1	1	1	1	1	1	5
	5	-1	0	1	2	0	1	1	2	2	2	1	3	2	2	2	5
	6	0	0	0	1	1	1	1	1	1	2	1	1	1	3	0	5
	7	-2	1	1	2	2	2	3	2	3	2	3	2	2	2	1	6
	8	0	2	1	2	0	3	2	2	1	2	1	2	2	1	2	6

*Measurement based upon engine disassembly and inspection.

The A/F and emissions data (tables A-61 and A-62) showed the range of A/F over the six modes is 12.2 to 14.0, which is within the range of A/F during other comparative tests with this engine. The daily average A/F ranged from 12.4 to 13.8. The 56-hour steady-state mode operated at an A/F of about 14.0.

Fuel Additive "C"

Fuel additive "C" was supplied by E. I. du Pont and was designated as DMA-4. The manufacturer recommended a concentration of 200 pounds of additive per 1,000 barrels of gasoline for this test. The additive "C" was tested in two engines: the GM-292 "A" and the John Deere 303.

GM-292 "A"

The additive "C" was tested in the GM-292 "A" engine using an engine head with hardness of Rockwell HRB 89 for the entire 200-hour test. The valve seat recession data (table 37) showed cylinders 5 and 6 receiving the greatest amount of recession of .052 and .039 inch, with .023 inch for cylinder No. 4, and about .010 inch for the remaining exhaust valve seats. All intake valve seats showed either a negative or no valve seat recession.

The valve train inspection data (table B-32) showed similar trends in valve seat recession, with cylinders 5 and 6 receiving the greater amount of recession. All cylinders showed some recession, whereas cylinders 1 through 3 showed no recession in previous tests with unleaded fuel. The inspection data also showed no change in valve height measurements during the test and very little change of valve guide and valve stem diameter. The other parameters indicated only nominal wear patterns.

The A/F and emissions data (tables A-63 and A-64) indicated the A/F variation among the five modes ranged from 12.7 to 13.7. The daily averaged A/F ranged from 12.9 to 13.9. These A/F values from this test are in the midrange of all other tests with this engine; therefore, any effect due to A/F is probably common to this test.

TABLE 37. - Effect of accumulated engine hours on valve seat recession--
GM-292 "A" engine--fuel additive "C"--average hardness HRB 89

Hours Accumulated		Valve Seat Recession, inches/1000															
		14	30	46	55	70	86	102	108	115	131	147	163	179	192	200	*
Intake	1	0	-1	-2	-2	-2	-2	-6	-6	-7	-6	-5	-6	-6	-4	-4	0
	2	2	2	2	2	2	1	-2	-2	-2	-2	-3	-2	-3	-2	-2	-1
	3	-2	-2	-2	-2	-1	-2	-2	-3	-2	-2	-3	-3	-3	-3	-2	0
	4	-1	-1	-2	-2	-1	-1	-2	-5	-2	-4	-4	-4	-4	-3	-3	-1
	5	0	0	-1	-1	-1	-2	-2	-1	-1	-1	-1	-1	-1	0	0	1
	6	-1	-1	-1	0	-1	-1	0	0	0	0	0	0	0	0	0	2
Exhaust	1	1	2	1	2	5	5	6	6	6	7	7	8	7	8	6	6
	2	0	4	6	6	9	10	10	10	10	11	10	11	11	11	10	12
	3	3	3	5	5	8	9	9	9	9	13	9	14	9	9	11	11
	4	3	3	5	7	11	15	19	17	18	20	24	22	22	22	23	21
	5	2	7	8	14	19	25	31	31	34	40	42	45	47	48	52	44
	6	1	6	7	9	11	16	21	23	25	28	31	33	33	38	39	33

*Measurement based upon engine disassembly and inspection.

John Deere 303

Fuel additive "C" was tested using the John Deere 303 engine. The head used for this test measured Rockwell hardness of HRB 95.4.

The test was discontinued after only 48 hours due to an engine failure unrelated to the fuel. The failure was diagnosed as stoppage of coolant around one cylinder due to a build-up of calcium deposits blocking the coolant passage. The coolant consisted of untreated "city water." The loss of coolant to the one cylinder resulted in deterioration of the cylinder liner seal which allowed coolant to be admitted to the lube oil reservoir. This test was not repeated due to time constraints of the program.

Neither the valve seat recession data (table 38) nor the valve train inspection data (table B-33) showed any recession of any valve seat outside the range of ±.002 inches. The valve train inspection data indicated essentially no changes in any of the parameters noted. This would be expected, considering the short time the engine operated.

The A/F and emissions data (tables A-65 and A-66) showed the A/F over the six modes and the daily averaged A/F to be typical of other tests with this engine.

While the test results are reported, the test duration was probably too short to produce meaningful results.

Fuel Additive "D"

Fuel additive "D" was a product supplied by Lubrizol Corporation with a trade name "Powershield." Due to the failure of additive "B" to eliminate valve seat recession, the supplier recommended a concentration of 1,000 pounds of additive per 1,000 barrels of fuel.

TABLE 38. - Effect of accumulated engine hours on valve seat recession, John Deere 303 engine--fuel additive "C", average hardness HRB 95.4

		Valve Seat Recession, inches/1000			
Hours Accumulated		16	32	48*	**
Intake 1	1	1	2	2	
	2	-2	-1	-2	1
	3	0	0	0	2
	4	-1	-1	-1	1
	5	-1	0	-1	1
	6	0	0	0	0
Exhaust 1	4	3	2	1	
	2	0	1	1	0
	3	1	1	2	0
	4	-2	1	1	0
	5	1	0	-1	2
	6	2	0	0	1

*Test terminated due to engine failure unrelated to fuel.
**Measurement based upon engine disassembly and inspection.

GM-292 "B"

The fuel additive was tested in the GM-292 "B" engine using a head with a hardness of Rockwell HRB 96.2. The engine completed the 200-hour test.

Valve seat recession data (table 39) showed no recession of any valve seat in excess of ±.004 inch. Most of the valves indicated a negative recession suggesting possible buildup of deposits on the valve seat surfaces.

The valve train inspection data (table B-34) indicated no valve seat recession of any valve seat in excess of ±.002 inch. The other parameters measured showed only nominal effects indicating no significant wear occurred during this test.

The A/F and emissions data (tables A-67 and A-68) gave the range of A/F among the five modes to be 11.5 to 13.7. Daily averaged A/F ranged from 12.3 to 13.1. These A/F values are consistent with the A/F reported for this engine in other tests, as well as tests with the companion GM-292 "A" engine.

TABLE 39. - Effect of accumulated engine hours on valve seat recession--
GM-292 "B" engine, fuel additive "D"--average hardness HRB 96.2

		Valve Seat Recession, inches/1000													
Hours Accumulated		16	32	48	64	80	96	112	127	143	159	175	191	200	*
Intake	1	-1	0	1	1	0	1	1	0	1	-1	1	0	-1	-1
	2	-1	-1	5	3	3	3	3	4	3	4	3	4	4	-2
	3	0	0	0	0	0	0	0	0	1	-1	-1	-1	-1	-1
	4	-1	-1	0	-1	-1	-1	-1	0	-1	-3	-3	-2	-3	-2
	5	0	-1	0	-1	-1	-1	-1	-3	-1	-2	0	-1	-2	-1
	6	0	-3	0	0	0	0	-1	-1	-1	-4	-3	-4	-4	-2
Exhaust	1	0	0	0	0	-4	-4	-4	-2	-3	-2	-1	-1	-3	1
	2	-2	-2	0	-1	-1	-2	-3	-3	-2	-2	-2	-2	-3	1
	3	1	1	1	0	0	-1	-2	-1	-2	-3	-2	-2	-3	0
	4	-2	-2	-2	0	-3	-3	-2	-3	-2	-2	-4	-3	-4	1
	5	-3	0	1	1	0	-1	-1	1	1	-3	1	1	0	0
	6	-1	0	0	0	-1	-1	-1	-2	-1	-2	-1	-1	-1	0

*Measurement based upon engine disassembly and inspection.

Deposits

Combustion chamber and exhaust valve deposits are influenced by many factors, including fuel quality, engine duty cycle, air-fuel ratio, exhaust gas recirculation, engine design, engine condition (amount of lube oil consumption), as well as fuel additives. Likewise, intake valve deposits are influenced by fuel quality, engine duty cycle, engine design, and fuel additives. Therefore, accumulation of combustion chamber and valve deposits from virtually any fuel/engine system is an accepted factor. Accumulation of combustion chamber deposits typically leads to octane requirement increase (ORI). Recent Coordinating Research Council publications show 50 percent of the vehicles are satisfied with 4.8 ORI, and 90 percent of the vehicles are satisfied with 5.7 ORI. Accumulation of intake valve deposits on top of the valve can restrict the air-fuel mixture flow into the cylinders, whereas valve deposits on the combustion chamber side of the valve can result in increased ORI and increase the possibility of "valve burning" brought on by irregular seating and subsequent leakage. A study of the impacts of changes of combustion chamber and valve deposit effects due to fuel additives was outside the scope of this project; however, some comparative observations which may be useful are offered.

Photographs of representative combustion chambers and valves for tests with the GM-454, GM-292A, and JD-303 using 1.2 gm/gal fuel are shown in figures 6, 7, and 8. Comparative photographs from tests using the unleaded fuel are shown in figures 9, 10, and 11. The photographs show the deposits from the leaded fuel to be more "crusty" or "flaky" and light grayish in color, compared to the more evenly coated dark-colored deposits from the unleaded fuels. The GM-454 engine had the greater amount of intake valve deposits for both the leaded and unleaded fuels compared to the other engines. The GM-292A and JD-303 had more deposits from the leaded fuel compared to the unleaded fuel, whereas the GM-454 had a similar amount of deposits for both fuels.

GM 454 1.2 gm/gal Fuel

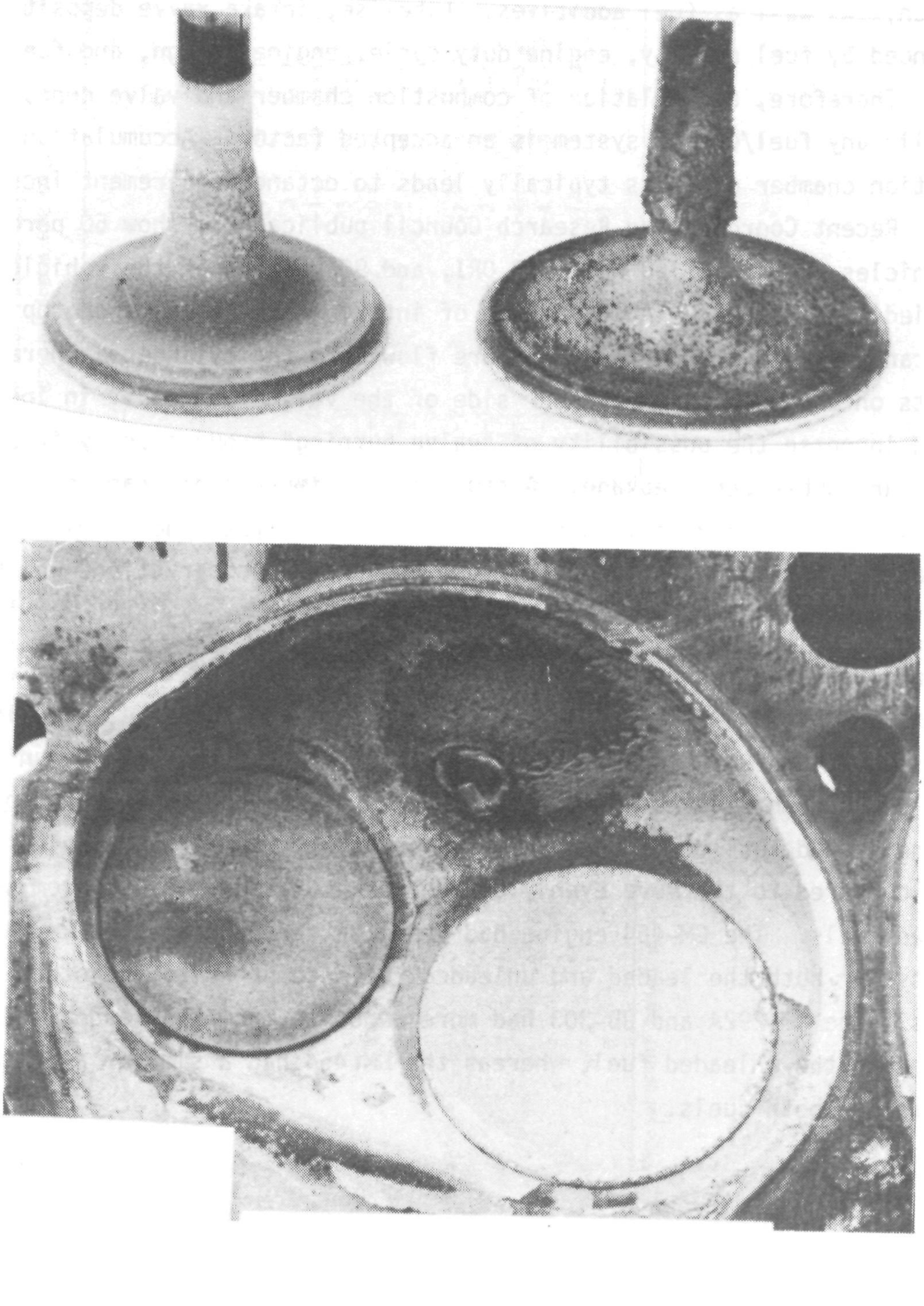
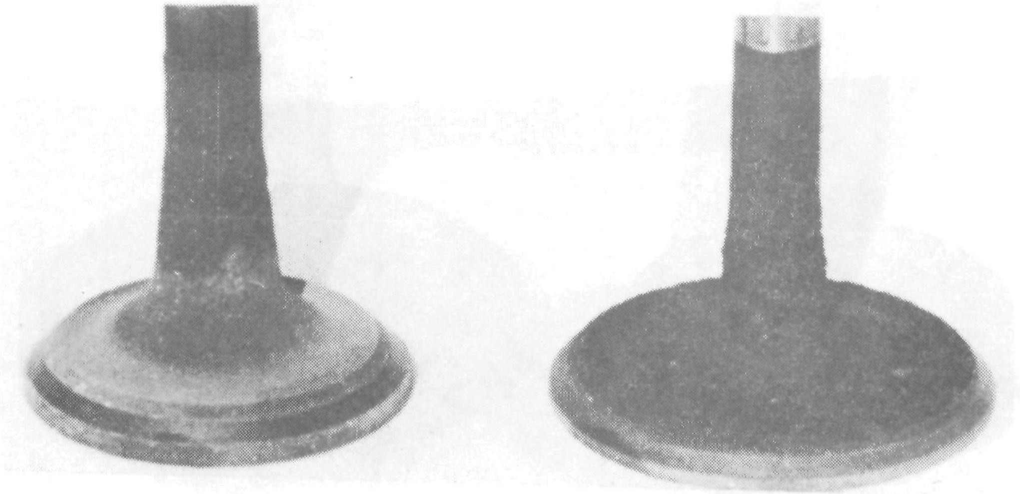


FIGURE 6. - GM-454--1.2 gm/gal fuel.

GM 292 A 1.2 gm/gal



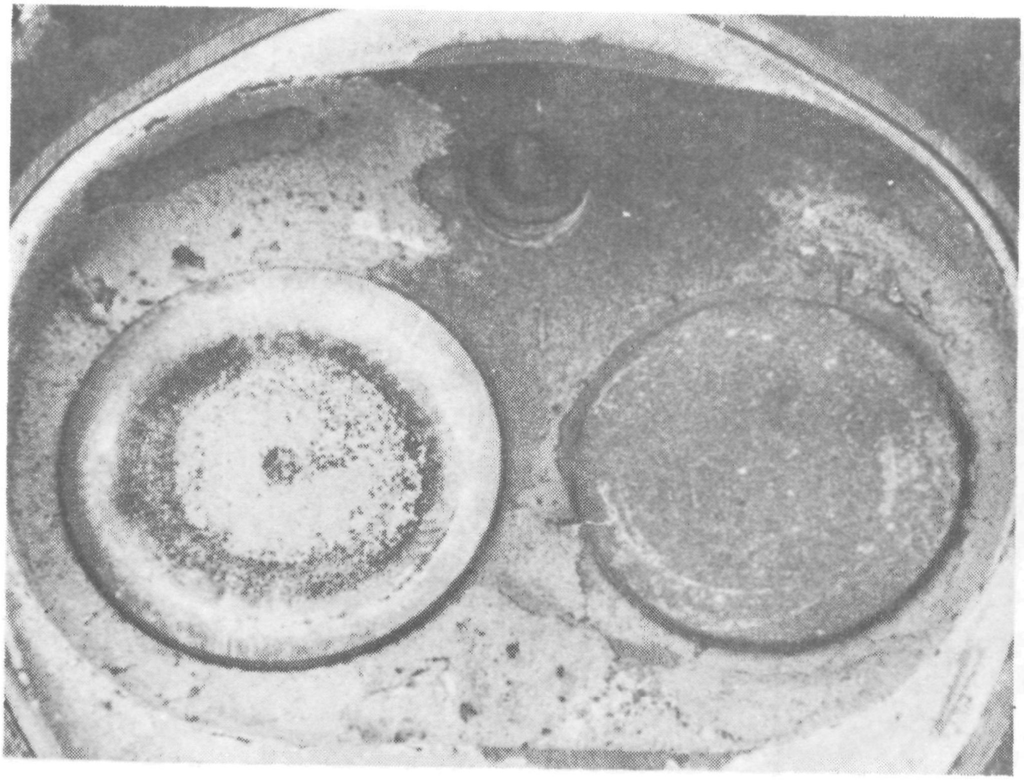
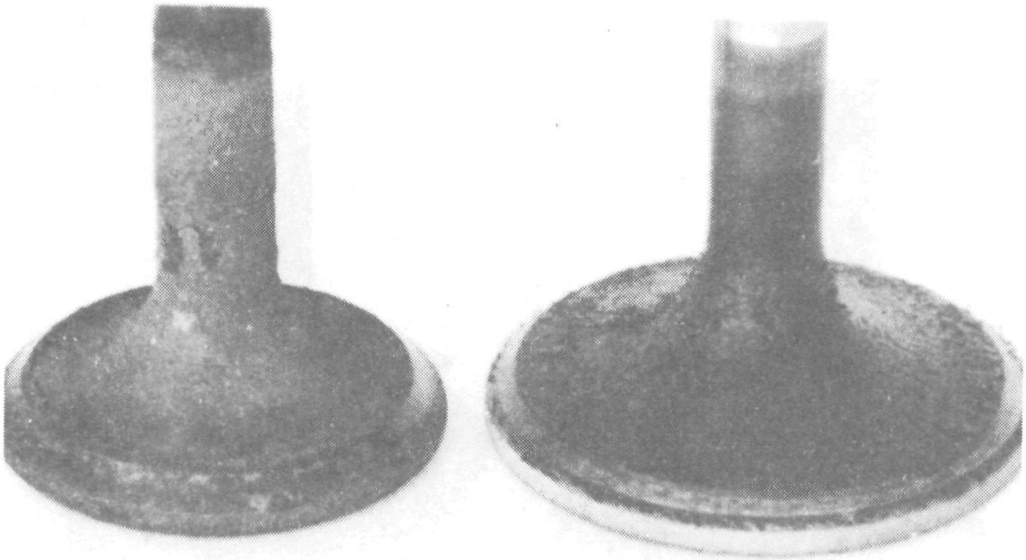


FIGURE 7. - GM-292A--1.2 gm/gal.

John Deere 303 1.2 gm/gal Fuel



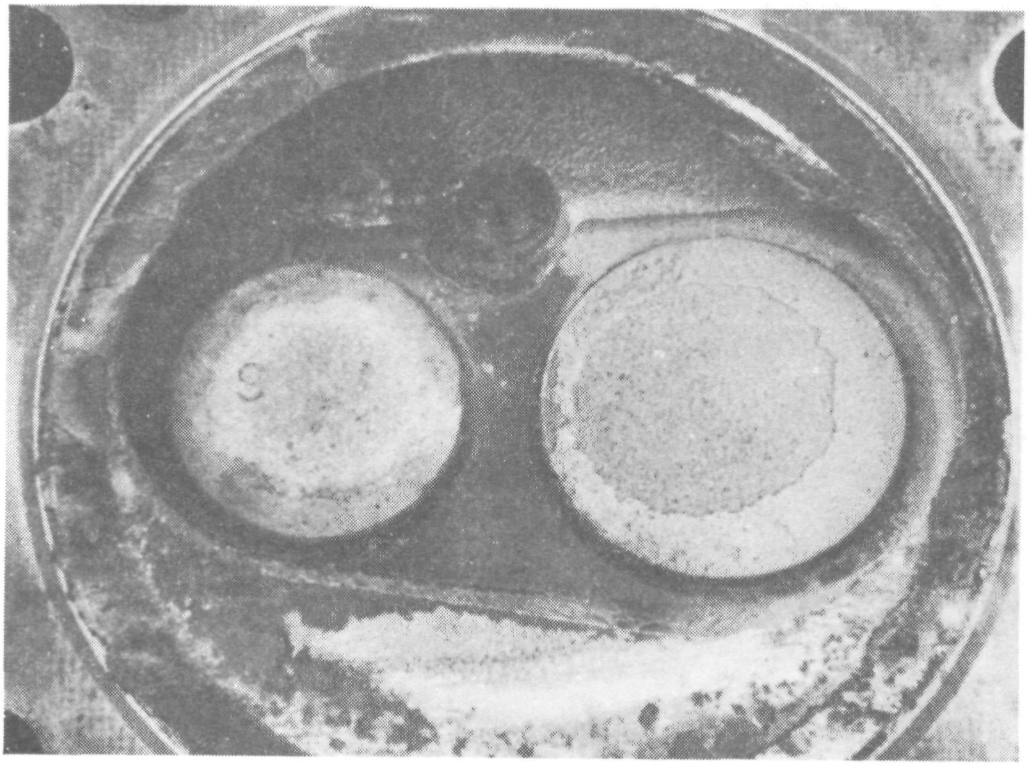


FIGURE 8. - John Deere 303--1.2 gm/gal fuel.

GM 454 Unleaded Fuel

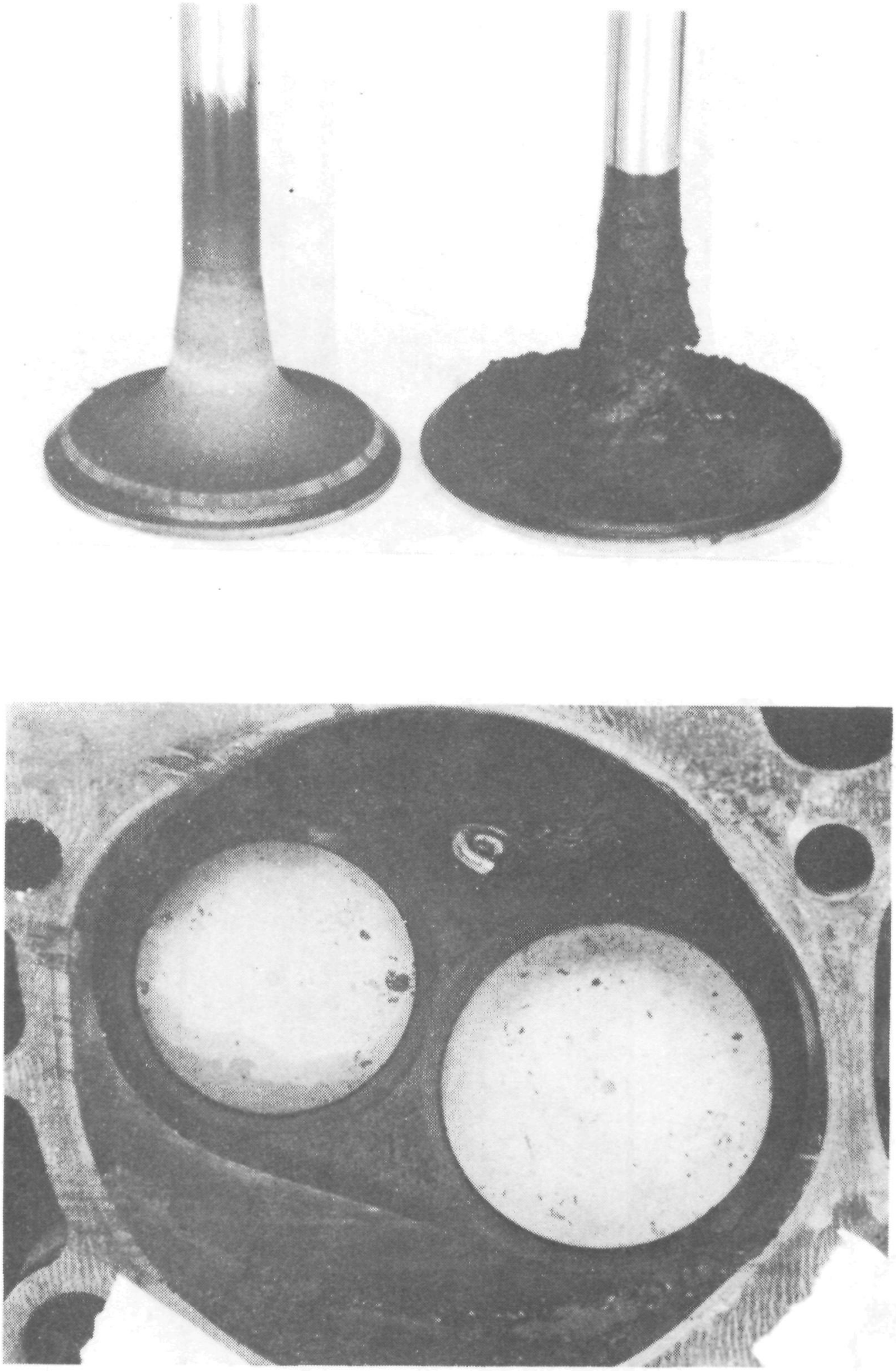


FIGURE 9. - GM-454--unleaded fuel.

GM 292 A Unleaded Fuel

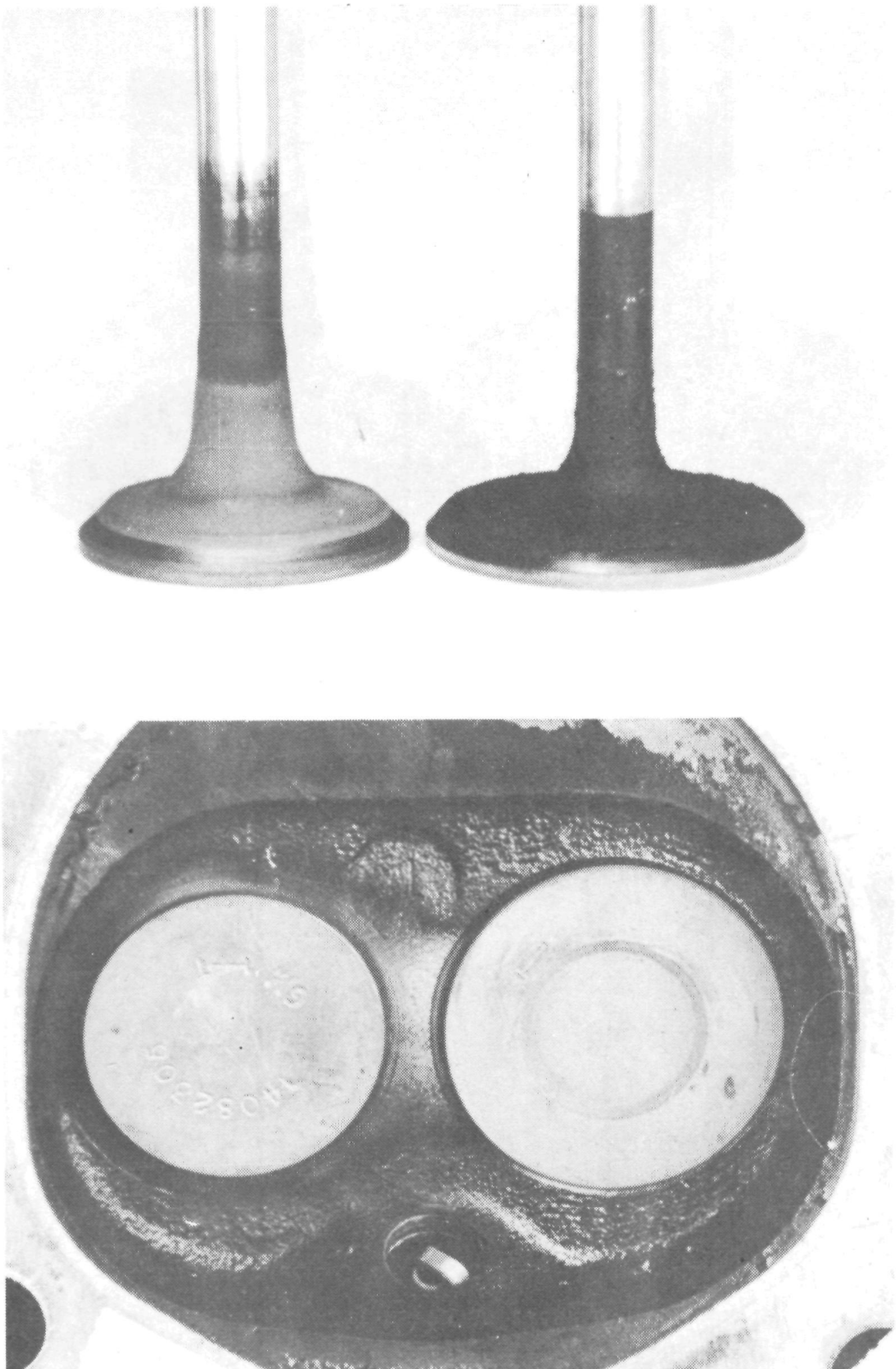


FIGURE 10. - GM-292A--unleaded fuel.

John Deere 303 Unleaded Fuel

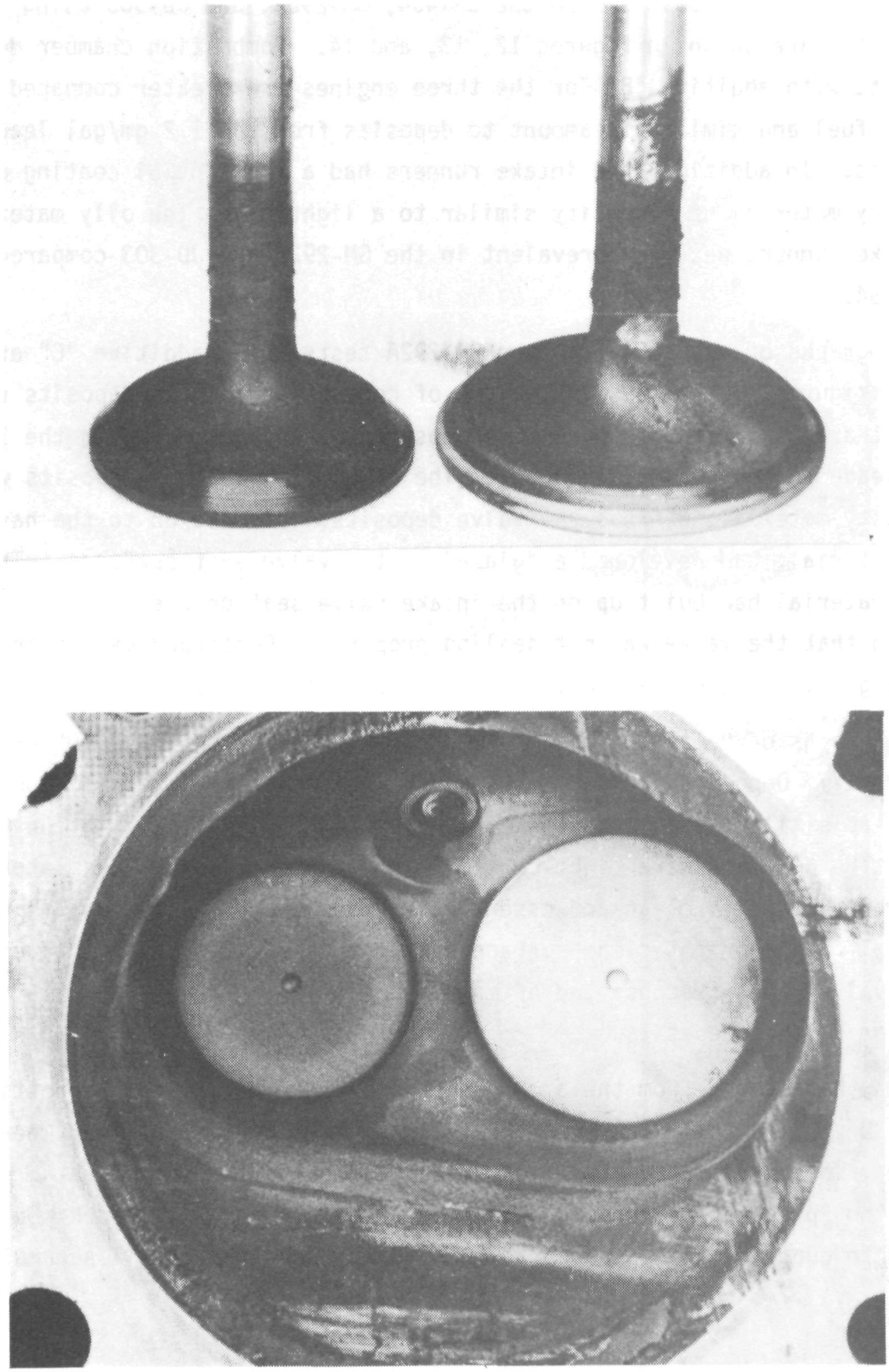


FIGURE 11. - John Deere 303--unleaded fuel.

Photographs of deposits from the GM-454, GM-292A, and JD-303 using additive "B" are shown in figures 12, 13, and 14. Combustion chamber deposits from tests with additive "B" for the three engines are greater compared to unleaded fuel and similar in amount to deposits from the 1.2 gm/gal leaded fuel tests. In addition, the intake runners had a substantial coating of a black oily material of viscosity similar to a light oil. The oily material in the intake runners was more prevalent in the GM-292A and JD-303 compared to the GM-454.

Photographs of deposits from the GM-292A tests using additive "C" are shown in figures 15 and 16. The amount of combustion chamber deposits from this test are significantly more than those compared to tests with the 1.2 gm/gal leaded or unleaded fuel tests. The combustion chamber deposits were a hard crusty material, whereas the valve deposits, in addition to the hard crusty material, had developed a "glaze" on the valve seat surfaces. The deposit material had built up on the intake valve seat of one cylinder (figure 16), such that the valve was not sealing properly. Continued use of the nonsealing valve would lead to valve or valve seat damage.

Photographs of deposits from the GM-292B test using additive "D" are shown in figure 17. Deposits from this test are significantly larger in amount compared to similar tests with the 1.2 gm/gal leaded fuel tests in the GM-292A engine. The deposits were light-colored flaky-type deposits. The intake valves were unusually clean and essentially void of any deposits. The valve stem itself had a bright clean surface almost to the valve tulip surface. The exhaust valve deposits consisted of material similar in composition to the combustion chamber deposits.

It may be assumed from the amount of deposits from tests with additives "C" and "D" that a potential exists for higher than normal octane number increase. The octane requirement was not measured during these tests; however, no "pinging" or "engine knock" was observed. Further work would be required to quantify any possible adverse effects due to deposit accumulation.

GM 454 Fuel Additive B

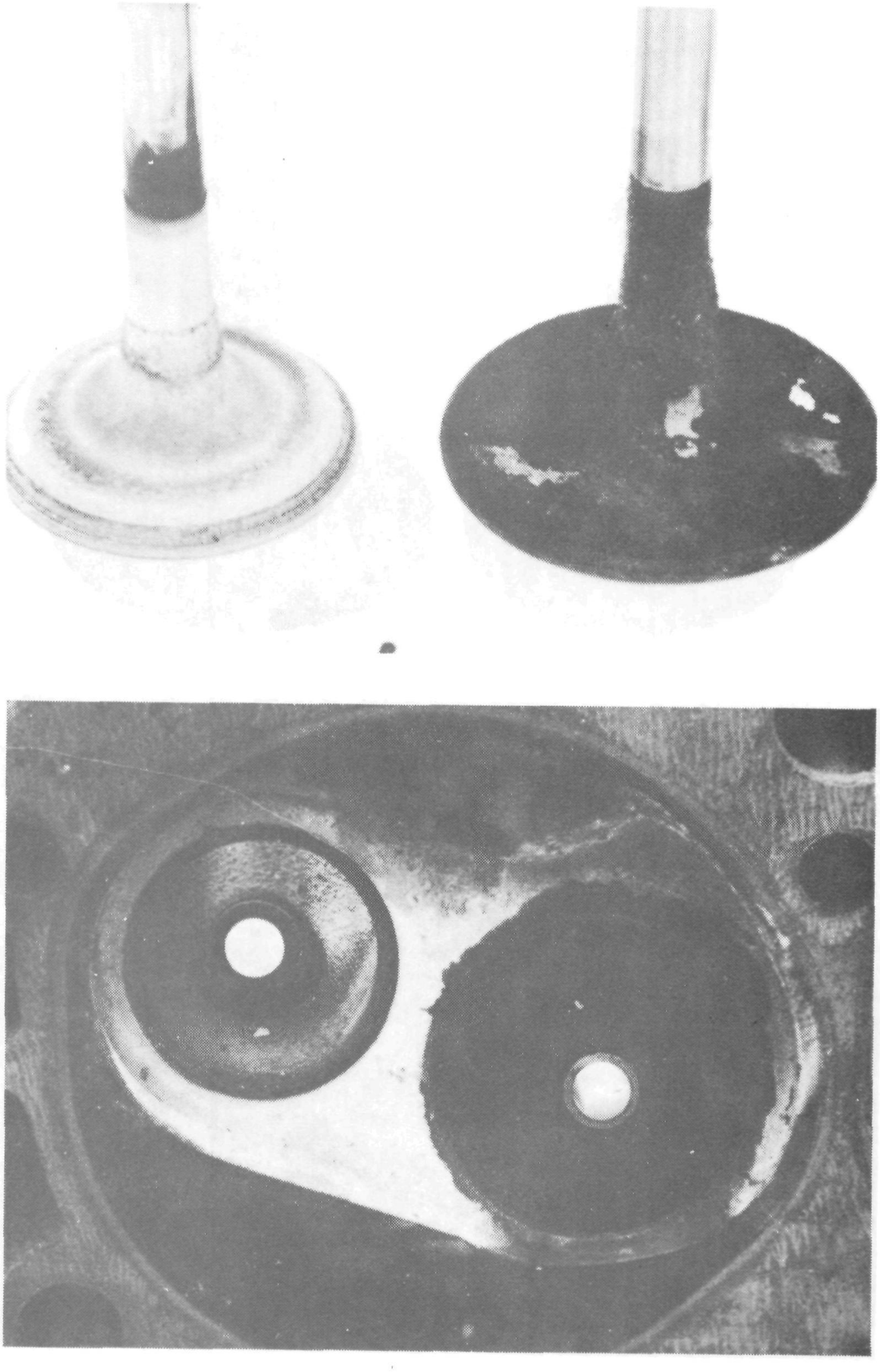
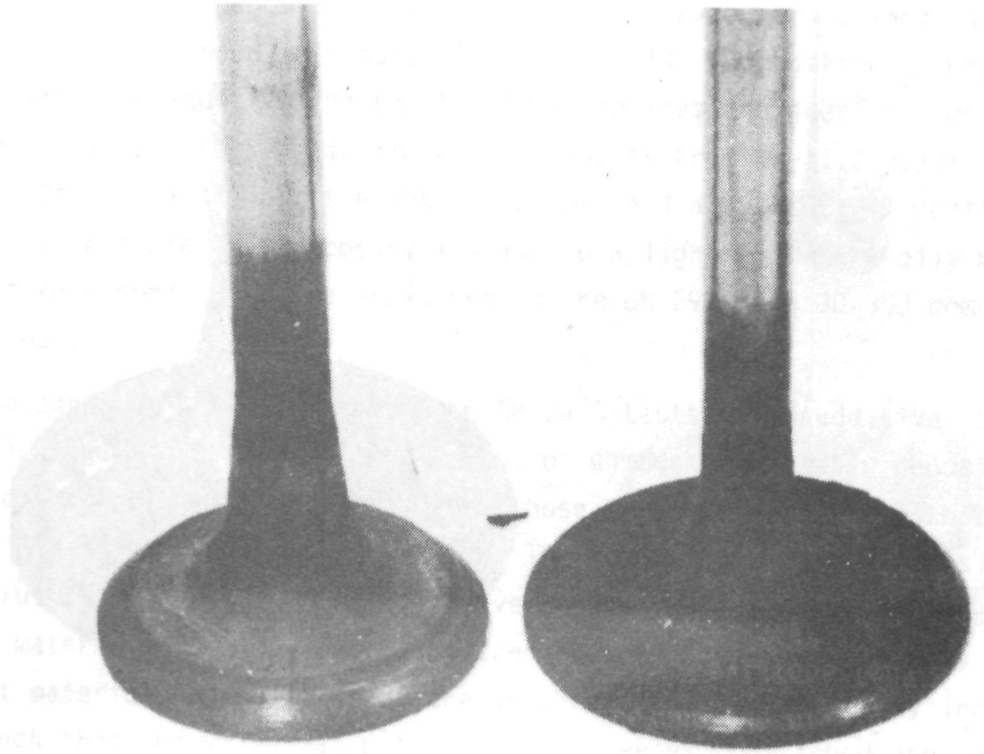


FIGURE 12. - GM-454--fuel additive "B".

GM 292 A Fuel Additive B



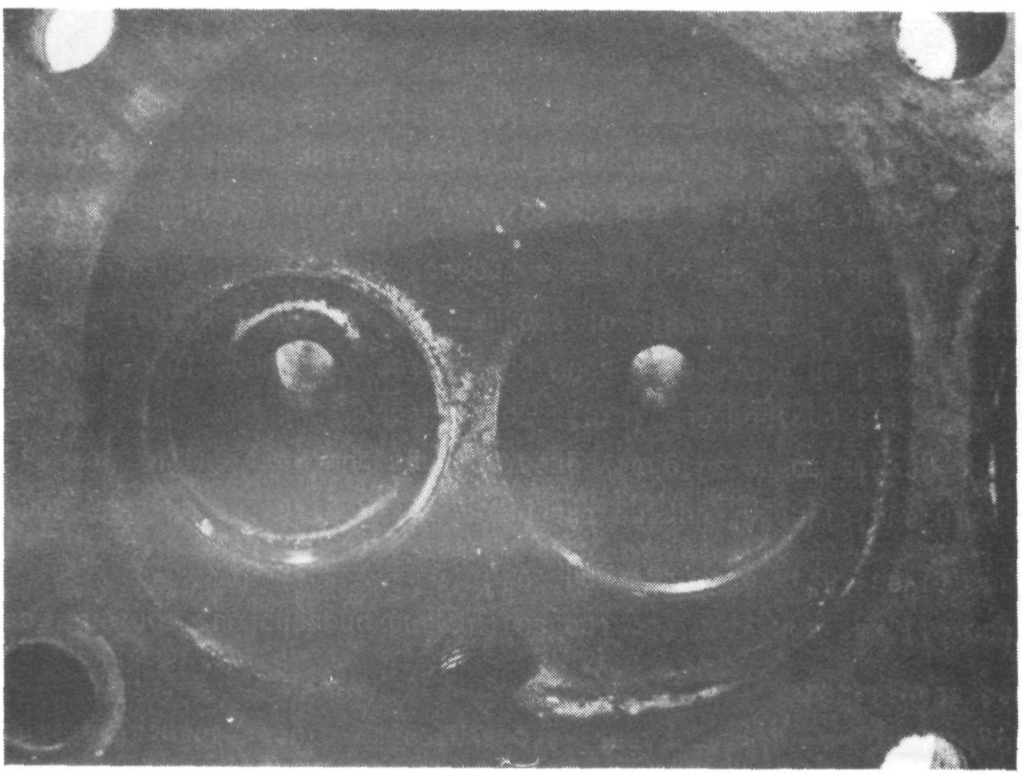


FIGURE 13. - GM-292A--fuel additive "B".

John Deere 303 Fuel Additive B

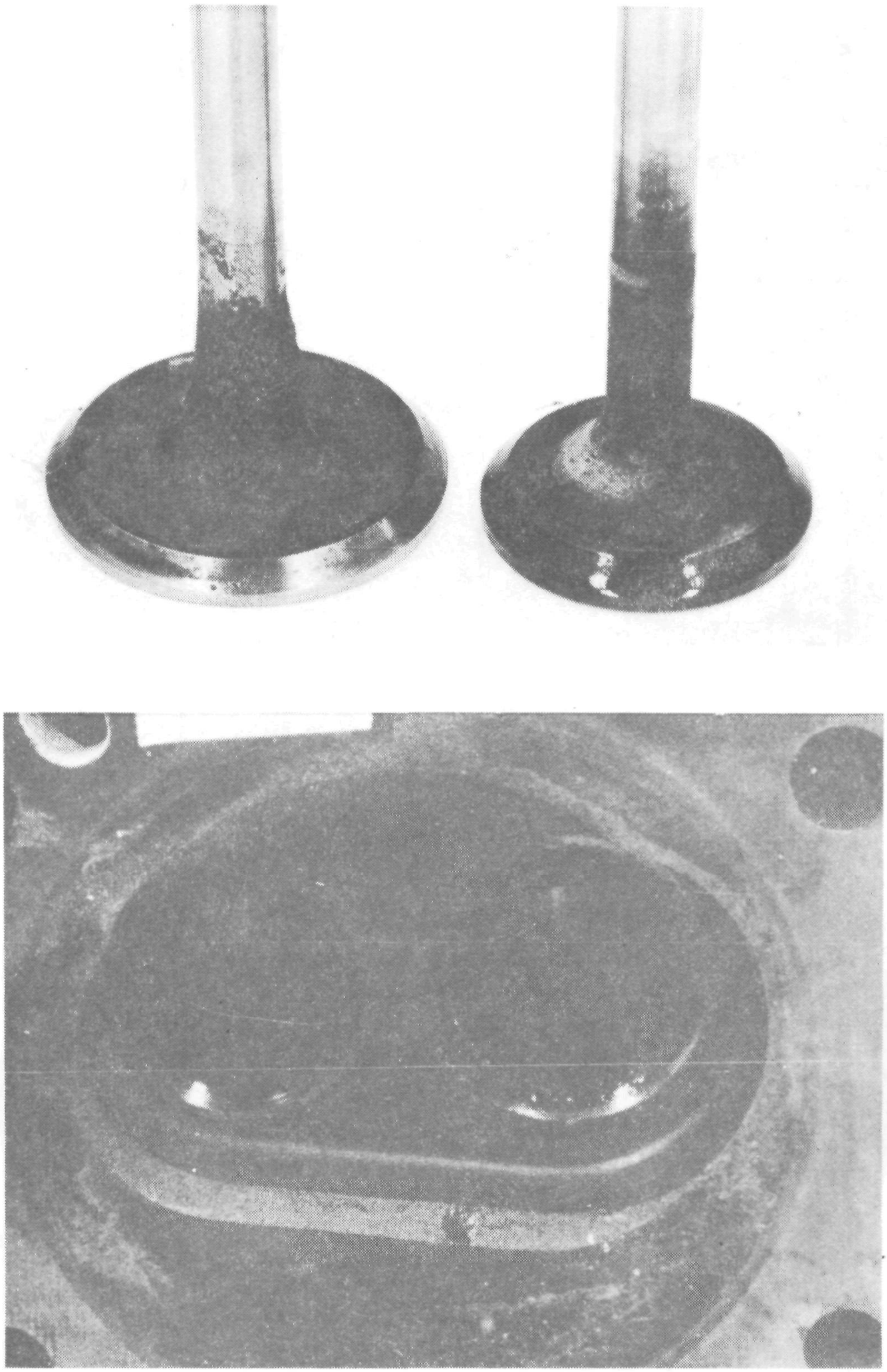


FIGURE 14. - John Deere 303--fuel additive "B".

GM 292 A Fuel Additive C

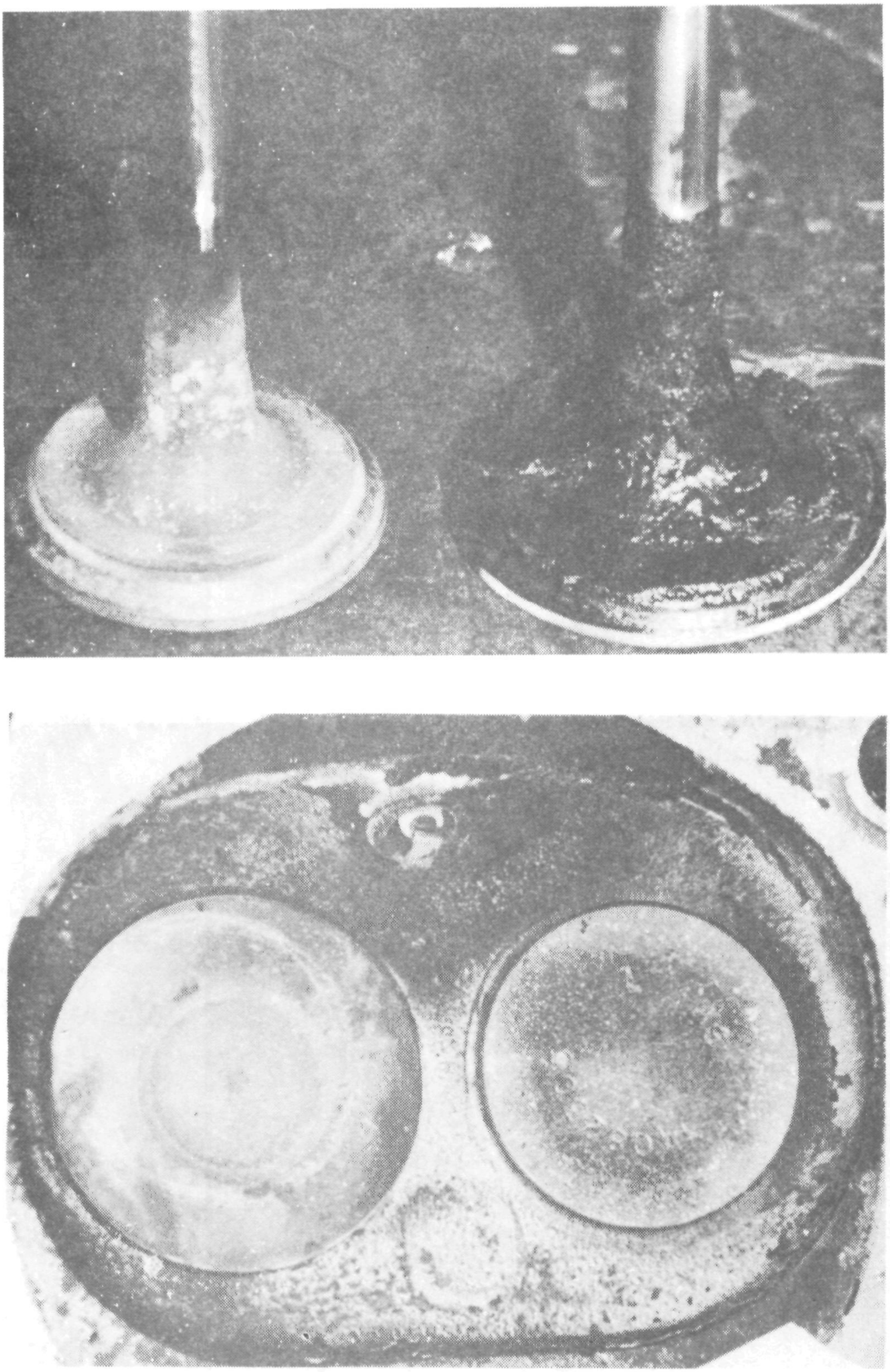


FIGURE 15. - GM-292A--fuel additive "C".

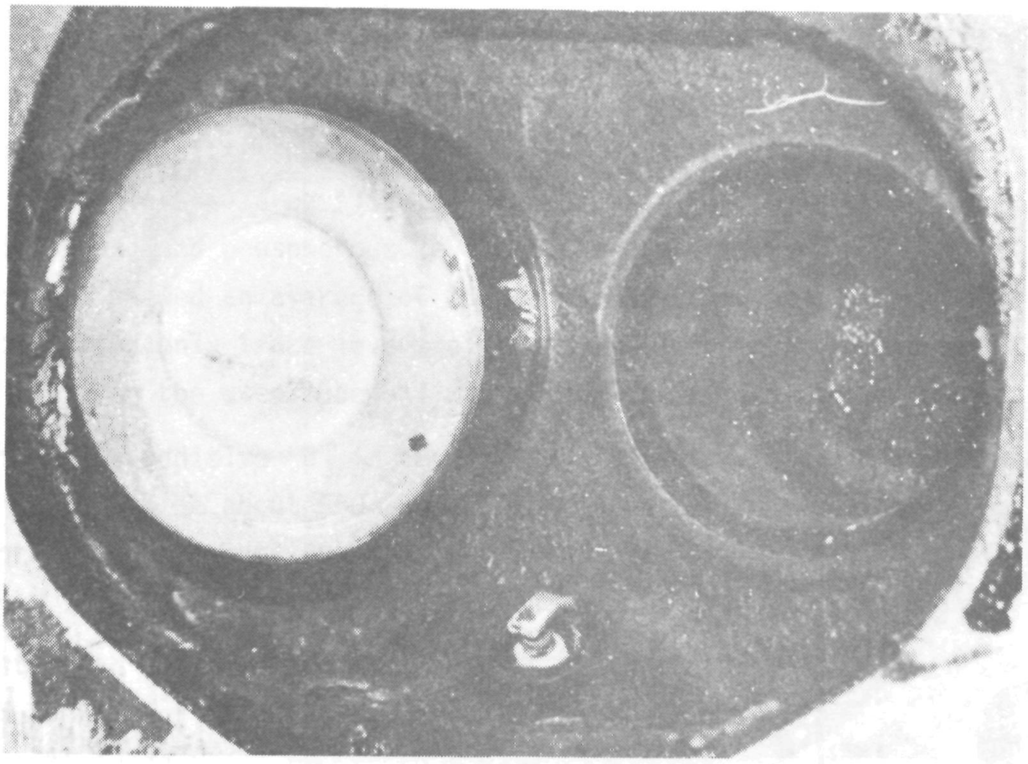


FIGURE 16. - GM-292A--fuel additive "C", showing intake valve leakage.

GM 292 B Fuel Additive D

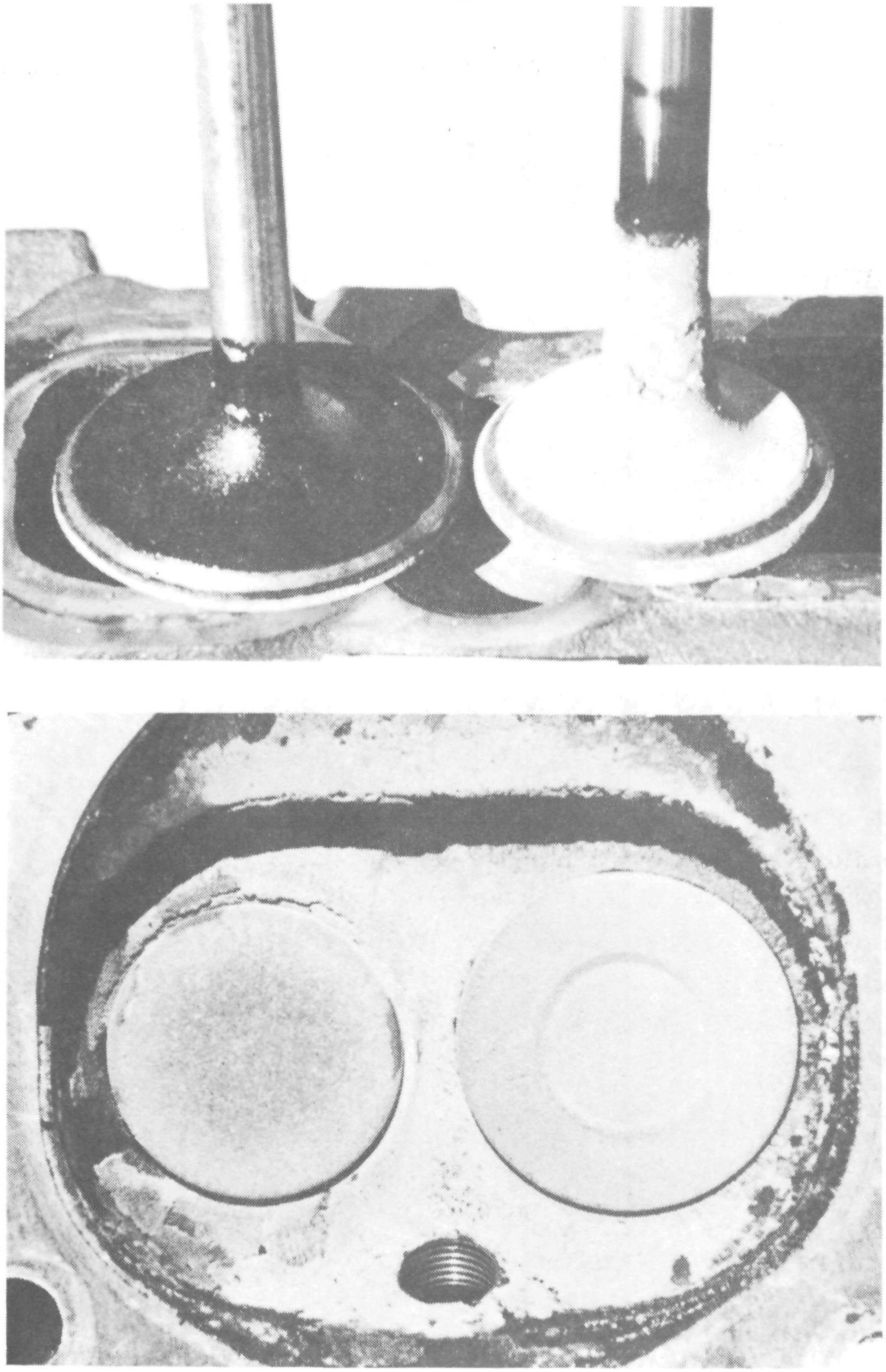


FIGURE 17. - GM-292B--fuel additive "D".

Lube Oil Analysis

The lube oil analysis of metals, shown in appendix "C", represent a single analysis per sample. The data showed generally consistent wear patterns with a few exceptions. The copper, iron, chrome, aluminum, and molybdenum are generally considered as representative of engine wear. Silica and sodium generally indicate contaminates from ingesting airborne dust or particulates. In addition, sodium as well as sulfur and phosphorous are a product from the lube oil or fuel additives. Lube oils typically contain substantial amounts of phosphorous as zinc dithiophosphate and sulfur as sulfonates. In addition, the sulfonates commonly use a sodium, magnesium, or calcium base. These compounds are part of the additive package added to the oil to enhance the performance of automobile engines.

Tests with the 1.2 gm/gal lead fuel showed somewhat higher wear rates in some of the engines. This was also the first test with the new or newly rebuilt engines in which wear rates were typically higher than after the engines had stabilized.

The lube oil was analyzed for the sulfur and phosphorous content for tests with the additives "A", "B", "C", and "D".

Tests with additive "A" during the brief tests with the GM-292A and JD-303 showed sodium levels to be slightly greater than 500 ppm, sulfur levels to be about 3200 ppm, and phosphorous levels to be about 1500 ppm. The analysis of new lube oil showed an average of 3600 ppm sulfur and about 1000 ppm phosphorous and only trace levels of sodium. It is expected that the higher sodium level in the used lube oil was a product of the fuel additive.

Tests with additive "B" in the GM-292A, JD-303, and GM-454 showed average sodium levels to be about 550 ppm, sulfur levels to be about 2800 ppm, and the phosphorous to be about 1800 ppm. As with additive "A", the high sodium levels in the used lube oil are expected to be a product of the fuel additive.

Tests with additive "C" in the GM-292A and the brief test with the JD-303 show an average of about 2400 ppm sulfur, and about 4500 ppm phosphorous. The significant increase in phosphorous in the lube oil is expected to be a product of the fuel additive.

Tests with additive "D" in the GM-292B showed an average of 650 ppm sodium and 6900 ppm sulfur. Phosphorous levels of 980 ppm were essentially equal to the base oil. The higher amounts of sodium and sulfur from this test is expected to be a product of the increased amount of fuel additive compared to additive "B".

SUMMARY

Leaded Fuel

Six engines (John Deere "B", Farmall "H", IH-240, GM-292 "A", John Deere 303, and GM-454) were operated on leaded fuel containing 1.2 gm/gal lead for a 200-hour durability cycle and valve seat recession measured.

Valve seat recession measurements, based upon head disassembly and inspection, showed no recession in excess of .006 inch for all engines.

Unleaded Fuel

Several engines were tested using unleaded fuel with the following results:

John Deere "B" - A 200-hour test was conducted with .009 inch recession noted in one exhaust valve seat. The test was repeated and after 200 hours of operation, .006- and .013-inches recession was noted in the exhaust valve seats. An additional 100-hour test resulted in total recession of .009 and .014 inches for the two cylinders.

Farmall "H" - No valve seat recession was noted in this engine in excess of .001 inch during the 200-hour test.

Ford 8N - A 200-hour test was completed with all of the exhaust valve seats receding from .017 to .030 inch.

International Harvester 240 - The IH-240 was tested with unleaded fuel using an engine head apparently harder than the other heads purchased. Results showed no valve seat recession in this engine

The test was repeated with a "softer" head which resulted in valve seat recession of .038 to .049 inches in two cylinders but no recession in the other valve seats. However, the A/F ratio was somewhat leaner during this compared to the earlier test. Subsequent examination showed that while the hardness of the two heads was different, they had about equally hard valve seats.

An additional test was conducted using cast iron valve seat inserts resulting in .068 to .085 inches recession in all exhaust valve seats after 200 hours of operation.

GM-292 "A" - The GM-292 "A" engine test was discontinued after using unleaded fuel for 71 hours due to excessive valve seat recession of .121 inches in one cylinder and .090 inches in another. Three cylinders were essentially unaffected.

GM-292 "B" - The GM-292 "B" was tested using an induction-hardened head for 200 hours. Exhaust valve seat recession from .003 to .011 inches for the six valve seats was noted.

The GM-292 "B" engine test using a modified engine duty cycle (eliminating the highest speed/load condition) with unleaded fuel was discontinued due to excessive wear after 88 hours with .094 inch recession noted in one valve seat. Three of the exhaust valve seats were unaffected.

John Deere 303 - The John Deere 303 engine operated for 200 hours with recession in all exhaust valve seats ranging from .041 to .064 inches.

GM-454 - The GM-454 engine was tested using induction-hardened valve seats for 200 hours resulting in exhaust valve seat recession from .007 to .032 inches for the eight cylinders.

The GM-454 was also tested using steel valve seat inserts designed for "moderate" duty for 200 hours. Exhaust valve seat recession ranging from .004 to .017 inches was noted for the eight cylinders.

Low Lead (0.10 gm/gal)

International Harvester - The IH-240 engine was tested for 188 hours using 0.10 gm/gal lead with no exhaust valve seat recession in excess of .001 inch.

The IH-240 was also tested using cast iron valve seat inserts for 200 hours resulting in no recession in excess of .002 inch.

GM-292 "A" - The GM-292 "A" engine operated for 200 hours using the 0.10 gm/gal fuel and resulted in .040 inches recession in one cylinder and no recession in the other exhaust valve seats. Intake valve seat No. 6 receded some .014 inch. The engine suffered a head gasket failure between cylinders 5 and 6; therefore, the test was repeated.

The GM-292 "A" repeat test showed one exhaust valve seat receding .010 inch; the other valve seats showed no change in excess of ±.003 inch.

GM-292 "B" - The GM-292 "B" engine operated on the 0.10 gm/gal lead fuel for a 200-hour period with no valve seat recession in excess of .002 inch.

John Deere 303 - The John Deere 303 engine operated for 200 hours using the 0.10 gm/gal lead fuel, and no valve seat recession in excess of .006 inch was observed.

GM-454 - The GM-454 engine operated for 200 hours using 0.10 gm/gal lead fuel with no exhaust valve seat recession in excess of ±.005 inch.

Fuel Additive "A"

Fuel additive "A" was a misformulated product supplied by The Lubrizol Corporation. However, the product was operated in two engines.

GM-292 "A" - Tests were discontinued after 64 hours of operation during which the engine received .049 and .077 inches recession in exhaust valve seats 5 and 6.

John Deere 303 - Tests were discontinued after 80 hours of operation during which the exhaust valve seats received from .006 to .012 inches recession.

Fuel Additive "B"

Fuel additive "B" was a correctly manufactured product known as "Powershield" supplied by Lubrizol Corporation. The product was tested in three engines at a concentration of 250 pounds per 1,000 barrel.

GM-292 "A" - The tests with fuel additive "B" were discontinued after 84 hours of operation due to excessive valve seat recession. Valve seats in cylinders 5 and 6 showed .109 and .085 inches recession.

John Deere 303 - Tests with the John Deere 303 using fuel additive B for 200 hours resulted in exhaust valve seat recession of .033 and .044 inches in cylinders 1 and 6. The other valve seats received no recession in excess of .006 inch.

GM-454 - Tests with the GM-454 engine for a 200-hour test period resulted in exhaust valve seat recession of .009 and .008 inches in cylinders 1 and 3; otherwise, no recession in excess of ±.006 inch was observed.

Fuel Additive "C"

Fuel additive "C" was a product known as "DMA-4" supplied by E. I. du Pont and blended at a concentration of 200 pounds per 1,000 barrel. Additive "C" was tested in two engines.

GM-292 "A" - The GM-292 "A" engine operated for 200 hours on fuel additive "C" and resulted in exhaust valve seat recession ranging from .006 to .044 inches.

John Deere 303 - The John Deere engine operated for 48 hours when a major engine failure occurred which was unrelated to the fuel. During the 48 hours, no valve seat recession occurred in any valve in excess of .002 inch. The test was probably too short to produce meaningful results.

Fuel Additive "D"

Fuel additive "D" was a product known as "Powershield" supplied by The Lubrizol Corporation and blended at a concentration of 1,000 pounds per 1,000 barrel. The product was tested in the GM-292 "B" engine for 200 hours, resulting in no valve seat recession of any valve in excess of .001 inch.

Deposits

An increase in combustion chamber deposits was noted with fuel additive "C" and "D" compared to the tests with 1.2 gm/gal leaded or unleaded fuels. Intake valve deposits from additive "C" resulted in one intake valve not properly seating. No other engine performance problems were observed which could be attributed to fuel additives, although further testing would be in order to determine possible long-term effects.

GLOSSARY

Feeler gauge - A set of metal strip gauges with varied thicknesses used to measure valve lash.

Induction hardening - The surface layer of a work piece is heated by induction to the hardening temperature and then quenched. The core is unaffected by the heat. Induction hardening of the engine head actually consists of hardening only a small area around the valve seats, with the sole purpose being to enhance the life of the valve seat.

Rocker arm - A supported fulcrum that transmits rotary action initiated by a camshaft lobe into vertical motion of the valves.

Rockwell Hardness - A measure of the resistance of a body to indentation of another body.

Rockwell Hardness HRB - Uses a hardened steel sphere with a diameter of 1.5875 mm forced into the material under a minor load of 98 N, the load is steadily increased to the full major load of 980 N. The permanent indention depth in mm is measured after reducing the load to minor load. HRB = 130 - permanent indention depth (mm)/0.002.

Rockwell Hardness HRC - Uses a spherical-tipped conical diamond indentor with a 120° point angle and a 0.2-mm tip radius forced into the material under a minor load of 98 N, the load is steadily increased to the full major load of 1471 N. The permanent indention depth in mm is measured after reducing the load to minor load. HRC = 100 - permanent indention depth (mm)/0.002.

Top dead center - A specific rotational position in which the No. 1 piston is at its highest position on the compression stroke of an engine.

Valve guide - An assembly mounted to the engine head in a rigid fashion in which the valve is allowed to travel back and forth in one direction. Valve guides are precisely sized to allow proper valve travel and valve lubrication.

Valve lash - The distance between the tip of the valve stem and the mechanism that contacts the tip of the valve causing the valve to open.

Valve rotators - A mechanical device that causes engine valves to rotate in order to keep the valve seats clean. Typical rotation of about one-quarter turn is initiated each time the valve begins to open.

Valve seat - The sealing surfaces that separate the engine combustion chamber from the intake manifold or from the exhaust manifold. One surface of the valve seat is on a moving valve; the other surface of the valve seat is on the engine head.

Valve seat angle - The angle of the seating surfaces of the valve and valve seat.

Valve seat inserts - Machined valve seats which are not a part of the original engine head casting. Valve seat inserts are installed in the engine head after machining the engine head to accept the inserts.

Valve seat recession - The phenomenon of the valve seat on the engine head being worn away such that the valve seat on the engine head recedes into the engine head. Wearing of the seat on the valve itself is not considered valve seat recession.

Valve spring - Coil springs that surround the valve which exert pressure to close the valve.

Valve stem - The body of the valve between the valve tip and the valve tulip.

Valve train assembly - The entire valve assembly including valves, valve seats,, valve springs, valve guides, rocker arms, and valve rotators.

Valve tulip - The area consisting of the largest diameter of the valve on which the sealing surface resides.

APPENDIX A

APPENDIX A

TABLE A-1. - Exhaust emissions profile - modes

Mode average for all test days, JD "B" engine, 1.2 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.9 ± 4.5	2531 ± 1444	1056 ± 898	13.5 ± 2.4
2	6.3 ± 3.9	4942 ± 3498	214 ± 192	12.7 ± 2.2
3	4.5 ± 3.8	2600 ± 1473	654 ± 400	13.6 ± 2.6
4	4.1 ± 3.9	2580 ± 1364	1195 ± 676	13.9 ± 2.5
5	5.6 ± 4.1	3795 ± 2751	298 ± 191	13.1 ± 2.7
6	4.0 ± 4.3	2410 ± 1201	1086 ± 784	14.1 ± 2.7

TABLE A-2. - Exhaust emissions profile - daily variation

Daily average of all test modes, JD "B" engine, 1.2 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	5.4	4053	648	12.6
2	5.9	4107	503	12.4
3	0.6	1753	1151	15.9
4	10.7	6420	86	10.5
5	2.9	1913	1315	12.9
6	.0	1000	1109	17.7
7	8.9	4608	153	11.5
8 (56 hr)	7.5	3125	413	11.5
9 (56 hr)	6.2	2750	736	12.2

TABLE A-3. - Exhaust emissions profile - modes

Mode average for all test days, Farmall "H" engine, 1.2 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	5.8 ± 4.4	2948 ± 1040	1083 ± 1163	12.9 ± 2.5
2	8.2 ± 2.8	6000 ± 2050	110 ± 98	11.5 ± 1.3
3	6.8 ± 3.4	3954 ± 705	307 ± 258	12.1 ± 1.5
4	8.6 ± 4.9	2777 ± 928	1225 ± 1214	11.1 ± 2.7
5	7.9 ± 2.8	4413 ± 984	175 ± 132	11.6 ± 1.3
6	6.3 ± 3.9	3568 ± 871	748 ± 699	12.3 ± 1.8

TABLE A-4. - Exhaust emissions profile - daily variation

Daily average of all test modes, Farmall "H" engine, 1.2 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	10.7	3147	67	10.0
2	9.2	3700	192	11.3
3	3.4	2960	765	13.5
4	5.3	3460	621	12.8
5	10.8	5548	86	10.3
6	2.6	3833	1298	14.2
7	3.9	3627	1397	13.8
8 (56 hr)	.1	2740	2840	15.8
9 (56 hr)	.1	2880	1810	15.4

TABLE A-5. - Exhaust emissions profile - modes

Mode average for all test days, IH-240 engine, 1.2 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	2.1 ± .9	2102 ± 176	1637 ± 262	13.9 ± .3
2	9.0 ± 1.3	4260 ± 1876	78 ± 15	11.1 ± .5
3	5.7 ± 1.2	3391 ± 965	368 ± 110	12.4 ± .3
4	2.7 ± .8	2170 ± 438	1576 ± 329	13.6 ± .2
5	8.2 ± 1.3	3742 ± 577	113 ± 16	11.5 ± .4
6	3.6 ± 1.2	2591 ± 399	1001 ± 224	13.3 ± .4

TABLE A-6. - Exhaust emissions profile - daily variation

Daily average of all test modes, IH-240 engine, 1.2 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.7	2653	879	12.6
2	4.1	2686	932	12.7
3	4.4	2613	947	12.9
4	4.9	3593	830	12.8
5	5.1	2886	784	12.8
6	5.2	2960	802	12.9
7	6.4	3386	561	12.3
8	6.3	3355	709	12.4
9	6.7	3873	637	12.2
10 (56 hr)	4.0	3020	1115	13.2
11 (56 hr)	5.2	3440	792	12.6

TABLE A-7. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "A" engine, 1.2 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	5.6 ± 1.5	2400 ± 1055	1180 ± 331	12.6 ± .7
2	1.6 ± 0.7	1665 ± 515	2068 ± 313	14.5 ± .8
3	1.6 ± 0.7	2047 ± 318	2126 ± 248	14.5 ± .8
4	2.9 ± 1.1	3180 ± 571	1024 ± 205	13.7 ± .6
5	7.2 ± 1.5	2528 ± 298	648 ± 368	11.9 ± .4

TABLE A-8. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "A" engine, 1.2 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.2	2344	958	14.1
2	5.0	2552	856	12.9
3	4.0	2368	1444	13.6
4	3.7	2536	1520	13.5
5	3.4	1920	1433	13.7
6	3.3	2160	1520	13.3
7	3.4	2416	1600	13.5
8	4.2	2552	1378	12.9

TABLE A-9. - Exhaust emissions profile - modes

Mode average for all test days, JD-303 engine, 1.2 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.0 ± .9	2126 ± 815	1627 ± 223	13.1 ± .4
2	6.9 ± .8	6528 ± 1450	350 ± 77	11.7 ± .6
3	5.5 ± .9	3484 ± 723	1016 ± 183	12.4 ± .4
4	3.4 ± .9	2173 ± 373	1722 ± 335	13.3 ± .5
5	6.6 ± 1.1	5960 ± 1743	495 ± 127	11.9 ± .6
6	4.6 ± 1.0	3617 ± 874	1381 ± 233	12.8 ± .4

TABLE A-10. - Exhaust emissions profile - daily variation

Daily average of all test modes, JD-303 engine, 1.2 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	5.3	3940	1082	12.3
2	5.1	3800	1146	12.3
3	4.7	4327	1164	12.4
4	5.6	3987	1002	12.3
5	5.9	3633	1029	12.2
6	6.1	5920	876	12.3
7	6.2	3633	868	12.3
8	3.7	3180	1440	13.4
9	4.2	3333	1278	13.2
10 (56 hr)	3.6	2080	1630	13.4
11 (56 hr)	3.3	1880	1820	13.5

TABLE A-11. - Exhaust emissions profile - modes

Mode average for all test days, GM-454 engine, 1.2 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	3.1 ± .7	1809 ± 388	1806 ± 337	13.5 ± .3
2	.5 ± .2	1680 ± 241	2244 ± 259	15.2 ± .8
3	4.6 ± 1.2	1375 ± 350	1717 ± 452	12.9 ± .6
4	.8 ± .3	1407 ± 310	2270 ± 192	14.7 ± .4
5	1.0 ± .3	1837 ± 465	1883 ± 465	14.5 ± .3
6	2.3 ± .6	1517 ± 401	2005 ± 303	13.9 ± .3

TABLE A-12. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-454 engine, 1.2 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	2.1	1713	1937	13.6
2	1.8	1540	2158	14.3
3	2.1	1887	1890	14.1
4	2.6	1407	2186	14.2
5	2.0	1637	2068	14.0
6	2.5	1375	1791	14.0
7	2.2	1852	2179	14.0
8 (56 hr)	1.4	2320	1258	14.0
9 (56 hr)	2.0	2358	1460	13.8
10 (56 hr)	1.3	1170	2570	14.4

TABLE A-13. - Exhaust emissions profile - modes

Mode average for all test days, JD "B" engine, unleaded fuel

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	9.4 ± .9	2457 ± 657	270 ± 85	10.8 ± .4
2	8.5 ± .9	5851 ± 2632	64 ± 54	11.3 ± .4
3	9.6 ± .8	3445 ± 2365	143 ± 39	10.7 ± .5
4	9.5 ± .8	2640 ± 1040	265 ± 75	10.8 ± .4
5	8.9 ± 1.3	3150 ± 1521	129 ± 46	10.9 ± .6
6	9.2 ± .8	2935 ± 865	231 ± 56	10.9 ± .4

TABLE A-14. - Exhaust emissions profile - daily variation

Daily average of all test modes, JD "B" engine, unleaded fuel

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	9.8	3488	160	10.9
2	10.6	5035	76	10.2
3	9.6	3827	214	10.8
4	9.0	2605	173	11.0
5	9.1	3560	204	10.9
6	9.2	2807	233	11.1
7	8.4	2647	212	11.3
8	7.9	2447	240	11.2
9 (56 hr)	9.9	2405	303	10.9

TABLE A-15. - Exhaust emissions profile - modes

Mode average for all test days, John Deere "B", unleaded fuel repeat test

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	5.6 ± 3.5	2731 ± 2009	1246 ± 2009	12.4 ± 1.6
2	8.2 ± 1.4	8266 ± 2980	92 ± 51	11.4 ± .6
3	6.2 ± 3.1	3025 ± 1651	591 ± 384	12.1 ± 1.5
4	5.6 ± 3.4	2631 ± 1660	1377 ± 960	12.4 ± 1.6
5	7.3 ± 2.7	4271 ± 3559	201 ± 117	11.7 ± 1.2
6	5.3 ± 3.6	2645 ± 1617	1114 ± 730	12.5 ± 1.6

TABLE A-16. - Exhaust emissions profile - daily variation

Daily average of all test modes, John Deere "B", unleaded fuel repeat test

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	10.6	6867	49	10.2
2	10.5	7240	62	10.1
3	10.6	6280	58	10.1
4	10.6	5953	81	10.4
5	4.6	2953	1149	12.9
6	4.0	2513	1260	13.3
7	4.0	2320	1199	13.2
8	3.9	1813	1337	13.2
9	3.6	1653	1361	13.3
10 (56 hr)	4.0	1600	1355	13.1
11 (56 hr)	4.0	1560	1230	13.2
12	5.2	3040	1052	12.5
13	5.0	3150	909	12.6
14	4.8	3420	794	12.8
15	4.6	3820	1104	12.7
16	6.5	3500	554	12.0

TABLE A-17. - Exhaust emissions profile - modes

Mode average for all test days, Farmall "H" engine, unleaded fuel, valve seat inserts

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	.5 ± .3	1203 ± 566	2268 ± 160	14.9 ± .3
2	10.2 ± .7	4337 ± 577	77 ± 19	10.5 ± .3
3	6.9 ± .6	2222 ± 224	369 ± 75	11.9 ± .3
4	.1 ± .1	789 ± 174	2158 ± 529	15.9 ± .6
5	9.5 ± .6	3337 ± 368	101 ± 11	10.8 ± .2
6	3.6 ± .5	1520 ± 162	1232 ± 163	13.2 ± .2

TABLE A-18. - Exhaust emissions profile - daily variation

Daily average of all test modes, Farmall "H" engine, unleaded fuel, valve seat inserts

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	5.3	2586	1000	12.9
2	4.9	2133	994	12.8
3	4.9	2073	1074	12.8
4	5.8	2280	747	12.6
5	4.9	2180	1117	12.9
6	4.8	2140	1155	13.1
7	5.0	1986	1483	13.1
8 (56 hr)	.9	2196	1290	14.4
9 (56 hr)	1.1	2110	1180	14.4

TABLE A-19. - Exhaust emissions profile - modes

Mode average for all test days, Ford 8N,
unleaded fuel, valve seat inserts

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	7.2 ± 2.1	3053 ± 558	-	12.0 ± .6
2	8.2 ± 1.6	4155 ± 332	-	11.6 ± .4
3	2.1 ± .6	2110 ± 122	-	13.9 ± .2
4	7.3 ± 2.5	2735 ± 319	-	12.0 ± .7
5	7.3 ± 1.5	3600 ± 270	-	11.9 ± .3
6	4.2 ± 1.2	2455 ± 234	-	13.0 ± .4

TABLE A-20. - Exhaust emissions profile - daily variation

Daily average of all test modes, Ford 8N,
unleaded fuel, valve seat inserts

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	5.4	2860	-	12.6
2	4.5	2713	-	12.9
3	7.3	3287	-	12.0
4	8.8	3140	-	11.7
5	6.2	3047	-	12.4
6	6.7	3193	-	12.1
7	4.9	2793	-	12.7
8	4.9	2993	-	12.7
9 (56 hr)	3.6	2680	-	13.1
10 (56 hr)	3.9	2240	-	13.0
11 (56 hr)	4.6	3320	-	12.7

TABLE A-21. - Exhaust emissions profile - modes

Mode average for all test days, IH-240 engine, unleaded fuel

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	3.6 ± .4	1484 ± 234	1181 ± 425	13.4 ± .4
2	9.9 ± .8	5537 ± 1942	88 ± 29	10.7 ± .4
3	5.9 ± .5	2285 ± 344	538 ± 118	12.3 ± .2
4	3.5 ± .7	1364 ± 242	1364 ± 242	13.4 ± .4
5	8.8 ± 1.1	3324 ± 463	143 ± 48	11.3 ± .4
6	4.1 ± 1.2	1555 ± 306	977 ± 175	13.0 ± .3

TABLE A-22. - Exhaust emissions profile - daily variation

Daily average of all test modes, IH-240 engine, unleaded fuel

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	6.3	2900	751	12.3
2	6.4	2453	614	12.5
3	6.4	2653	691	12.0
4	6.6	3387	721	12.2
5	6.3	3006	682	12.0
6	5.7	2060	789	12.3
7	5.7	2087	827	12.5
8	5.6	2120	847	12.4
9	5.8	2633	757	12.8
10 (56 hr)	4.1	1292	1680	13.0
11 (56 hr)	3.3	1345	1820	13.3

TABLE A-23. - Exhaust emissions profile - modes

Mode average for all test days, IH-240 engine, unleaded fuel (repeat)

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	.7 ± .2	815 ± 185	2238 ± 299	15.2 ± .9
2	3.5 ± 2.1	2115 ± 795	290 ± 101	13.3 ± 1.1
3	1.5 ± 1.5	1150 ± 484	1234 ± 289	14.7 ± 1.3
4	.9 ± .9	915 ± 287	1731 ± 571	15.0 ± 1.0
5	3.1 ± 2.3	1750 ± 762	484 ± 235	13.7 ± 1.4
6	1.3 ± .9	935 ± 282	1801 ± 275	14.9 ± 1.1

TABLE A-24. - Exhaust emissions profile - daily variation

Daily average of all test modes, IH-240 engine, unleaded fuel (repeat)

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	4.6	1960	846	12.7
2	1.9	1480	1387	14.1
3	2.0	1400	1127	14.2
4	1.9	1420	1423	14.2
5	1.7	1286	1549	14.3
6	1.4	1200	1555	14.6
7	.4	759	1540	15.9
8	.1	560	1523	16.1
9 (56 hr)	3.8	1700	1450	13.1
10 (56 hr)	3.5	1610	1395	13.3

TABLE A-25. - Exhaust emissions profile - modes

Mode average for all test days, IH-240 engine, unleaded fuel, valve seat inserts

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	2.5 ± .7	1456 ± 745	-	13.7 ± .3
2	8.4 ± 1.6	3378 ± 944	-	11.6 ± .5
3	5.6 ± 1.1	2315 ± 841	-	12.5 ± .4
4	2.5 ± .8	1392 ± 779	-	13.7 ± .3
5	7.8 ± 1.5	3068 ± 1407	-	11.8 ± .5
6	3.6 ± .9	1938 ± 1306	-	13.3 ± .3

TABLE A-26. - Exhaust emissions profile - daily variation

Daily average of all test modes, IH-240 engine, unleaded fuel, valve seat inserts

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.3	1391	-	13.4
2	5.6	2093	-	12.3
3	5.4	2020	-	12.6
4	5.3	1886	-	12.6
5	5.0	1060	-	12.8
6	4.2	1541	-	13.1
7	3.8	4673	-	12.9
8	4.5	2552	-	13.0
9	6.5	2207	-	12.3
10 (56 hr)	3.5	1420	-	13.2
11 (56 hr)	3.7	1400	-	13.1

TABLE A-27. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "A" engine, unleaded fuel

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	6.6 ± .8	1084 ± 202	509 ± 145	12.1 ± .3
2	2.6 ± .9	890 ± 128	1640 ± 386	13.8 ± .5
3	1.9 ± .3	930 ± 136	2195 ± 498	14.1 ± .3
4	3.3 ± .6	1320 ± 150	977 ± 205	13.4 ± .3
5	7.2 ± .8	1130 ± 119	533 ± 225	11.9 ± .3

TABLE A-28. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "A" engine, unleaded fuel

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	4.9	992	1112	12.9
2	3.8	1040	1276	13.4
3	4.2	936	1128	13.1
4	4.3	1056	960	12.9

TABLE A-29. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "B" engine, induction-hardened head, unleaded fuel

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	5.7 ± .7	1460 ± 359	1084 ± 371	12.3 ± .3
2	1.8 ± .6	1148 ± 181	2304 ± 459	14.0 ± .3
3	1.6 ± .6	1244 ± 134	2317 ± 338	14.0 ± .4
4	3.1 ± .7	1640 ± 311	790 ± 173	13.4 ± .3
5	7.4 ± .9	1680 ± 364	518 ± 249	11.6 ± .4

TABLE A-30. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "B" engine, induction-hardened head, unleaded fuel

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	2.6	1504	1860	13.7
2	3.4	1688	919	13.3
3	4.1	1448	1356	13.1
4	3.5	1216	1538	13.1
5	4.4	1328	1550	12.9
6	3.7	1676	1315	13.0
7	3.5	1688	1500	13.2
8	4.5	1256	1174	12.8
9	4.4	1296	1409	12.8
10	4.6	1256	1356	12.8

TABLE A-31. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "B" engine, unleaded fuel, modified cycle

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	7.1 ± 1.1	1208 ± 186	-	12.2 ± .3
2	2.3 ± .4	1088 ± 273	-	13.8 ± .1
3	2.3 ± .5	1112 ± 270	-	13.6 ± .3
4	3.9 ± .5	1480 ± 268	-	13.1 ± .2

TABLE A-32. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "B" engine, unleaded fuel, modified cycle

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.2	980	1204	13.4
2	3.9	1080	1373	13.2
3	4.0	1180	1342	13.1
4	3.6	1620	1545	13.3
5	4.9	1250	-	12.9

TABLE A-33. - Exhaust emissions profile - modes

Mode average for all test days, JD-303 engine, unleaded fuel

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	5.0 ± 3.0	1573 ± 294	1384 ± 693	12.8 ±1.2
2	6.1 ± .5	3868 ± 1128	538 ± 87	12.2 ± .1
3	4.5 ± .6	1924 ± 449	1265 ± 210	12.9 ± .3
4	2.5 ± 1.3	1230 ± 156	2174 ± 492	13.9 ± .5
5	5.6 ± .5	2799 ± 257	743 ± 158	12.6 ± .3
6	3.9 ± .7	1622 ± 110	1558 ± 258	13.3 ± .3

TABLE A-34. - Exhaust emissions profile - daily variation

Daily average of all test modes, JD-303 engine, unleaded fuel

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.7	2122	1623	13.5
2	4.4	1852	1242	13.1
3	4.3	2080	1305	12.9
4	4.1	2280	1396	13.2
5	4.2	1940	1415	12.9
6	4.2	2106	1358	12.9
7	5.1	2073	1248	12.8
8	5.6	1960	1109	12.5
9	6.1	2447	801	12.8
10 (56 hr)	4.0	1240	1600	13.1
11 (56 hr)	4.5	1360	1260	12.8

TABLE A-35. - Exhaust emissions profile - modes

Mode average for all test days, GM-454 engine, unleaded fuel

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.7 ± .7	1340 ± 990	1150 ± 260	12.8 ± .3
2	2.4 ± 2.4	1130 ± 465	1664 ± 593	13.9 ± 1.2
3	4.2 ± 1.6	946 ± 140	1187 ± 335	13.1 ± .9
4	2.7 ± 3.1	1270 ± 558	1637 ± 685	13.8 ± 1.3
5	2.8 ± 2.1	910 ± 301	1610 ± 582	13.7 ± 1.1
6	2.6 ± .7	776 ± 63	1544 ± 762	13.9 ± .3

TABLE A-36. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-454 engine, unleaded fuel

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	2.8	801	1914	13.7
2	2.8	840	1694	13.5
3	1.9	680	2115	14.3
4	4.0	963	1099	12.7
5	2.4	1126	1448	13.8
6	2.3	2196	1531	13.8
7	4.7	1147	1200	12.8
8 (56 hr)	1.0	490	2483	14.7
9 (56 hr)	1.3	535	2285	14.5
10 (56 hr)	1.4	520	2250	14.6

TABLE A-37. - Exhaust emissions profile - modes

Mode average for all test days, GM-454, unleaded fuel--valve seat inserts

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	5.6 ± .6	891 ± 127	-	12.6 ± .2
2	2.0 ± .7	794 ± 355	-	14.0 ± .5
3	3.9 ± 1.9	874 ± 319	-	13.2 ± .7
4	3.4 ± 1.4	826 ± 222	-	13.3 ± .5
5	3.6 ± .5	906 ± 69	-	13.2 ± .2
6	4.6 ± 1.2	869 ± 90	-	12.9 ± .4

TABLE A-38. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-454, unleaded fuel--valve seat inserts

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.5	797	-	13.4
2	2.9	703	-	13.5
3	3.7	833	-	13.2
4	3.9	917	-	13.2
5	5.1	870	-	12.9
6	4.7	1097	-	12.9
7	3.2	803	-	13.4
8 (56 hr)	2.1	640	-	13.8
9 (56 hr)	3.0	920	-	13.4
10 (56 hr)	2.1	620	-	13.8
11 (56 hr)	2.7	740	-	13.5

TABLE A-39. - Exhaust emissions profile - modes

Mode average for all test days, IH-240 engine, 0.10 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	3.7 ± .4	1610 ± 509	1392 ± 225	13.3 ± .2
2	10.3 ± .2	4689 ± 1339	70 ± 6	10.6 ± .2
3	7.6 ± .4	2816 ± 743	285 ± 53	11.7 ± .1
4	3.0 ± .3	1498 ± 306	1899 ± 232	13.6 ± .2
5	9.9 ± .4	3608 ± 403	96 ± 16	10.9 ± .2
6	5.2 ± .2	2004 ± 468	883 ± 133	12.7 ± .1

TABLE A-40. - Exhaust emissions profile - daily variation

Daily average of all test modes, IH-240 engine, 0.10 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	6.4	2186	699	12.1
2	6.7	2206	723	12.0
3	6.6	2235	868	12.2
4	6.3	3026	912	12.3
5	6.5	3600	849	12.0
6	6.5	3373	961	12.1
7	6.9	2038	706	12.1
8	7.1	2800	664	12.0
9	6.9	2747	674	12.2
10 (56 hr)	4.7	2340	1255	12.9
11 (56 hr)	5.0	2120	1240	12.9

TABLE A-41. - Exhaust emissions profile - modes

Mode average for all test days, IH-240, 0.10 gm/gal lead--valve seat inserts

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	3.7 ± .5	1450 ± 380	-	13.2 ± .2
2	9.7 ± 1.1	2763 ± 604	-	11.2 ± .3
3	6.8 ± .9	2040 ± 121	-	12.1 ± .2
4	3.7 ± .6	1305 ± 306	-	13.2 ± .2
5	9.0 ± 1.0	2790 ± 302	-	11.4 ± .2
6	4.7 ± .6	1610 ± 181	-	12.8 ± .2

TABLE A-42. - Exhaust emissions profile - daily variation

Daily average of all test modes, IH-240, 0.10 gm/gal lead--valve seat inserts

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	6.0	1603	-	12.4
2	6.5	1840	-	12.2
3	5.9	1760	-	12.5
4	6.3	2060	-	12.3
5	6.7	2067	-	12.3
6	7.6	2053	-	12.1
7	5.8	2307	-	12.4
8	5.5	2253	-	12.5
9 (56 hr)	3.4	2000	-	13.1
10 (56 hr)	3.5	2660	-	13.1
11 (56 hr)	4.3	2540	-	12.9

TABLE A-43. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "A" engine, 0.10 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.8 ± .5	1167 ± 241	1179 ± 148	12.9 ± .2
2	1.0 ± .3	1880 ± 2440	2382 ± 569	14.7 ± .4
3	.9 ± .4	1112 ± 735	2442 ± 560	14.7 ± .3
4	2.0 ± .4	1978 ± 723	1423 ± 405	13.9 ± .2
5	6.5 ± .8	1563 ± 516	1192 ± 169	12.1 ± .3

TABLE A-44. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "A" engine, 0.10 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	2.6	992	1780	13.9
2	3.3	1144	1565	13.5
3	3.1	920	1019	13.5
4	2.1	656	1384	14.1
5	2.8	1000	2062	13.8
6	3.3	1136	1499	13.6
7	3.3	2440	1804	13.5
8	3.3	2760	1974	13.8
9	3.3	2250	1704	13.5
10	3.1	1824	1894	13.6
11	3.2	2448	1972	13.6

TABLE A-45. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "A", 0.10 gm/gal lead--repeat

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.3 ± .7	896 ± 132	-	13.1 ± .2
2	2.9 ± .4	1112 ± 99	-	13.5 ± .1
3	2.8 ± .4	1152 ± 132	-	13.5 ± .1
4	4.2 ± .4	1656 ± 141	-	12.9 ± .1
5	5.2 ± 1.1	1092 ± 119	-	12.7 ± .3

TABLE A-46. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "A", 0.10 gm/gal lead--repeat

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	4.3	1104		12.9
2	3.7	968		13.2
3	3.8	1072		13.2
4	3.8	1144		13.2
5	5.1	1216		12.8
6	3.7	1232		13.2
7	3.7	1232		13.2
8	3.6	1304		13.2
9	3.2	1296		13.4
10	3.9	1248		13.2

TABLE A-47. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "B", 0.10 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	7.7 ± 1.3	1357 ± 147	-	11.9 ± .3
2	2.6 ± .6	1215 ± 225	-	13.6 ± .2
3	2.8 ± .8	1276 ± 204	-	13.5 ± .2
4	4.2 ± .6	1649 ± 277	-	13.0 ± .2
5	8.7 ± 1.4	1569 ± 279	-	11.6 ± .6

TABLE A-48. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "B", 0.10 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	5.1	1248	-	12.9
2	5.3	1208	-	12.8
3	5.3	1208	-	12.6
4	4.8	1232	-	12.8
5	4.8	1184	-	12.8
6	4.4	1312	-	13.0
7	5.0	1440	-	12.8
8	4.7	1301	-	12.8
9	4.5	1432	-	12.9
10	5.6	1680	-	12.5
11	4.8	1648	-	12.8
12	5.9	1768	-	12.5
13	7.1	1744	-	12.2

TABLE A-49. - Exhaust emissions profile - modes

Mode average for all test days, JD-303 engine, 0.10 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	5.8 ± .6	1564 ± 238	945 ± 189	12.4 ± .2
2	7.6 ± .9	3468 ± 187	242 ± 118	11.7 ± .6
3	6.5 ± .7	2458 ± 328	693 ± 221	12.1 ± .3
4	5.3 ± .7	1742 ± 450	1141 ± 230	12.6 ± .3
5	7.2 ± .7	3844 ± 1605	396 ± 186	11.9 ± .4
6	5.9 ± .4	1835 ± 210	913 ± 202	12.4 ± .1

TABLE A-50. - Exhaust emissions profile - daily variation

Daily average of all test modes, JD-303 engine, 0.10 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	5.8	3873	989	12.5
2	5.9	3980	831	12.6
3	6.5	2447	567	12.2
4	6.5	2287	605	12.0
5	6.7	2260	608	12.1
6	6.6	2233	499	12.0
7	7.0	2553	620	11.9
8	7.0	2440	604	12.0
9	5.2	2313	990	12.5
10 (56 hr)	6.0	2210	910	12.2
11 (56 hr)	5.9	2140	890	12.3

TABLE A-51. - Exhaust emissions profile - modes

Mode average for all test days, GM-454 engine, 0.10 gm/gal lead

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.3 ± 1.8	1108 ± 161	1238 ± 604	13.2 ± 1.0
2	1.7 ± 1.3	1231 ± 331	1665 ± 546	14.2 ± .8
3	2.4 ± 1.4	991 ± 235	1842 ± 648	14.0 ± .7
4	1.7 ± .1	1110 ± 402	2101 ± 476	14.2 ± .7
5	2.2 ± 1.2	1348 ± 552	1843 ± 815	14.0 ± .6
6	3.0 ± 1.5	985 ± 243	1787 ± 557	13.7 ± .7

TABLE A-52. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-454 engine, 0.10 gm/gal lead

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.4	923	1785	13.3
2	.2	647	2564	14.6
3	1.3	1187	2213	14.5
4	2.7	1310	1632	13.8
5	3.1	1180	1462	13.7
6	2.7	1231	1495	13.6
7	2.4	960	1904	14.1
8	3.5	1226	1581	13.4
9 (56 hr)	1.8	820	2225	14.3
10 (56 hr)	3.4	1345	1753	13.4
11 (56 hr)	2.7	1160	1930	13.7

TABLE A-53. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "A" engine, fuel additive "A"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	6.1 ± .9	1160 ± 212	799 ± 72	12.6 ± .1
2	2.8 ± .1	1093 ± 61	2030 ± 182	13.8 ± .1
3	2.7 ± .2	1213 ± 23	2080 ± 165	13.8 ± .1
4	4.5 ± .1	1773 ± 23	888 ± 14	12.8 ± .3
5	6.7 ± 1.2	1240 ± 317	942 ± 220	12.2 ± .4

TABLE A-54. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "A" engine, fuel additive "A"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	4.3	1216	1379	13.0
2	4.4	1248	1436	13.1
3	5.0	1424	1228	12.9

TABLE A-55. - Exhaust emissions profile - modes

Mode average for all test days, JD-303 engine, fuel additive "A"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	6.3 ± .4	1928 ± 121	663 ± 69	12.3 ± .1
2	8.3 ± .5	3744 ± 128	140 ± 11	11.5 ± .2
3	6.9 ± .4	2552 ± 131	432 ± 70	12.0 ± .2
4	5.4 ± .5	1656 ± 46	985 ± 91	12.6 ± .2
5	7.6 ± .3	3256 ± 112	215 ± 28	11.7 ± .1
6	6.2 ± .4	2088 ± 111	631 ± 69	12.3 ± .1

TABLE A-56. - Exhaust emissions profile - daily variation

Daily average of all test modes, JD-303 engine, fuel additive "A"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	6.5	2393	540	12.2
2	6.7	2507	533	12.0
3	7.2	2607	429	11.9
4	7.0	2595	521	12.0
5	6.6	2487	536	12.1

TABLE A-57. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "A" engine, fuel additive "B"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	2.8 ± .7	872 ± 297	1498 ± 662	13.7 ± .5
2	1.7 ± .4	1072 ± 299	2692 ± 350	14.2 ± .3
3	1.7 ± .4	1184 ± 275	2658 ± 482	14.1 ± .3
4	3.4 ± .2	1840 ± 350	1073 ± 155	13.2 ± .2
5	3.8 ± .8	1056 ± 182	1698 ± 561	12.7 ± .5

TABLE A-58. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "A" engine, fuel additive "B"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	2.3	992	2208	14.0
2	3.1	1168	2094	13.5
3	2.3	984	2350	13.8
4	2.9	1448	1528	13.5
5	3.0	1432	1439	13.4

TABLE A-59. - Exhaust emissions profile - modes

Mode average for all test days, JD-303 engine, fuel additive "B"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	7.5 ± 1.1	2140 ± 147	532 ± 212	11.7 ± .4
2	9.8 ± .8	4010 ± 552	98 ± 24	10.9 ± .3
3	8.1 ± .9	2820 ± 296	247 ± 94	11.4 ± .4
4	6.1 ± 1.0	1875 ± 339	1034 ± 308	12.2 ± .4
5	9.4 ± .8	3495 ± 288	130 ± 29	11.0 ± .4
6	7.8 ± 1.1	2420 ± 199	332 ± 121	11.5 ± .4

TABLE A-60. - Exhaust emissions profile - daily variation

Daily average of all test modes, JD-303 engine, fuel additive "B"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	9.4	2927	281	10.8
2	7.5	2527	996	11.6
3	8.8	2927	275	11.1
4	8.1	3167	388	11.3
5	6.5	2787	510	11.8
6	8.3	2600	448	11.7
7	8.4	2400	348	11.6
8	7.8	2200	292	11.8
9 (56 hr)	4.1	1610	-	13.1
10 (56 hr)	4.5	1680	-	13.0

TABLE A-61. - Exhaust emissions profile - modes

Mode average for all test days, GM-454 engine, fuel additive "B"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	6.5 ± 1.3	1184 ± 265	-	12.2 ± .4
2	2.2 ± 2.0	1052 ± 375	-	13.8 ± .7
3	2.2 ± .5	540 ± 171	-	14.0 ± .3
4	2.9 ± 1.9	1056 ± 271	-	13.5 ± .7
5	3.3 ± 1.6	1096 ± 325	-	13.4 ± .6
6	4.6 ± 1.5	1064 ± 264	-	12.9 ± .6

TABLE A-62. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-454 engine, fuel additive "B"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	2.5	727	1799	13.8
2	3.1	721	1849	13.5
3	3.0	997	1040	13.5
4	3.3	1070	766	13.4
5	6.1	1410	-	12.4
6 (56 hr)	1.9	725	-	14.1
7 (56 hr)	1.5	600	-	14.3
8 (56 hr)	2.4	880	-	13.7

TABLE A-63. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "A" engine, fuel additive "C"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.5 ± .9	763 ± 225	-	13.0 ± .4
2	2.7 ± .6	1017 ± 221	-	13.6 ± .2
3	2.4 ± .4	1053 ± 207	-	13.7 ± .2
4	4.1 ± .4	1547 ± 183	-	13.1 ± .1
5	5.4 ± .7	993 ± 257	-	12.7 ± .2

TABLE A-64. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "A" engine, fuel additive "C"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	3.2	776	2210	13.5
2	3.4	832	1758	13.4
3	3.4	848	1790	13.4
4	3.3	864	1541	13.4
5	3.3	944	1838	13.4
6	4.5	1136	1524	13.0
7	3.9	1336	-	13.2
8	4.9	1368	-	12.9
9	4.2	1248	-	13.2
10	3.6	1192	-	13.3

TABLE A-65. - Exhaust emissions profile - modes

Mode average for all test days, John Deere 303, fuel additive "C"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	4.9 ± 1.8	1413 ± 61	-	12.8 ± .6
2	8.0 ± 1.3	3267 ± 361	-	11.7 ± .3
3	4.9 ± 1.9	1933 ± 305	-	12.8 ± .7
4	3.2 ± .5	1160 ± 69	-	13.3 ± .1
5	5.8 ± 1.2	2733 ± 167	-	12.4 ± .4
6	4.5 ± 1.6	1680 ± 183	-	12.9 ± .5

TABLE A-66. - Exhaust emissions profile - daily variation

Daily average of all test modes, John Deere 303, fuel additive "C"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	5.1	2092	-	12.7
2	5.9	1967	-	12.5
3	4.6	2040	-	12.8

TABLE A-67. - Exhaust emissions profile - modes

Mode average for all test days, GM-292 "B", fuel additive "D"

Mode	CO, %	HC, ppmC	NO_x, ppm	Air Fuel Ratio
1	7.9 ± 1.0	2867 ± 880	-	11.6 ± .3
2	2.2 ± .3	2257 ± 723	-	13.7 ± .2
3	2.4 ± .4	2430 ± 735	-	13.6 ± .2
4	3.5 ± .6	3177 ± 860	-	13.1 ± .2
5	8.4 ± 1.3	3180 ± 971	-	11.5 ± .4

TABLE A-68. - Exhaust emissions profile - daily variation

Daily average of all test modes, GM-292 "B", fuel additive "D"

Day	CO, %	HC, ppmC	NO_x, ppm	Air-Fuel Ratio
1	4.5	2488	-	12.9
2	5.1	2040	-	12.6
3	3.7	2088	-	13.1
4	5.3	2168	-	12.6
5	4.4	2360	-	12.9
6	4.8	2560	-	12.7
7	5.0	2744	-	12.7
8	4.5	2856	929	12.8
9	5.2	3520	1182	12.6
10	4.4	3576	502	12.8
11	5.8	4008	958	12.3
12	5.6	3976	973	12.3

APPENDIX B

TABLE B-1. - Valve train inspection data - before and after test
John Deere B, 1.2 gm/gal lead

	Intake		Exhaust	
	1	2	1	2
Valve seat angle				
Start	30	30	45	45
End	30	30	45	45
Valve seat recession, inches/1000	-1	-2	0	-1
Valve height, inches				
Start	6.764	6.761	7.004	7.005
End	6.763	6.760	7.003	7.004
Valve tulip diameter, inches				
Start	1.808	1.808	1.599	1.598
End	1.808	1.807	1.599	1.598
Valve guide diameter, inches				
Start	.4398	.4396	.4394	.4396
End	.4398	.4396	.4394	.4406
Valve stem diameter, inches				
Start	.4340	.4340	.4342	.4340
End	.4338	.4331	.4340	.4338
Valve spring height, inches				
Start	2.730	2.740	2.707	2.695
End	2.730	2.739	2.696	2.690
Valve spring force, normal lbs.				
Start	35	35	39	39
End	35	35	39	38
Valve spring force compressed, lbs.				
Start	55	55	52	51
End	51	50	48	46

TABLE B-2. - Valve train inspection data - before and after test
Farmall "H" engine - 1.2 gm/gal lead, valve seat inserts

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-1	0	-5	-2	0	-5	-5	-3
Valve height, inches								
Start	5.359	5.359	5.359	5.360	5.395	5.383	5.379	5.389
End	5.359	5.359	5.359	5.360	5.394	5.383	5.379	5.389
Valve tulip diameter, inches								
Start	1.500	1.500	1.500	1.498	1.375	1.375	1.375	1.372
End	1.499	1.498	1.499	1.497	1.375	1.375	1.374	1.370
Valve guide diameter, inches								
Start	.3433	.3433	.3433	.3433	.3434	.3433	.3433	.3433
End	.3440	.3442	.3442	.3442	.3441	.3440	.3440	.3441
Valve stem diameter, inches								
Start	.3407	.3405	.3404	.3405	.3407	.3409	.3410	.3409
End	.3406	.3404	.3402	.3406	.3406	.3407	.3409	.3406
Valve spring height, inches								
Start	1.900	1.909	1.890	1.916	1.912	1.943	1.938	1.948
End	1.911	1.916	1.895	1.917	1.918	1.946	1.942	1.950
Valve spring force, normal lbs.								
Start	32	32	35	32	32	29	30	32
End	30	29	32	28	30	27	27	26
Valve spring force compressed, lbs.								
Start	64	64	63	63	65	64	62	67
End	55	55	56	55	57	56	56	55

TABLE B-3. - Valve train inspection data - before and after test
International Harvester-240, 1.2 gm/gal lead

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-1	-1	2	2	2	3	2	3
Valve height, inches								
Start	5.265	5.266	5.265	5.268	5.293	5.291	5.289	5.294
End	5.266	5.267	5.266	5.268	5.291	5.288	5.288	5.291
Valve tulip diameter, inches								
Start	1.499	1.499	1.499	1.499	1.312	1.313	1.314	1.313
End	1.499	1.499	1.499	1.499	1.312	1.313	1.314	1.313
Valve guide diameter, inches								
Start	.3434	.3434	.3435	.3435	.3436	.3433	.3437	.3434
End	.3435	.3437	.3578	.3436	.3445	.3439	.3438	.3441
Valve stem diameter, inches								
Start	.3409	.3408	.3409	.3407	.3408	.3406	.3408	.3409
End	.3405	.3403	.3403	.3404	.3403	.3403	.3403	.3404
Valve spring height, inches								
Start	2.000	1.992	2.003	2.019	1.814	1.821	1.852	1.883
End	2.001	1.996	2.003	2.023	1.817	1.823	1.855	1.885
Valve spring force, normal lbs.								
Start	36	37	37	32	36	34	37	35
End	32	34	35	30	36	33	30	31
Valve spring force compressed, lbs.								
Start	82	82	80	79	84	86	90	94
End	80	80	80	80	66	70	74	79

TABLE B-4. - Valve train inspection data - before and after test GM-292 "A", 1.2 gm/gal lead

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	2	2	3	2	3	0
Valve height, inches						
Start	4.873	4.882	4.877	4.870	4.869	4.885
End	4.873	4.882	4.877	4.871	4.871	4.885
Valve tulip diameter, inches						
Start	1.722	1.720	1.719	1.723	1.717	1.719
End	1.722	1.720	1.719	1.723	1.717	1.719
Valve guide diameter, inches						
Start	.3430	.3428	.3428	.3428	.3430	.3430
End	.3436	.3438	.3434	.3433	.3436	.3436
Valve stem diameter, inches						
Start	.3410	.3410	.3410	.3410	.3410	.3410
End	.3408	.3407	.3408	.3409	.3408	.3409
Valve spring height, inches						
Start	1.699	1.681	1.674	1.669	1.681	1.692
End	1.710	1.686	1.680	1.679	1.689	1.693
Valve spring force, normal lbs.						
Start	85	90	92	93	87	83
End	83	90	89	88	87	78
Valve spring force compressed, lbs.						
Start	199	200	200	200	200	185
End	198	199	198	198	196	180

TABLE B-4. - Valve train inspection data - before and after test
GM-292 "A", 1.2 gm/gal lead (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-3	-5	2	-4	2	-5
Valve height, inches						
Start	4.923	4.921	4.923	4.922	4.922	4.920
End	4.926	4.925	4.926	4.926	4.925	4.924
Valve tulip diameter, inches						
Start	1.497	1.498	1.498	1.499	1.498	1.498
End	1.497	1.498	1.498	1.499	1.498	1.498
Valve guide diameter, inches						
Start	.3735	.3729	.3733	.3733	.3729	.3733
End	.3741	.3733	.3745	.3741	.3734	.3751
Valve stem diameter, inches						
Start	.3715	.3713	.3715	.3715	.3716	.3713
End	.3715	.3711	.3713	.3713	.3713	.3710
Valve spring height, inches						
Start	1.690	1.675	1.658	1.694	1.689	1.685
End	1.695	1.676	1.658	1.694	1.689	1.685
Valve spring force, normal lbs.						
Start	85	88	90	86	85	83
End	72	66	70	69	70	70
Valve spring force compressed, lbs.						
Start	193	200	186	198	195	195
End	184	183	182	190	185	186

TABLE B-5. - Valve train inspection data - before and after test
John Deere 303, 1.2 gm/gal lead

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	1	-1	1	-1	0	0
Valve height, inches						
Start	5.313	5.308	5.314	5.301	5.305	5.316
End	5.312	5.309	5.314	5.303	5.306	5.315
Valve tulip diameter, inches						
Start	1.773	1.771	1.770	1.771	1.762	1.773
End	1.773	1.771	1.770	1.771	1.765	1.773
Valve guide diameter, inches						
Start	.3748	.3748	.3745	.3749	.3748	.3744
End	.3749	.3750	.3746	.3749	.3748	.3744
Valve stem diameter, inches						
Start	.3714	.3719	.3718	.3715	.3718	.3718
End	.3712	.3716	.3716	.3710	.3713	.3711
Valve spring height, inches						
Start	1.792	1.808	1.805	1.819	1.810	1.825
End	1.808	1.814	1.813	1.816	1.818	1.822
Valve spring force, normal lbs.						
Start	62	59	59	57	56	55
End	58	56	58	57	55	54
Valve spring force compressed, lbs.						
Start	145	145	146	146	144	141
End	144	142	144	142	140	139

TABLE B-5. - Valve train inspection data - before and after test
John Deere 303, 1.2 gm/gal lead (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	0	-1	1	1	1	0
Valve height, inches						
Start	5.322	5.320	5.322	5.320	5.322	5.322
End	5.323	5.323	5.324	5.321	5.324	5.323
Valve tulip diameter, inches						
Start	1.456	1.457	1.456	1.455	1.455	1.458
End	1.456	1.457	1.456	1.455	1.455	1.458
Valve guide diameter, inches						
Start	.3742	.3744	.3746	.3748	.3747	.3744
End	.3744	.3746	.3747	.3748	.3747	.3744
Valve stem diameter, inches						
Start	.3717	.3718	.3719	.3718	.3717	.3719
End	.3715	.3717	.3715	.3715	.3714	.3713
Valve spring height, inches						
Start	1.814	1.818	1.811	1.822	1.810	1.842
End	1.836	1.841	1.822	1.826	1.826	1.854
Valve spring force, normal lbs.						
Start	61	57	60	56	57	52
End	56	54	57	56	54	50
Valve spring force compressed, lbs.						
Start	150	146	146	145	143	145
End	149	146	144	143	141	143

TABLE B-6. - Valve train inspection data - before and after test
GM-454, 1.2 gm/gal lead

	Intake							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	1	-1	-1	-2	3	-2	2	1
Valve height, inches								
Start	5.115	5.110	5.111	5.106	5.105	5.121	5.110	5.112
End	5.115	5.110	5.112	5.106	5.104	5.122	5.110	5.113
Valve tulip diameter, inches								
Start	2.066	2.066	2.067	2.066	2.064	2.062	2.067	2.065
End	2.066	2.066	2.067	2.066	2.064	2.062	2.067	2.065
Valve guide diameter, inches								
Start	.3731	.3738	.3733	.3734	.3734	.3733	.3739	.3732
End	.3736	.3742	.3736	.3738	.3739	.3736	.3742	.3737
Valve stem diameter, inches								
Start	.3715	.3715	.3716	.3717	.3717	.3716	.3716	.3714
End	.3711	.3712	.3714	.3714	.3713	.3712	.3711	.3712
Valve spring height, inches								
Start	1.800	1.800	1.800	1.800	1.800	1.800	1.800	1.800
End	1.800	1.800	1.800	1.800	1.800	1.800	1.800	1.800
Valve spring force, normal lbs.								
Start	95	95	95	95	97	95	95	95
End	80	84	84	81	82	79	82	83
Valve spring force compressed, lbs.								
Start	244	243	240	242	235	240	243	244
End	228	230	228	227	218	225	222	227

TABLE B-6. - Valve train inspection data - before and after test GM-454, 1.2 gm/gal lead (continued)

	Exhaust							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	5	2	6	0	2	2	2	2
Valve height, inches								
Start	5.342	5.348	5.345	5.346	5.342	5.344	5.346	5.338
End	5.342	5.347	5.344	5.345	5.342	5.342	5.345	5.339
Valve tulip diameter, inches								
Start	1.719	1.718	1.718	1.723	1.719	1.715	1.717	1.719
End	1.719	1.718	1.718	1.723	1.719	1.715	1.717	1.719
Valve guide diameter, inches								
Start	.3731	.3731	.3731	.3730	.3730	.3731	.3731	.3731
End	.3736	.3737	.3733	.3740	.3738	.3734	.3736	.3738
Valve stem diameter, inches								
Start	.3715	.3715	.3712	.3712	.3714	.3710	.3713	.3712
End	.3712	.3710	.3708	.3710	.3710	.3711	.3709	.3710
Valve spring height, inches								
Start	1.800	1.800	1.800	1.800	1.800	1.800	1.800	1.800
End	1.800	1.800	1.800	1.800	1.800	1.800	1.800	1.800
Valve spring force, normal lbs.								
Start	95	95	95	95	97	95	95	95
End	82	81	79	76	80	84	82	82
Valve spring force compressed, lbs.								
Start	240	241	243	240	242	240	242	240
End	219	228	225	214	222	219	226	225

TABLE B-7. - Valve train inspection data - before and after test John Deere "B", unleaded fuel

	Intake		Exhaust	
	1	2	1	2
Valve seat angle				
Start	30	30	45	45
End	30	30	45	45
Valve seat recession, inches/1000	1	0	0	9
Valve height, inches				
Start	6.788	6.787	7.006	7.003
End	6.788	6.787	7.007	7.004
Valve tulip diameter, inches				
Start	1.805	1.804	1.597	1.597
End	1.805	1.804	1.597	1.597
Valve guide diameter, inches				
Start	.4399	.4400	.4400	.4398
End	.4401	.4402	.4401	.4430
Valve stem diameter, inches				
Start	.4334	.4334	.4339	.4337
End	.4333	.4333	.4334	.4332
Valve spring height, inches				
Start	2.730	2.740	2.700	2.718
End	2.728	2.737	2.708	2.698
Valve spring force, normal lbs.				
Start	39	39	41	40
End	37	38	39	40
Valve spring force compressed, lbs.				
Start	53	54	57	57
End	50	50	51	54

TABLE B-8. - Valve train inspection data - before and after test
John Deere "B"--unleaded fuel--repeat test

	Intake		Exhaust	
	1	2	1	2
Valve seat angle				
Start	30	30	45	45
End	30	30	45	45
Valve seat recession, inches/1000	0	-2	9	14
Valve height, inches				
Start	6.791	6.793	7.014	6.998
End	6.790	6.793	7.013	6.996
Valve tulip diameter, inches				
Start	1.807	1.808	1.602	1.597
End	1.807	1.808	1.602	1.597
Valve guide diameter, inches				
Start	.4394	.4395	.4394	.4393
End	.4398	.4398	.4402	.4400
Valve stem diameter, inches				
Start	.4338	.4336	.4340	.4336
End	.4330	.4326	.4335	.4328
Valve spring height, inches				
Start	2.772	2.778	2.735	2.727
End	2.767	2.770	2.736	2.736
Valve spring force, normal lbs.				
Start	39	37	38	38
End	37	35	34	35
Valve spring force compressed, lbs.				
Start	52	55	52	51
End	52	50	48	49

TABLE B-9. - Valve train inspection data - before and after test
Farmall "H", unleaded fuel, valve seat inserts

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-3	-3	-4	-4	-4	-3	-2	-4
Valve height, inches								
Start	5.323	5.333	5.283	5.332	5.366	5.367	5.349	5.350
End	5.326	5.336	5.287	5.336	5.370	5.370	5.351	5.354
Valve tulip diameter, inches								
Start	1.498	1.501	1.498	1.497	1.377	1.375	1.376	1.375
End	1.499	1.502	1.498	1.498	1.377	1.375	1.376	1.375
Valve guide diameter, inches								
Start	.3432	.3429	.3429	.3429	.3430	.3428	.3428	.3427
End	.3434	.3436	.3436	.3434	.3436	.3432	.3432	.3433
Valve stem diameter, inches								
Start	.3407	.3407	.3407	.3409	.3408	.3408	.3408	.3406
End	.3405	.3406	.3405	.3406	.3405	.3406	.3406	.3402
Valve spring height, inches								
Start	1.925	1.925	1.901	1.909	1.909	1.912	1.934	1.928
End	1.919	1.926	1.897	1.907	1.911	1.915	1.934	1.921
Valve spring force, normal lbs.								
Start	29	29	30	30	30	30	29	30
End	28	27	29	29	29	28	28	28
Valve spring force compressed, lbs.								
Start	42	42	42	42	42	41	42	42
End	41	42	43	42	43	42	43	43

TABLE B-10. - Valve train inspection data - before and after test
Ford 8N, unleaded fuel, valve seat inserts

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	0	-1	-1	-2	17	21	30	25
Valve height, inches								
Start	4.790	4.785	4.786	4.786	4.700	4.701	4.699	4.696
End	4.790	4.785	4.786	4.786	4.699	4.701	4.699	4.695
Valve tulip diameter, inches								
Start	1.510	1.510	1.510	1.510	1.282	1.285	1.285	1.283
End	1.510	1.510	1.510	1.510	1.282	1.285	1.285	1.283
Valve guide diameter, inches								
Start	.3435	.3435	.3434	.3434	.3434	.3435	.3436	.3434
End	.3437	.3439	.3439	.3437	.3438	.3455	.3447	.3437
Valve stem diameter, inches								
Start	.3408	.3409	.3409	.3409	.3407	.3405	.3406	.3403
End	.3408	.3408	.3408	.3408	.3406	.3405	.3406	.3403
Valve spring height, inches								
Start	1.806	1.827	1.802	1.805	1.825	1.800	1.811	1.820
End	1.808	1.830	1.805	1.806	1.845	1.823	1.833	1.838
Valve spring force, normal lbs.								
Start	46	45	45	46	46	47	46	46
End	43	36	41	42	39	40	40	38
Valve spring force compressed, lbs.								
Start	84	78	80	81	84	85	87	84
End	70	69	70	70	74	70	71	71

TABLE B-11. - Valve train inspection data - before and after test International Harvester-240, unleaded fuel

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-4	-3	-2	-2	-5	-3	-5	-5
Valve height, inches								
Start	5.263	5.269	5.262	5.252	5.308	5.310	5.285	5.304
End	5.267	5.274	5.267	5.254	5.313	5.315	5.290	5.309
Valve tulip diameter, inches								
Start	1.499	1.500	1.500	1.500	1.311	1.312	1.311	1.309
End	1.499	1.500	1.500	1.500	1.311	1.312	1.311	1.309
Valve guide diameter, inches								
Start	.3447	.3446	.3447	.3443	.3445	.3447	.3446	.3447
End	.3448	.3449	.3448	.3450	.3446	.3447	.3468	.3449
Valve stem diameter, inches								
Start	.3410	.3404	.3407	.3407	.3410	.3407	.3407	.3405
End	.3406	.3403	.3403	.3406	.3407	.3403	.3406	.3403
Valve spring height, inches								
Start	2.028	2.036	2.027	2.013	1.863	1.857	1.862	1.858
End	2.032	2.034	2.020	2.017	1.868	1.863	1.868	1.858
Valve spring force, normal lbs.								
Start	35	36	35	33	36	36	34	34
End	30	30	30	30	30	30	30	30
Valve spring force compressed, lbs.								
Start	50	51	50	50	76	75	74	75
End	50	50	51	50	58	56	57	57

TABLE B-12. - Valve train inspection data - before and after test
International Harvester-240, unleaded fuel repeat

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-2	-4	-4	-4	-2	-1	38	47
Valve height, inches								
Start	5.257	5.261	5.269	5.267	5.302	5.293	5.297	5.281
End	5.261	5.265	5.273	5.271	5.305	5.296	5.299	5.284
Valve tulip diameter, inches								
Start	1.497	1.497	1.497	1.499	1.312	1.312	1.311	1.311
End	1.497	1.497	1.497	1.499	1.312	1.313	1.311	1.311
Valve guide diameter, inches								
Start	.3432	.3434	.3446	.3445	.3428	.3427	.3447	.3445
End	.3432	.3439	.3446	.3445	.3431	.3432	.3454	.3464
Valve stem diameter, inches								
Start	.3407	.3407	.3405	.3406	.3407	.3405	.3405	.3406
End	.3403	.3403	.3404	.3403	.3404	.3403	.3402	.3403
Valve spring height, inches								
Start	1.976	1.985	1.981	1.986	1.831	1.839	1.839	1.836
End	1.978	1.983	1.989	1.985	1.838	1.843	1.891	1.888
Valve spring force, normal lbs.								
Start	37	37	38	36	35	35	35	36
End	36	35	37	35	32	32	28	29
Valve spring force compressed, lbs.								
Start	63	61	63	61	75	71	72	75
End	61	61	62	58	56	55	57	60

TABLE B-13. - Valve train inspection data - before and after test International Harvester-240, unleaded fuel, valve seat inserts

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-3	-3	0	-1	63	58	77	85
Valve height, inches								
Start	5.259	5.257	5.249	5.260	5.291	5.274	5.278	5.307
End	5.259	5.257	5.249	5.260	5.291	5.274	5.278	5.307
Valve tulip diameter, inches								
Start	1.497	1.497	1.503	1.496	1.312	1.312	1.311	1.312
End	1.497	1.497	1.503	1.496	1.312	1.312	1.311	1.312
Valve guide diameter, inches								
Start	.3432	.3433	.3445	.3446	.3433	.3433	.3445	.3444
End	.3433	.3436	.3446	.3448	.3434	.3436	.3464	.3531
Valve stem diameter, inches								
Start	.3405	.3406	.3406	.3404	.3404	.3407	.3405	.3402
End	.3404	.3402	.3404	.3402	.3402	.3403	.3403	.3399
Valve spring height, inches								
Start	1.985	1.990	1.992	1.999	1.863	1.863	1.883	1.920
End	1.988	1.987	1.993	1.994	1.868	1.869	1.886	1.920
Valve spring force, normal lbs.								
Start	43	43	42	41	39	38	39	37
End	37	38	37	35	30	30	30	25
Valve spring force compressed, lbs.								
Start	73	69	69	68	64	63	64	64
End	64	63	64	62	61	59	60	59

TABLE B-14. - Valve train inspection data - before and after test GM-292 "A", unleaded fuel

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	0	-4	-5	-5	-4	2
Valve height, inches						
Start	4.875	4.870	4.877	4.879	4.879	4.868
End	4.880	4.874	4.882	4.884	4.883	4.871
Valve tulip diameter, inches						
Start	1.719	1.723	1.719	1.719	1.720	1.718
End	1.719	1.723	1.719	1.719	1.720	1.718
Valve guide diameter, inches						
Start	.3430	.3429	.3428	.3427	.3430	.3431
End	.3439	.3434	.3434	.3433	.3438	.3435
Valve stem diameter, inches						
Start	.3410	.3411	.3411	.3412	.3412	.3411
End	.3405	.3406	.3407	.3409	.3409	.3407
Valve spring height, inches						
Start	1.683	1.693	1.694	1.694	1.695	1.671
Eng	1.689	1.699	1.692	1.693	1.702	1.668
Valve spring force, normal lbs.						
Start	90	87	90	88	88	90
End	66	71	72	68	68	71
Valve spring force, compressed, lbs.						
Start	196	195	195	195	196	191
End	172	179	178	171	176	167

TABLE B-14. - Valve train inspection data - before and after test GM-292 "A", unleaded fuel (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-5	1	-4	16	90	121
Valve height, inches						
Start	4.925	4.925	4.925	4.923	4.922	4.919
End	4.930	4.929	4.929	4.927	4.926	4.923
Valve tulip diameter, inches						
Start	1.499	1.498	1.499	1.498	1.499	1.499
End	1.499	1.498	1.499	1.498	1.499	1.498
Valve guide diameter, inches						
Start	.3734	.3728	.3732	.3730	.3728	.3732
End	.3750	.3740	.3747	.3740	.3730	.3754
Valve stem diameter, inches						
Start	.3716	.3718	.3719	.3715	.3719	.3718
End	.3713	.3714	.3714	.3711	.3716	.3714
Valve spring height, inches						
Start	1.692	1.675	1.642	1.693	1.682	1.678
End	1.702	1.686	1.648	1.713	1.766	1.797
Valve spring force, normal lbs.						
Start	90	95	95	87	89	90
End	66	73	74	64	50	44
Valve spring force compressed, lbs.						
Start	196	201	187	196	195	196
End	174	176	164	173	177	173

TABLE B-15. - Valve train inspection data - before and after test GM-292 "B", unleaded fuel, induction-hardened head

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	3	6	5	4	4	4
Valve height, inches						
Start	4.874	4.878	4.882	4.881	4.883	4.871
End	4.868	4.872	4.876	4.876	4.879	4.866
Valve tulip diameter, inches						
Start	1.720	1.719	1.718	1.719	1.714	1.718
End	1.720	1.719	1.718	1.719	1.714	1.718
Valve guide diameter, inches						
Start	.3428	.3429	.3429	.3430	.3428	.3429
End	.3430	.3429	.3432	.3432	.3429	.3431
Valve stem diameter, inches						
Start	.3405	.3406	.3405	.3405	.3404	.3403
End	.3405	.3405	.3403	.3405	.3404	.3402
Valve spring height, inches						
Start	1.680	1.679	1.675	1.704	1.686	1.686
End	1.682	1.683	1.678	1.705	1.687	1.687
Valve spring force, normal lbs.						
Start	81	81	80	79	82	80
End	75	74	74	66	72	72
Valve spring force compressed, lbs.						
Start	182	179	180	189	182	181
End	176	174	172	173	174	170

TABLE B-15. - Valve train inspection data - before and after test GM-292-B, unleaded fuel, induction-hardened head (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	8	3	10	8	11	11
Valve height, inches						
Start	4.886	4.888	4.882	4.897	4.890	4.898
End	4.878	4.885	4.875	4.891	4.883	4.892
Valve tulip diameter, inches						
Start	1.499	1.494	1.499	1.500	1.497	1.499
End	1.499	1.494	1.500	1.499	1.498	1.499
Valve guide diameter, inches						
Start	.3430	.3432	.3430	.3431	.3433	.3431
End	.3437	.3456	.3455	.3471	.3453	.3447
Valve stem diameter, inches						
Start	.3404	.3405	.3403	.3402	.3402	.3403
End	.3404	.3403	.3403	.3400	.3402	.3402
Valve spring height, inches						
Start	1.674	1.674	1.655	1.676	1.686	1.682
End	1.670	1.674	1.660	1.678	1.686	1.686
Valve spring force, normal lbs.						
Start	81	81	80	79	81	79
End	77	73	70	74	69	72
Valve spring force compressed, lbs.						
Start	181	179	175	178	183	176
End	172	171	170	176	173	173

TABLE B-16. - Valve train inspection data - before and after test
GM-292 "B", unleaded fuel--modified cycle

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-1	-1	2	0	-3	1
Valve height, inches						
Start	4.884	4.880	4.879	4.874	4.876	4.877
End	4.884	4.879	4.879	4.873	4.873	4.877
Valve tulip diameter, inches						
Start	1.720	1.721	1.719	1.723	1.719	1.720
End	1.720	1.721	1.719	1.723	1.719	1.720
Valve guide diameter, inches						
Start	.3432	.3430	.3428	.3431	.3432	.3432
End	.3434	.3429	.3428	.3429	.3432	.3431
Valve stem diameter, inches						
Start	.3407	.3405	.3406	.3406	.3407	.3408
End	.3405	.3405	.3406	.3404	.3403	.3405
Valve spring height, inches						
Start	1.680	1.684	1.679	1.679	1.678	1.680
End	1.684	1.679	1.683	1.675	1.675	1.681
Valve spring force, normal lbs.						
Start	81	83	84	82	81	80
End	69	71	74	70	70	69
Valve spring force compressed, lbs.						
Start	185	184	180	183	184	180
End	179	178	170	176	178	176

TABLE B-16. - Valve train inspection data - before and after test GM-292 "B", unleaded fuel--modified cycle (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-1	-1	2	6	10	94
Valve height, inches						
Start	4.925	4.923	4.925	4.915	4.923	4.925
End	4.925	4.923	4.923	4.913	4.921	4.920
Valve tulip diameter, inches						
Start	1.500	1.500	1.499	1.499	1.500	1.500
End	1.500	1.500	1.499	1.499	1.500	1.500
Valve guide diameter, inches						
Start	.3733	.3734	.3733	.3728	.3729	.3730
End	.3739	.3739	.3737	.3730	.3732	.3733
Valve stem diameter, inches						
Start	.3715	.3714	.3718	.3714	.3716	.3715
End	.3713	.3714	.3716	.3712	.3713	.3711
Valve spring height, inches						
Start	1.671	1.669	1.664	1.668	1.665	1.672
End	1.670	1.673	1.664	1.671	1.669	1.674
Valve spring force, normal lbs.						
Start	82	81	84	83	8u	84
End	74	73	73	70	68	71
Valve spring force compressed, lbs.						
Start	185	189	187	181	186	183
End	174	176	172	168	172	170

TABLE B-17. - Valve train inspection data - before and after test
John Deere 303, unleaded fuel

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-4	-2	-3	-4	-3	0
Valve height, inches						
Start	5.259	5.279	5.283	5.266	5.279	5.266
End	5.263	5.283	5.287	5.270	5.283	5.270
Valve tulip diameter, inches						
Start	1.769	1.771	1.771	1.770	1.773	1.771
End	1.769	1.771	1.771	1.770	1.773	1.771
Valve guide diameter, inches						
Start	.3743	.3745	.3745	.3746	.3745	.3743
End	.3748	.3750	.3748	.3750	.3750	.3748
Valve stem diameter, inches						
Start	.3717	.3718	.3718	.3719	.3718	.3719
End	.3712	.3714	.3714	.3716	.3714	.3715
Valve spring height, inches						
Start	1.842	1.842	1.839	1.839	1.834	1.831
End	1.841	1.845	1.843	1.838	1.832	1.835
Valve spring force, normal lbs.						
Start	54	53	58	57	58	56
End	43	42	46	46	49	49
Valve spring force compressed, lbs.						
Start	145	143	144	142	145	142
End	132	132	132	130	132	135

TABLE B-17. - Valve train inspection data - before and after test
John Deere 303, unleaded fuel (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	56	41	64	41	36	43
Valve height, inches						
Start	5.288	5.288	5.295	5.291	5.289	5.288
End	5.292	5.292	5.299	5.295	5.293	5.293
Valve tulip diameter, inches						
Start	1.459	1.458	1.460	1.458	1.453	1.457
End	1.458	1.458	1.459	1.458	1.453	1.457
Valve guide diameter, inches						
Start	.3743	.3743	.3743	.3745	.3745	.3742
End	.3746	.3746	.3758	.3750	.3748	.3750
Valve stem diameter, inches						
Start	.3716	.3716	.3718	.3716	.3716	.3716
End	.3714	.3712	.3713	.3712	.3713	.3713
Valve spring height, inches						
Start	1.831	1.845	1.847	1.831	1.844	1.849
End	1.900	1.893	1.909	1.881	1.888	1.893
Valve spring force, normal lbs.						
Start	56	58	58	56	58	56
End	32	38	36	41	38	37
Valve spring force compressed, lbs.						
Start	144	146	146	142	147	145
End	130	132	131	133	133	131

TABLE B-18. - Valve train inspection data - before and after test GM-454, unleaded fuel

	Intake							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	0	1	0	-3	0	-2	0	-1
Valve height, inches								
Start	5.115	5.113	5.112	5.115	5.117	5.098	5.115	5.114
End	5.117	5.115	5.113	5.118	5.120	5.101	5.118	5.116
Valve tulip diameter, inches								
Start	2.064	2.065	2.063	2.065	2.066	2.066	2.065	2.067
End	2.064	2.065	2.063	2.065	2.065	2.066	2.065	2.066
Valve guide diameter, inches								
Start	.3732	.3731	.3735	.3737	.3736	.3733	.3736	.3732
End	.3742	.3733	.3735	.3742	.3739	.3736	.3741	.3736
Valve stem diameter, inches								
Start	.3714	.3716	.3713	.3716	.3718	.3717	.3714	.3716
End	.3712	.3713	.3713	.3712	.3714	.3714	.3713	.3713
Valve spring height, inches								
Start	1.805	1.799	1.797	1.790	1.809	1.803	1.811	1.810
End	1.801	1.804	1.806	1.804	1.813	1.806	1.817	1.810
Valve spring force, normal lbs.								
Start	97	96	98	98	96	97	94	94
End	79	82	77	80	75	80	79	75
Valve spring force compressed, lbs.								
Start	248	244	249	249	245	246	247	250
End	222	222	221	224	223	224	228	218

TABLE B-18. - Valve train inspection data - before and after test GM-454, unleaded fuel (continued)

	Exhaust							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	7	26	10	32	20	15	16	22
Valve height, inches								
Start	5.353	5.348	5.355	5.355	5.354	5.355	5.354	5.356
End	5.357	5.351	5.358	5.357	5.356	5.358	5.356	5.358
Valve tulip diameter, inches								
Start	1.721	1.722	1.718	1.722	1.718	1.717	1.719	1.721
End	1.721	1.721	1.718	1.722	1.718	1.717	1.719	1.721
Valve guide diameter, inches								
Start	.3732	.3732	.3732	.3736	.3737	.3732	.3734	.3733
End	.3740	.3744	.3756	.3742	.3783	.3740	.3741	.3740
Valve stem diameter, inches								
Start	.3714	.3714	.3712	.3714	.3711	.3713	.3712	.3714
End	.3710	.3710	.3708	.3710	.3709	.3710	.3708	.3712
Valve spring height, inches								
Start	1.795	1.795	1.800	1.803	1.797	1.800	1.797	1.795
End	1.801	1.813	1.815	1.818	1.815	1.823	1.810	1.815
Valve spring force, normal lbs.								
Start	96	96	93	97	98	97	97	97
End	84	73	74	75	80	77	77	76
Valve spring force compressed, lbs.								
Start	245	244	246	249	248	247	251	241
End	229	227	219	228	221	224	220	224

TABLE B-19. - Valve train inspection data - before and after test
GM-454, unleaded fuel--steel valve seat inserts

	Intake							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-3	-2	0	-3	-3	0	-4	-4
Valve height, inches								
Start	5.108	5.109	5.108	5.114	5.102	5.116	5.119	5.110
End	5.109	5.109	5.108	5.115	5.102	5.116	5.119	5.111
Valve tulip diameter, inches								
Start	2.065	2.065	2.067	2.065	2.066	2.067	2.066	2.067
End	2.065	2.065	2.067	2.065	2.066	2.067	2.066	2.067
Valve guide diameter, inches								
Start	.3733	.3734	.3733	.3734	.3732	.3734	.3733	.3734
End	.3739	.3745	.3736	.3745	.3737	.3740	.3739	.3743
Valve stem diameter, inches								
Start	.3715	.3711	.3711	.3710	.3711	.3711	.3712	.3712
End	.3713	.3710	.3708	.3706	.3706	.3709	.3708	.3711
Valve spring height, inches								
Start	1.799	1.818	1.810	1.804	1.800	1.795	1.815	1.810
End	1.812	1.810	1.812	1.810	1.808	1.800	1.808	1.808
Valve spring force, normal lbs.								
Start	96	95	90	96	98	97	95	92
End	80	83	83	80	83	81	82	81
Valve spring force compressed, lbs.								
Start	235	241	235	234	240	239	255	241
End	227	231	225	227	229	231	232	232

TABLE B-19. - Valve train inspection data - before and after test GM-454, unleaded fuel--steel valve seat inserts (continued)

	Exhaust							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	6	5	17	4	8	15	8	12
Valve height, inches								
Start	5.355	5.355	5.355	5.355	5.355	5.350	5.351	5.351
End	5.354	5.354	5.354	5.354	5.354	5.350	5.350	5.349
Valve tulip diameter, inches								
Start	1.718	1.720	1.721	1.721	1.722	1.719	1.720	1.720
End	1.718	1.720	1.721	1.721	1.722	1.719	1.720	1.720
Valve guide diameter, inches								
Start	.3733	.3734	.3733	.3733	.3733	.3733	.3733	.3733
End	.3745	.3744	.3742	.3741	.3740	.3744	.3744	.3750
Valve stem diameter, inches								
Start	.3711	.3707	.3708	.3708	.3707	.3712	.3708	.3712
End	.3708	.3705	.3706	.3704	.3705	.3708	.3707	.3708
Valve spring height, inches								
Start	1.784	1.790	1.788	1.791	1.787	1.788	1.786	1.785
End	1.804	1.804	1.807	1.798	1.800	1.812	1.817	1.802
Valve spring force, normal lbs.								
Start	96	96	96	96	98	95	98	94
End	80	83	83	80	83	81	82	81
Valve spring force compressed, lbs.								
Start	232	238	235	230	236	240	240	235
End	228	220	225	222	229	228	227	225

TABLE B-20. - Valve train inspection data - before and after test International Harvester-240, 0.10 gm/gal lead

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-4	3	1	3	1	-1	1	0
Valve height, inches								
Start	5.284	5.316	5.285	5.311	5.315	5.286	5.315	5.284
End	5.284	5.316	5.284	5.311	5.314	5.286	5.315	5.284
Valve tulip diameter, inches								
Start	1.499	1.499	1.499	1.502	1.311	1.311	1.314	1.310
End	1.499	1.499	1.499	1.502	1.311	1.311	1.314	1.310
Valve guide diameter, inches								
Start	.3444	.3448	.3446	.3446	.3444	.3448	.3445	.3448
End	.3447	.3448	.3446	.3447	.3445	.3448	.3449	.3448
Valve stem diameter, inches								
Start	.3406	.3406	.3408	.3406	.3410	.3406	.3405	.3403
End	.3403	.3403	.3404	.3403	.3407	.3405	.3402	.3402
Valve spring height, inches								
Start	1.996	1.995	1.995	1.995	1.813	1.823	1.823	1.823
End	1.990	1.991	1.994	1.994	1.821	1.829	1.826	1.825
Valve spring force, normal lbs.								
Start	42	43	43	45	37	37	37	37
End	38	37	37	39	35	34	34	34
Valve spring force compressed, lbs.								
Start	70	72	72	72	60	60	64	60
End	64	61	63	64	55	55	55	55

TABLE B-21. - Valve train inspection data - before and after test
International Harvester-240, 0.10 gm/gal lead--valve seat inserts

	Intake				Exhaust			
	1	2	3	4	1	2	3	4
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	0	0	-1	1	1	-1	2	0
Valve height, inches								
Start	5.257	5.261	5.267	5.265	5.295	5.280	5.293	5.284
End	5.258	5.261	5.268	5.266	5.291	5.278	5.290	5.282
Valve tulip diameter, inches								
Start	1.497	1.499	1.500	1.497	1.311	1.313	1.313	1.312
End	1.497	1.499	1.500	1.497	1.311	1.313	1.313	1.312
Valve guide diameter, inches								
Start	.3435	.3433	.3434	.3435	.3434	.3444	.3445	.3440
End	.3437	.3436	.3438	.3437	.3438	.3446	.3446	.3443
Valve stem diameter, inches								
Start	.3402	.3406	.3406	.3404	.3404	.3407	.3409	.3402
End	.3401	.3404	.3402	.3402	.3401	.3404	.3406	.3400
Valve spring height, inches								
Start	1.992	1.997	2.003	2.010	1.814	1.823	1.867	1.869
End	1.999	1.998	2.000	2.012	1.807	1.825	1.868	1.869
Valve spring force, normal lbs.								
Start	40	43	39	37	35	38	40	39
End	36	38	30	31	27	30	33	33
Valve spring force compressed, lbs.								
Start	78	82	80	76	84	86	89	87
End	74	77	70	65	78	79	80	78

TABLE B-22. - Valve train inspection data - before and after test
GM-292 "A", 0.10 gm/gal lead

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	0	0	-2	-2	-1	14
Valve height, inches						
Start	4.875	4.870	4.873	4.865	4.886	4.874
End	4.875	4.870	4.875	4.867	4.887	4.874
Valve tulip diameter, inches						
Start	1.725	1.721	1.719	1.726	1.721	1.724
End	1.725	1.721	1.719	1.726	1.721	1.723
Valve guide diameter, inches						
Start	.3430	.3429	.3428	.3428	.3430	.3432
End	.3433	.3433	.3432	.3432	.3435	.3442
Valve stem diameter, inches						
Start	.3410	.3410	.3409	.3412	.3408	.3407
End	.3407	.3403	.3405	.3408	.3404	.3401
Valve spring height, inches						
Start	1.669	1.665	1.680	1.679	1.684	1.670
End	1.669	1.663	1.685	1.680	1.689	1.691
Valve spring force, normal lbs.						
Start	90	86	80	86	82	85
End	80	77	72	79	73	67
Valve spring force compressed, lbs.						
Start	189	187	179	178	188	188
End	178	179	173	168	180	176

TABLE B-22. - Valve train inspection data - before and after test
GM-292 "A", 0.10 gm/gal lead (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-2	2	-4	-4	-3	40
Valve height, inches						
Start	4.922	4.925	4.923	4.925	4.923	4.924
End	4.924	4.923	4.926	4.924	4.926	4.922
Valve tulip diameter, inches						
Start	1.499	1.498	1.498	1.498	1.499	1.498
End	1.499	1.498	1.498	1.498	1.499	1.498
Valve guide diameter, inches						
Start	.3736	.3732	.3736	.3736	.3733	.3736
End	.3740	.3739	.3740	.3741	.3744	.3751
Valve stem diameter, inches						
Start	.3716	.3712	.3712	.3713	.3712	.3711
End	.3713	.3710	.3711	.3711	.3708	.3707
Valve spring height, inches						
Start	1.649	1.642	1.640	1.652	1.644	1.642
End	1.649	1.640	1.639	1.655	1.648	1.683
Valve spring force, normal lbs.						
Start	94	94	92	84	86	90
End	82	83	83	77	77	70
Valve spring force compressed, lbs.						
Start	190	188	187	179	174	179
End	175	176	173	172	169	176

TABLE B-23. - Valve train inspection data - before and after test
GM-292 "A", 0.10 gm/gal lead--repeat test

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	1	-1	-1	-2	-1	0
Valve height, inches						
Start	4.881	4.894	4.883	4.891	4.888	4.880
End	4.880	4.894	4.883	4.890	4.888	4.880
Valve tulip diameter, inches						
Start	1.720	1.721	1.719	1.722	1.718	1.719
End	1.720	1.721	1.719	1.722	1.718	1.719
Valve guide diameter, inches						
Start	.3428	.3428	.3429	.3430	.3429	.3429
End	.3429	.3428	.3429	.3430	.3429	.3429
Valve stem diameter, inches						
Start	.3412	.3412	.3410	.3410	.3412	.3411
End	.3412	.3412	.3409	.3409	.3411	.3410
Valve spring height, inches						
Start	1.697	1.692	1.683	1.687	1.682	1.697
End	1.696	1.691	1.687	1.691	1.682	1.697
Valve spring force, normal lbs.						
Start	86	85	83	82	85	87
End	79	71	72	70	73	72
Valve spring force compressed, lbs.						
Start	198	195	189	185	193	192
End	189	179	177	173	178	183

TABLE B-23. - Valve train inspection data - before and after test GM-292 "A", 0.10 gm/gal lead--repeat test (continued)

	Exhaust					
	1	2	3	4	5	6
Valve[redacted] angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valv[redacted] recession, In[redacted]000	0	0	0	3	10	2
Valv[redacted]ght, inches						
Start	4.924	4.913	4.922	4.924	4.923	4.917
End	4.923	4.912	4.921	4.923	4.922	4.915
Valv[redacted]p diameter, in[redacted]						
Start	1.500	1.500	1.501	1.498	1.499	1.501
End	1.500	1.500	1.501	1.498	1.499	1.501
Valv[redacted]de diameter, in[redacted]						
Start	.3729	.3730	.3733	.3733	.3731	.3729
End	.3737	.3735	.3741	.3741	.3745	.3737
Valv[redacted] diameter, in[redacted]						
Start	.3713	.3713	.3710	.3713	.3714	.3711
End	.3713	.3711	.3710	.3713	.3714	.3710
Valv[redacted]ing height, in[redacted]						
Start	1.648	1.647	1.630	1.654	1.643	1.647
End	1.647	1.654	1.634	1.656	1.657	1.646
Valv[redacted]ing force, no[redacted]lbs.						
Start	89	87	88	86	88	88
End	81	78	80	80	78	79
Valv[redacted]ing force co[redacted]sed, lbs.						
Start	184	175	179	181	178	186
End	189	179	177	173	178	183

TABLE B-24. - Valve train inspection data - before and after test
GM-292 "B", 0.10 gm/gal lead

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-1	0	2	1	-3	1
Valve height, inches						
Start	4.871	4.870	4.873	4.865	4.874	4.870
End	4.870	4.870	4.875	4.867	4.872	4.868
Valve tulip diameter, inches						
Start	1.720	1.719	1.720	1.721	1.724	1.722
End	1.720	1.719	1.720	1.721	1.724	1.722
Valve guide diameter, inches						
Start	.3430	.3428	.3429	.3429	.3429	.3432
End	.3433	.3432	.3433	.3433	.3432	.3440
Valve stem diameter, inches						
Start	.3410	.3408	.3411	.3411	.3409	.3408
End	.3407	.3404	.3406	.3408	.3405	.3403
Valve spring height, inches						
Start	1.669	1.663	1.680	1.678	1.683	1.681
End	1.669	1.664	1.685	1.680	1.681	1.683
Valve spring force, normal lbs.						
Start	90	85	83	87	87	83
End	80	76	74	79	79	70
Valve spring force compressed, lbs.						
Start	179	182	185	186	184	189
End	170	174	173	174	172	176

TABLE B-24. - Valve train inspection data - before and after test
GM-292 "B", 0.10 gm/gal lead (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	1	1	2	-1	0	1
Valve height, inches						
Start	4.925	4.922	4.924	4.923	4.925	4.924
End	4.924	4.921	4.926	4.920	4.926	4.923
Valve tulip diameter, inches						
Start	1.500	1.500	1.499	1.498	1.500	1.499
End	1.500	1.500	1.499	1.498	1.500	1.499
Valve guide diameter, inches						
Start	.3735	.3733	.3736	.3736	.3734	.3736
End	.3740	.3736	.3739	.3740	.3739	.3742
Valve stem diameter, inches						
Start	.3712	.3715	.3714	.3714	.3716	.3714
End	.3701	.3713	.3707	.3710	.3710	.3711
Valve spring height, inches						
Start	1.649	1.640	1.652	1.644	1.649	1.640
End	1.649	1.642	1.648	1.642	1.645	1.642
Valve spring force, normal lbs.						
Start	94	94	90	86	90	92
End	82	82	80	77	74	81
Valve spring force compressed, lbs.						
Start	190	189	188	179	180	183
End	175	176	172	170	176	176

TABLE B-25. - Valve train inspection data - before and after test
John Deere 303, 0.10 gm/gal lead

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	0	0	0	-2	2	0
Valve height, inches						
Start	5.260	5.290	5.272	5.279	5.281	5.268
End	5.260	5.290	5.272	5.279	5.281	5.268
Valve tulip diameter, inches						
Start	1.772	1.768	1.768	1.771	1.770	1.772
End	1.772	1.768	1.768	1.771	1.770	1.772
Valve guide diameter, inches						
Start	.3744	.3742	.3743	.3745	.3743	.3741
End	.3747	.3748	.3747	.3750	.3748	.3745
Valve stem diameter, inches						
Start	.3718	.3718	.3713	.3714	.3717	.3716
End	.3715	.3712	.3711	.3714	.3716	.3712
Valve spring height, inches						
Start	1.806	1.822	1.820	1.822	1.819	1.811
End	1.816	1.824	1.828	1.826	1.821	1.815
Valve spring force, normal lbs.						
Start	57	58	55	56	58	59
End	52	48	51	50	52	54
Valve spring force compressed, lbs.						
Start	138	142	137	138	142	141
End	133	132	138	133	137	137

TABLE B-25. - Valve train inspection data - before and after test John Deere 303, 0.10 gm/gal lead (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	4	0	0	0	0	0
Valve height, inches						
Start	5.314	5.317	5.317	5.317	5.306	5.315
End	5.314	5.317	5.318	5.317	5.306	5.315
Valve tulip diameter, inches						
Start	1.459	1.458	1.457	1.454	1.456	1.456
End	1.459	1.458	1.457	1.454	1.456	1.456
Valve guide diameter, inches						
Start	.3742	.3744	.3744	.3743	.3742	.3745
End	.3745	.3756	.3748	.3745	.3744	.3748
Valve stem diameter, inches						
Start	.3714	.3712	.3712	.3712	.3713	.3713
End	.3712	.3709	.3711	.3712	.3713	.3713
Valve spring height, inches						
Start	1.828	1.824	1.820	1.819	1.822	1.821
End	1.836	1.832	1.824	1.824	1.826	1.827
Valve spring force, normal lbs.						
Start	54	55	56	57	57	56
End	46	47	49	49	51	50
Valve spring force compressed, lbs.						
Start	140	140	138	140	141	138
End	131	132	132	134	136	132

TABLE B-26. - Valve train inspection data - before and after test
GM-454, 0.10 gm/gal lead

	Intake							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	-5	1	1	1	5	1	6	0
Valve height, inches								
Start	5.106	5.111	5.099	5.118	5.108	5.110	5.111	5.115
End	5.108	5.109	5.097	5.116	5.103	5.108	5.105	5.113
Valve tulip diameter, inches								
Start	2.065	2.065	2.064	2.066	2.064	2.066	2.063	2.065
End	2.065	2.065	2.064	2.066	2.064	2.066	2.063	2.065
Valve guide diameter, inches								
Start	.3732	.3734	.3735	.3735	.3735	.3732	.3735	.3733
End	.3734	.3737	.3737	.3742	.3739	.3736	.3744	.3739
Valve stem diameter, inches								
Start	.3716	.3718	.3717	.3718	.3716	.3716	.3716	.3711
End	.3713	.3713	.3712	.3713	.3712	.3712	.3711	.3713
Valve spring height, inches								
Start	1.802	1.800	1.794	1.797	1.800	1.790	1.796	1.805
End	1.814	1.802	1.812	1.806	1.811	1.796	1.806	1.805
Valve spring force, normal lbs.								
Start	96	98	96	96	95	98	95	94
End	80	80	76	80	73	80	82	78
Valve spring force compressed, lbs.								
Start	247	244	241	240	242	237	242	239
End	228	223	228	223	222	220	224	219

TABLE B-26. - Valve train inspection data - before and after test GM-454, 0.10 gm/gal lead (continued)

	Exhaust							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	5	1	3	2	0	2	3	1
Valve height, inches								
Start	5.357	5.355	5.358	5.356	5.353	5.354	5.353	5.355
End	5.350	5.352	5.354	5.353	5.354	5.351	5.350	5.352
Valve tulip diameter, inches								
Start	1.722	1.718	1.721	1.721	1.720	1.720	1.719	1.721
End	1.722	1.718	1.721	1.721	1.720	1.720	1.719	1.721
Valve guide diameter, inches								
Start	.3733	.3732	.3733	.3735	.3735	.3735	.3733	.3731
End	.3740	.3739	.3741	.3745	.3749	.3745	.3753	.3739
Valve stem diameter, inches								
Start	.3713	.3714	.3715	.3713	.3713	.3712	.3710	.3717
End	.3712	.3712	.3711	.3708	.3710	.3708	.3703	.3710
Valve spring height, inches								
Start	1.799	1.795	1.796	1.804	1.793	1.790	1.803	1.804
End	1.799	1.795	1.805	1.804	1.800	1.796	1.812	1.805
Valve spring force, normal lbs.								
Start	96	96	95	97	97	98	94	93
End	82	83	80	80	80	85	73	82
Valve spring force compressed, lbs.								
Start	240	239	245	242	239	240	242	236
End	225	225	227	224	229	230	219	228

TABLE B-27. - Valve train inspection data - before and after test
GM-292 "A", fuel additive "A"

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	3	4	5	5	5	3
Valve height, inches						
Start	4.883	4.879	4.890	4.880	4.880	4.891
End	4.879	4.875	4.885	4.875	4.875	4.887
Valve tulip diameter, inches						
Start	1.719	1.723	1.719	1.720	1.722	1.720
End	1.719	1.723	1.719	1.720	1.721	1.720
Valve guide diameter, inches						
Start	.3430	.3428	.3428	.3428	.3429	.3429
End	.3434	.3432	.3432	.3432	.3432	.3434
Valve stem diameter, inches						
Start	.3409	.3409	.3400	.3409	.3408	.3407
End	.3407	.3408	.3400	.3407	.3407	.3404
Valve spring height, inches						
Start	1.690	1.679	1.683	1.677	1.677	1.678
End	1.700	1.680	1.687	1.677	1.687	1.686
Valve spring force, normal lbs.						
Start	81	85	81	79	83	84
End	69	74	74	72	74	73
Valve spring force compressed, lbs.						
Start	180	189	180	181	185	188
End	175	175	173	176	180	178

TABLE B-27. - Valve train inspection data - before and after test GM-292 "A", fuel additive "A" (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	5	5	6	12	49	77
Valve height, inches						
Start	4.930	4.930	4.929	4.929	4.926	4.929
End	4.925	4.926	4.925	4.925	4.922	4.925
Valve tulip diameter, inches						
Start	1.502	1.503	1.502	1.501	1.502	1.501
End	1.502	1.502	1.502	1.501	1.502	1.501
Valve guide diameter, inches						
Start	.3734	.3729	.3733	.3733	.3729	.3735
End	.3742	.3737	.3739	.3740	.3740	.3744
Valve stem diameter, inches						
Start	.3718	.3712	.3712	.3711	.3715	.3716
End	.3714	.3710	.3711	.3711	.3713	.3712
Valve spring height, inches						
Start	1.680	1.686	1.662	1.666	1.684	1.678
End	1.685	1.687	1.667	1.710	1.732	1.755
Valve spring force, normal lbs.						
Start	83	80	82	87	82	81
End	74	73	75	63	61	55
Valve spring force compressed, lbs.						
Start	185	183	181	186	189	186
End	176	177	171	173	179	175

TABLE B-28. - Valve train inspection data - before and after test
John Deere 303, fuel additive "A"

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	6	6	6	7	7	8
Valve height, inches						
Start	5.286	5.272	5.268	5.282	5.271	5.269
End	5.280	5.266	5.262	5.276	5.265	5.262
Valve tulip diameter, inches						
Start	1.773	1.769	1.772	1.772	1.770	1.770
End	1.773	1.769	1.772	1.772	1.770	1.770
Valve guide diameter, inches						
Start	.3744	.3746	.3746	.3746	.3747	.3745
End	.3747	.3749	.3747	.3749	.3749	.3747
Valve stem diameter, inches						
Start	.3716	.3717	.3715	.3713	.3718	.3718
End	.3715	.3713	.3713	.3711	.3717	.3713
Valve spring height, inches						
Start	1.806	1.815	1.815	1.810	1.814	1.811
End	1.810	1.817	1.818	1.812	1.819	1.811
Valve spring force, normal lbs.						
Start	60	59	56	58	58	57
End	56	52	52	53	52	54
Valve spring force compressed, lbs.						
Start	143	140	138	138	141	140
End	138	135	136	137	136	137

TABLE B-28. - Valve train inspection data - before and after test John Deere 303, fuel additive "A" (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	7	6	12	7	8	7
Valve height, inches						
Start	5.305	5.307	5.306	5.306	5.302	5.308
End	5.300	5.303	5.301	5.301	5.297	5.303
Valve tulip diameter, inches						
Start	1.454	1.453	1.456	1.452	1.455	1.452
End	1.454	1.453	1.456	1.452	1.455	1.452
Valve guide diameter, inches						
Start	.3744	.3744	.3745	.3748	.3746	.3744
End	.3747	.3749	.3745	.3749	.3779	.3746
Valve stem diameter, inches						
Start	.3717	.3718	.3718	.3717	.3712	.3715
End	.3714	.3712	.3714	.3714	.3712	.3712
Valve spring height, inches						
Start	1.837	1.835	1.834	1.825	1.834	1.839
End	1.839	1.840	1.841	1.826	1.836	1.841
Valve spring force, normal lbs.						
Start	55	53	54	57	53	54
End	47	50	47	49	47	50
Valve spring force compressed, lbs.						
Start	139	137	139	141	137	139
End	136	137	133	135	134	136

TABLE B-29. - Valve train inspection data - before and after test GM-292 "A", fuel additive "B"

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-1	-2	1	0	-2	1
Valve height, inches						
Start	4.878	4.879	4.879	4.880	4.878	4.880
End	4.878	4.879	4.879	4.880	4.878	4.880
Valve tulip diameter, inches						
Start	1.720	1.719	1.719	1.720	1.721	1.721
End	1.720	1.719	1.719	1.720	1.721	1.719
Valve guide diameter, inches						
Start	.3430	.3429	.3429	.3431	.3430	.3431
End	.3432	.3430	.3430	.3429	.3428	.3431
Valve stem diameter, inches						
Start	.3402	.3402	.3404	.3405	.3406	.3408
End	.3401	.3400	.3403	.3403	.3404	.3406
Valve spring height, inches						
Start	1.685	1.697	1.693	1.680	1.675	1.682
End	1.687	1.698	1.694	1.685	1.680	1.683
Valve spring force, normal lbs.						
Start	81	85	84	83	80	82
End	73	71	71	70	70	71
Valve spring force compressed, lbs.						
Start	186	189	180	185	180	179
End	175	177	173	176	173	173

TABLE B-29. - Valve train inspection data - before and after test GM-292 "A", fuel additive "B" (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	2	13	8	13	109	85
Valve height, inches						
Start	4.927	4.928	4.930	4.928	4.930	4.928
End	4.927	4.928	4.930	4.928	4.930	4.928
Valve tulip diameter, inches						
Start	1.501	1.500	1.500	1.499	1.500	1.500
End	1.501	1.500	1.500	1.499	1.500	1.500
Valve guide diameter, inches						
Start	.3734	.3729	.3730	.3731	.3730	.3729
End	.3736	.3734	.3732	.3735	.3739	.3736
Valve stem diameter, inches						
Start	.3719	.3712	.3711	.3714	.3712	.3714
End	.3717	.3710	.3708	.3711	.3708	.3713
Valve spring height, inches						
Start	1.675	1.680	1.672	1.671	1.669	1.670
End	1.676	1.683	1.674	1.673	1.669	1.671
Valve spring force, normal lbs.						
Start	84	83	82	84	81	80
End	74	73	75	72	71	70
Valve spring force compressed, lbs.						
Start	184	179	183	185	186	179
End	174	169	171	173	172	167

TABLE B-30. - Valve train inspection data - before and after test
John Deere 303, fuel additive "B"

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	2	4	5	4	5	5
Valve height, inches						
Start	5.261	5.259	5.265	5.266	5.265	5.271
End	5.259	5.255	5.260	5.262	5.260	5.266
Valve tulip diameter, inches						
Start	1.770	1.771	1.772	1.772	1.772	1.770
End	1.770	1.771	1.772	1.772	1.772	1.770
Valve guide diameter, inches						
Start	.3744	.3743	.3742	.3744	.3742	.3740
End	.3748	.3748	.3746	.3749	.3750	.3746
Valve stem diameter, inches						
Start	.3718	.3716	.3716	.3716	.3716	.3716
End	.3717	.3715	.3714	.3713	.3713	.3713
Valve spring height, inches						
Start	1.813	1.830	1.825	1.826	1.818	1.812
End	1.822	1.832	1.827	1.830	1.822	1.815
Valve spring force, normal lbs.						
Start	52	55	57	53	53	52
End	48	48	55	49	51	52
Valve spring force compressed, lbs.						
Start	132	141	143	139	137	142
End	132	133	137	133	138	137

TABLE 30.- Valve train inspection data - before and after test John Deere 303, fuel additive "B" (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	33	5	5	5	6	40
Valve height, inches						
Start	5.318	5.313	5.312	5.324	5.313	5.323
End	5.313	5.308	5.308	5.320	5.308	5.322
Valve tulip diameter, inches						
Start	1.455	1.458	1.456	1.457	1.455	1.456
End	1.455	1.458	1.456	1.457	1.455	1.456
Valve guide diameter, inches						
Start	.3745	.3744	.3742	.3742	.3741	.3743
End	.3748	.3748	.3749	.3746	.3745	.3750
Valve stem diameter, inches						
Start	.3715	.3714	.3714	.3713	.3713	.3716
End	.3711	.3710	.3710	.3710	.3712	.3714
Valve spring height, inches						
Start	1.836	1.833	1.832	1.836	1.825	1.833
End	1.866	1.829	1.832	1.832	1.827	1.832
Valve spring force, normal lbs.						
Start	52	54	56	53	55	55
End	41	48	49	47	49	44
Valve spring force compressed, lbs.						
Start	140	140	141	141	140	142
End	132	134	133	132	132	137

TABLE B-31. - Valve train inspection data - before and after test GM-454, fuel additive "B"

	Intake							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	6	6	4	5	5	6	5	6
Valve height, inches								
Start	5.119	5.116	5.112	5.112	5.119	5.117	5.116	5.120
End	5.113	5.110	5.107	5.106	5.113	5.111	5.110	5.114
Valve tulip diameter, inches								
Start	2.068	2.067	2.065	2.065	2.065	2.065	2.063	2.067
End	2.068	2.067	2.065	2.065	2.065	2.065	2.063	2.067
Valve guide diameter, inches								
Start	.3736	.3736	.3733	.3736	.3736	.3736	.3736	.3736
End	.3740	.3738	.3742	.3742	.3738	.3738	.3738	.3740
Valve stem diameter, inches								
Start	.3717	.3717	.3714	.3713	.3714	.3716	.3716	.3715
End	.3711	.3713	.3708	.3707	.3708	.3712	.3711	.3710
Valve spring height, inches								
Start	1.801	1.791	1.803	1.807	1.813	1.796	1.798	1.791
End	1.804	1.797	1.799	1.811	1.819	1.796	1.798	1.815
Valve spring force, normal lbs.								
Start	97	98	98	91	92	94	96	96
End	79	80	79	78	74	81	81	77
Valve spring force compressed, lbs.								
Start	241	232	244	239	245	234	237	235
End	224	220	219	222	225	223	222	222

TABLE B-31. - Valve train inspection data - before and after test GM-454, fuel additive "B" (continued)

	Exhaust							
	1	2	3	4	5	6	7	8
Valve seat angle								
Start	45	45	45	45	45	45	45	45
End	45	45	45	45	45	45	45	45
Valve seat recession, inches/1000	9	5	8	5	5	5	6	6
Valve height, inches								
Start	5.361	5.363	5.363	5.363	5.364	5.364	5.362	5.364
End	5.356	5.358	5.358	5.358	5.359	5.359	5.357	5.359
Valve tulip diameter, inches								
Start	1.720	1.718	1.718	1.719	1.716	1.718	1.720	1.717
End	1.720	1.718	1.718	1.719	1.716	1.718	1.720	1.717
Valve guide diameter, inches								
Start	.3735	.3739	.3740	.3743	.3742	.3739	.3737	.3736
End	.3740	.3748	.3746	.3750	.3750	.3748	.3750	.3743
Valve stem diameter, inches								
Start	.3716	.3711	.3714	.3715	.3713	.3714	.3712	.3711
End	.3710	.3707	.3707	.3709	.3704	.3709	.3707	.3707
Valve spring height, inches								
Start	1.798	1.806	1.807	1.808	1.807	1.799	1.806	1.802
End	1.810	1.812	1.822	1.822	1.814	1.815	1.814	1.815
Valve spring force, normal lbs.								
Start	96	96	92	92	94	97	90	94
End	78	80	74	77	77	76	75	76
Valve spring force compressed, lbs.								
Start	237	245	242	242	244	237	237	238
End	221	230	223	230	226	226	222	227

TABLE B-32. - Valve train inspection data - before and after test GM-292 "A", fuel additive "C"

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	0	-1	0	-1	1	2
Valve height, inches						
Start	4.885	4.880	4.874	4.881	4.879	4.877
End	4.885	4.880	4.874	4.881	4.879	4.877
Valve tulip diameter, inches						
Start	1.721	1.720	1.721	1.720	1.718	1.722
End	1.721	1.720	1.721	1.720	1.718	1.722
Valve guide diameter, inches						
Start	.3432	.3430	.3429	.3429	.3430	.3431
End	.3434	.3430	.3429	.3432	.3432	.3432
Valve stem diameter, inches						
Start	.3408	.3410	.3411	.3411	.3410	.3406
End	.3406	.3405	.3406	.3404	.3407	.3406
Valve spring height, inches						
Start	1.680	1.694	1.692	1.690	1.671	1.688
End	1.684	1.697	1.697	1.694	1.673	1.699
Valve spring force, normal lbs.						
Start	81	82	78	81	82	80
End	73	70	70	71	75	70
Valve spring force compressed, lbs.						
Start	186	186	183	185	179	180
End	178	177	178	178	176	178

TABLE B-32. - Valve train inspection data - before and after test GM-292-A, fuel additive "C" (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	6	12	11	21	44	33
Valve height, inches						
Start	4.925	4.925	4.925	4.924	4.924	4.925
End	4.925	4.925	4.925	4.924	4.924	4.925
Valve tulip diameter, inches						
Start	1.500	1.500	1.499	1.498	1.499	1.500
End	1.500	1.500	1.499	1.498	1.499	1.500
Valve guide diameter, inches						
Start	.3733	.3728	.3730	.3731	.3729	.3733
End	.3744	.3734	.3738	.3756	.3746	.3745
Valve stem diameter, inches						
Start	.3714	.3713	.3710	.3713	.3715	.3713
End	.3712	.3710	.3708	.3712	.3714	.3714
Valve spring height, inches						
Start	1.664	1.657	1.664	1.668	1.655	1.652
End	1.665	1.671	1.665	1.699	1.710	1.691
Valve spring force, normal lbs.						
Start	81	80	80	84	80	81
End	70	70	70	68	56	62
Valve spring force compressed, lbs.						
Start	179	173	179	179	175	173
End	175	169	167	174	168	167

TABLE B-33. - Valve train inspection data - before and after test
John Deere 303, fuel additive "C"

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	2	1	2	1	1	0
Valve height, inches						
Start	5.265	5.270	5.273	5.274	5.270	5.271
End	5.263	5.269	5.271	5.273	5.269	5.271
Valve tulip diameter, inches						
Start	1.770	1.769	1.767	1.769	1.774	1.769
End	1.770	1.769	1.767	1.769	1.774	1.769
Valve guide diameter, inches						
Start	.3745	.3747	.3747	.3748	.3748	.3749
End	.3747	.3749	.3748	.3750	.3751	.3749
Valve stem diameter, inches						
Start	.3714	.3715	.3714	.3714	.3716	.3715
End	.3714	.3713	.3714	.3714	.3715	.3713
Valve spring height, inches						
Start	1.827	1.819	1.815	1.819	1.822	1.818
End	1.827	1.823	1.816	1.817	1.824	1.820
Valve spring force, normal lbs.						
Start	56	59	59	59	58	58
End	52	53	53	54	53	54
Valve spring force compressed, lbs.						
Start	151	152	152	153	152	152
End	145	146	146	147	147	146

TABLE B-33. - Valve train inspection data - before and after test
John Deere 303, fuel additive "C" (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	1	0	0	0	2	1
Valve height, inches						
Start	5.312	5.319	5.288	5.293	5.290	5.289
End	5.311	5.319	5.288	5.293	5.288	5.288
Valve tulip diameter, inches						
Start	1.462	1.457	1.456	1.456	1.458	1.457
End	1.462	1.457	1.456	1.456	1.458	1.457
Valve guide diameter, inches						
Start	.3745	.3745	.3746	.3749	.3750	.3747
End	.3747	.3746	.3747	.3750	.3753	.3747
Valve stem diameter, inches						
Start	.3714	.3712	.3711	.3712	.3711	.3715
End	.3713	.3711	.3710	.3712	.3711	.3712
Valve spring height, inches						
Start	1.835	1.836	1.833	1.828	1.838	1.853
End	1.841	1.838	1.832	1.831	1.840	1.850
Valve spring force, normal lbs.						
Start	55	55	52	56	56	55
End	47	49	47	50	49	49
Valve spring force compressed, lbs.						
Start	149	153	147	147	152	153
End	142	145	140	142	143	145

TABLE B-34. - Valve train inspection data - before and after test GM-292 "B", fuel additive "D"

	Intake					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	-1	-2	-1	-2	-1	-2
Valve height, inches						
Start	4.876	4.880	4.878	4.882	4.883	4.879
End	4.876	4.880	4.878	4.882	4.883	4.879
Valve tulip diameter, inches						
Start	1.719	1.719	1.719	1.719	1.719	1.716
End	1.719	1.719	1.719	1.719	1.719	1.716
Valve guide diameter, inches						
Start	.3428	.3430	.3428	.3428	.3429	.3429
End	.3431	.3435	.3432	.3431	.3435	.3433
Valve stem diameter, inches						
Start	.3409	.3411	.3414	.3413	.3412	.3411
End	.3403	.3402	.3408	.3407	.3405	.3404
Valve spring height, inches						
Start	1.667	1.675	1.680	1.690	1.670	1.667
End	1.673	1.678	1.686	1.694	1.676	1.669
Valve spring force, normal lbs.						
Start	88	83	83	86	83	88
End	74	72	69	68	66	71
Valve spring force compressed, lbs.						
Start	190	188	190	198	185	194
End	176	178	176	180	170	176

TABLE B-34. - Valve train inspection data - before and after test GM-292 "B", fuel additive "D" (continued)

	Exhaust					
	1	2	3	4	5	6
Valve seat angle						
Start	45	45	45	45	45	45
End	45	45	45	45	45	45
Valve seat recession, inches/1000	1	1	0	1	0	0
Valve height, inches						
Start	4.922	4.921	4.922	4.922	4.923	4.923
End	4.921	4.920	4.921	4.921	4.922	4.922
Valve tulip diameter, inches						
Start	1.501	1.499	1.501	1.499	1.501	1.501
End	1.501	1.499	1.501	1.499	1.501	1.501
Valve guide diameter, inches						
Start	.3731	.3732	.3736	.3735	.3732	.3731
End	.3745	.3748	.3759	.3757	.3745	.3739
Valve stem diameter, inches						
Start	.3711	.3710	.3713	.3710	.3713	.3713
End	.3710	.3706	.3710	.3705	.3710	.3710
Valve spring height, inches						
Start	1.655	1.659	1.645	1.656	1.660	1.657
End	1.664	1.664	1.652	1.661	1.660	1.660
Valve spring force, normal lbs.						
Start	85	89	87	87	88	85
End	80	74	80	75	73	70
Valve spring force compressed, lbs.						
Start	181	187	175	185	185	185
End	176	178	176	180	170	176

APPENDIX C

APPENDIX C

TABLE C-1. - Lube oil metals analysis John Deere "B" engine

Test Sequence	Fuel	Hours on Oil	Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum
			Metals, ppm						
1	1.2 gm/gal	100 (1)	128	183	0	5	27	20	0
	lead	100 (2)	128	93	1	2	13	14	1
2	unleaded	100 (1)	97	81	1	3	9	17	0
		100 (2)	73	79	1	1	7	23	0
3	unleaded	100 (1)	68	60	0	4	11	14	0
	repeat	100 (2)	93	86	1	3	11	11	1
		100 (3)	79	96	0	2	7	23	0
	new oil		83	2	0	1	6	2	4

TABLE C-2. - Lube oil metals analysis Farmall "H" engine

Test Sequence	Fuel	Hours on Oil	Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum
			Metals, ppm						
1	1.2 gm/gal	100 (1)	137	38	3	7	17	34	1
	lead	100 (2)	103	38	7	11	6	17	1
2	unleaded	100 (1)	102	36	3	9	12	19	2
		100 (2)	78	40	6	13	7	33	1
	new oil		83	2	0	1	6	2	4

TABLE C-3. - Lube oil metals analysis Ford 8N engine

Test Sequence	Fuel	Hours on Oil	Metals, ppm						
			Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum
1	unleaded	100 (1)	118	69	1	15	51	16	5
		100 (2)	92	48	1	8	12	30	5
	new oil		83	2	0	1	6	2	4

TABLE C-4. - Lube oil metals analysis International Harvester 240 engine

Test Sequence	Fuel	Hours on Oil	Metals, ppm						
			Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum
1	1.2 gm/gal	100 (1)	190	56	1	12	34	102	2
	lead	100 (2)	142	35	3	6	17	68	1
2	unleaded	100 (1)	93	34	1	10	16	27	2
		100 (2)	98	43	2	4	8	30	2
3	unleaded	100 (1)	84	58	1	8	12	42	0
	repeat	100 (2)	74	39	1	12	19	21	0
4	0.10 gm/gal	100 (1)	106	99	0	9	14	29	3
	lead	188 (2)	102	60	0	5	9	20	1
5	unleaded	100 (1)	101	28	0	4	17	18	0
	inserts	100 (2)	84	63	2	4	19	29	3
6	0.10 gm/gal lead	100 (1)	106	55	1	36	16	22	1
	repeat	100 (2)	100	43	0	6	24	19	0
	new oil		83	2	0	1	6	2	4

TABLE C-5. - Lube oil metals analysis GM-292 "A" engine

Test Sequence	Fuel	Hours on Oil	Metals, ppm								
			Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum	Sulfur	Phosphorous
1	1.2 gm/gal lead	100 (1)	104	151	6	8	7	47	7	NA	NA
		100 (2)	111	91	7	6	4	27	7		
2	unleaded	71	91	78	6	4	4	22	7	NA	NA
3	0.10 gm/gal lead	100 (1)	66	73	2	12	2	20	3	NA	NA
		100 (2)	60	84	2	11	4	19	3		
4	fuel additive "A"	64	41	59	1	6	8	500 +	3	3130	1200
5	fuel additive "B"	84	54	65	3	6	8	500 +	5	2810	1240
6	fuel additive "C"	100 (1)	107	52	2	6	8	39	3	2350	4400
		100 (2)	78	36	1	4	10	29	3	2670	4490
7	0.10 gm/gal repeat	100 (1)	90	44	1	4	14	27	3	NA	NA
		100 (2)	89	46	1	5	10	29	4		
	new oil		69	1	1	0	6	1	4	4100	1020

TABLE C-6. - Lube oil metals analysis GM-292 "B" engine

Test Sequence	Fuel	Hours on Oil	Metals, ppm								
			Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum	Sulfur	Phosphorous
1	unleaded induction hardened	100 (1)	111	55	2	3	10	26	2	NA	NA
		100 (2)	91	41	1	4	7	30	4		
2	unleaded modified cycle	88	83	41	0	4	14	20	2	NA	NA
3	0.10 gm/gal lead	100 (1)	80	47	0	3	13	30	2	NA	NA
		100 (2)	80	48	0	3	10	26	2		
4	fuel additive "D"	100 (1)	89	110	5	4	20	382	10	8270	910
		100 (2)	82	73	2	2	9	921	4	5510	1050
	new oil		69	1	1	0	6	1	4	4100	1020

TABLE C-7. - Lube oil metals analysis John Deere 303 engine

Test Sequence	Fuel	Hours on Oil	Metals, ppm Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum	Sulfur	Phosphorous
1	1.2 gm/gal lead	100 (1)	227	46	2	19	22	46	10	NA	NA
		100 (2)	168	61	5	18	11	28	10		
2	unleaded	100 (1)	101	46	2	8	9	33	6	NA	NA
		100 (2)	84	70	6	12	11	27	9		
3	0.10 gm/gal lead	100 (1)	122	32	1	3	9	26	3	NA	NA
		100 (2)	118	17	3	2	9	21	2		
4	fuel additive "A"	80	135	32	0	8	16	588	3	3260	1960
5	fuel additive "B"	100 (1)	137	32	1	7	20	574	4	2790	2170
		100 (2)	77	33	2	14	17	393	5	2770	2210
6	fuel additive "C"	48	151	58	1	47	24	320	3	2310	4480
	new oil		83	2	0	1	6	2	4	3190	940

TABLE C-8. - Lube oil metals analysis GM-454 engine

Test Sequence	Fuel	Hours on Oil	Metals, ppm Copper	Iron	Chrome	Aluminum	Silica	Sodium	Molybdenum	Sulfur	Phosphorous
1	1.2 gm/gal lead	100 (1)	80	199	13	20	22	30	6	NA	NA
		100 (2)	96	79	7	3	12	22	7		
2	unleaded	100 (1)	76	80	6	-	12	25	6	NA	NA
		100 (2)	70	92	7	3	8	28	6		
3	0.10 gm/gal lead	100 (1)	53	51	0	6	16	23	3	NA	NA
		100 (2)	59	32	1	4	7	33	3		
4	fule additive "B"	100 (1)	67	105	5	10	46	613	15	3330	2271
		100 (2)	67	103	6	10	45	737	15	2265	1059
5	unleaded inserts	100 (1)	109	81	7	38	32	37	9	NA	NA
		100 (2)	86	70	5	22	17	25	6		
	new oil		69	[illegible]	1	0	6	1	4	4100	1029

APPENDIX 2

Commenters at Public Hearing in Washington, D.C., June 1, 1987

Ed Senn, Congressman Tom Tauke's Office

Dennis Stolte, American Farm Bureau Federation

Walter R. Haessner, International Society for VEHICLE Preservation

Ralph H. Hemphill, Crown Central Petroleum Corporation

Jerry H. Gass, Southern States Cooperative

Roger Moser, Ethyl Corporation

Dennis Moran, Ethyl Corporation, Research Department

Robert Tupa, Lubrizol Corporation

Bob Pinder, Interject Corporation

Don Young, TK-7 Corporation

Moshe Tal, TK-7 Corporation

Mark Nelson, Polar Molecular Corporation

Franklin G. Reick, Floramics, Inc.

James Lewis, United Parcel Service

Commenters at Public Hearing in Indianapolis, IN, June 4, 1987

Lt. Governor, John Mutz, State of Indiana

Lane Ralph, Senator Dan Quayle's Office

Joe Russell, President, Indiana Farm Bureau, Inc.

Thomas Daugherty, Indiana Vocational Agricultural Teacher's Association

John Stern, Vice-President, Indiana Farm Bureau Cooperative Association, Inc.

Dean Eppley, Indiana Corn Growers Association

Indianapolis, IN, June 4, 1987 (Continued)

Ray M. Lien, Purdue University

Alice Huffman, Chairman, Indiana Women Involve in Farm Economics (WIFE)

Charles Hudson, Navistar International

Gary Strong, Winsert, Inc.

Charles W. Fluharty, Indiana Beef Cattle Association

Robert Tupa, Lubrizol Corporation

James Larson, Polar Molecular Corporation

Mr. Young, TK-7 Corporation

Robert Kiger, Farmer

Orville Borcherding, President, Jackson County Farm Bureau, Inc.

Dennis Riggs, Champaign County Farm Bureau

Walter R. Haessner, International Society for VEHICLE Preservation

Douglas Pond, Indiana Department of Commerce

Commenters at Public Hearing in Des Moines, Iowa, June 9, 1987

Stan Nielsen, National Council of Farmer Cooperatives

Walter R. Haessner, International Society for VEHICLE Preservation

Carl Hutter, E.I. DuPont de Nemours and Company

John McChesney, Ethyl Corporation

Robert Tupa, Lubrizol Corporation

Charles Worman, Coastal Corporation

APPENDIX 2 (Continued)

Written Commenters

(other than private vehicle owners)

Lubrizol Corporation

Harley Davidson, Inc.

Marathon Petroleum Company

Polar Molecular Corporation

Walter Haessner, Internation Society for Vehicle Preservation

Sun Refining and Marketing Company

University of Maine Cooperative Extension Service

Polk County, State of Oregon

Idaho Grain Producers Association

Women Involved in Farm Economics (WIFE)

American Petroleum Institute

Iowa Department of Agriculture

E.I. DuPont de Nemours and Company

Union Oil Company of California

Department of the Air Force

Illinois Farm Bureau

APPENDIX 3

United States Department of Agriculture
Office of Energy
Washington, D.C. 20250

June 19, 1987

Mr. Richard D. Wilson
Director
Office of Mobile Sources
Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Dear Dick:

The U.S. Department of Agriculture (USDA) appreciated having the opportunity to work with the Environmental Protection Agency (EPA) on the impacts of using low-lead and unleaded gasoline and non-lead substitute additives in agricultural equipment designed to use leaded gasoline. We especially want to commend Richard Kozlowski, John Garbak, Hugh Pitcher, and Jim Caldwell for their efforts on this project. They are highly competent individuals and it has been a pleasure to work with them. We readily resolved differences of opinion as they arose and enjoyed an excellent working relationship. We also very much appreciate your support and leadership on this issue.

We have reviewed the findings of the EPA-USDA study and the testimony received during the three EPA hearings. A summary of our observations of the EPA hearings is enclosed.

It is clear that hundreds of thousands of farm engines would face the threat of significant damage resulting in large economic losses to farmers if leaded gasoline was no longer available. Non-lead additives have not yet proven to be a satisfactory substitute for lead. Therefore, USDA urges that EPA:

1. Not ban sales of leaded gasoline;

2. Take steps necessary to assure that companies continue to sell leaded gasoline in the farming communities;

3. Limit the minimum amount of lead that may be contained in every gallon of leaded gasoline sold at retail. We recommend a range of 0.1-0.15 grams of tetraethyl lead per gallon of gasoline; and

4. Continue testing non-lead additives or work with USDA, the American Farm Bureau Federation, the National Council of Farmer Cooperatives and other interested parties to establish an acceptable procedure for additive manufacturers to demonstrate the overall efficacy of their products for use in agricultural equipment.

For its part, USDA also will expand its efforts through the Extension Service and other means to inform farmers about this issue and help them identify and minimize risks of using low-lead and unleaded gasoline and non-lead additives.

Our joint efforts to date have defined the problem but have not identified the best solutions. The Office of Energy is prepared to continue working with EPA toward this end, including assistance in preparing EPA's report to Congress, further assessing impacts of unleaded gasoline on agriculture and assessing the efficacy of non-lead substitute additives.

Sincerely,

EARLE E. GAVETT, Director

1 Enclosure

cc Ewen Wilson

Observations Based on EPA Hearings on Leaded Gasoline for Farm Equipment

1. General consensus of witnesses was that unleaded gasoline will result in substantial damage to agricultural engines. The findings of the EPA-USDA study are sound.

2. 0.1 gram of lead per gallon of gasoline is the absolute minimum needed. Many witnesses believe that larger concentrations of lead are needed under certain circumstances. 0.2 grams or more are needed to protect all farm engines.

3. EPA should not ban sales of leaded gasoline and should take steps to help assure that leaded gasoline will continue to be available.

4. Some gasoline being marketed as leaded actually contains little or no lead. 0.1 grams per gallon should be the minimum that can be sold.

5. Independent oil companies and farmer cooperatives will continue to sell leaded gasoline as long as there is a large enough market. If leaded gasoline should cease to be available from pipelines, it probably will disappear from the market.

6. Technically, it would be possible to inject lead into gasoline at terminals but economic considerations will determine whether this is done.

7. Lead additives should not and will not be available in consumer size containers.

8. The need for leaded gasoline or a non-lead substitute extends beyond agriculture and includes recreational vehicles and fleet trucks.

9. USDA should work with farmers to help them identify and minimize risks of using low-lead and unleaded gasoline.

10. Cylinder head repairs are expensive; about $500-$1,500 per engine.

11. Lubrizol's "Powershield" may stop wear at high concentrations but questions remain unanswered about the concentration actually needed and the implications of combustion chamber deposits and lubricating oil modifications caused by the additive.

12. No other additives have demonstrated effectiveness and engine compatability.

13. Further study is needed to address questions about:
    - -Vulnerability of engines not tested.
    - -Effects under actual field conditions.
    - -Costs of leaded gasoline if blended at terminals, and/or if made with aviation gasoline.
    - -Cost and suitability of non-lead additives.

APPENDIX 4

Additive Manufacturers

The following is a list of Additive Manufacturers/Distributors that have developed a product which, they feel, will take care of the valve lubrication problem associated with some engines designed for leaded gasoline if operated on unleaded gasoline.

Manufacturer

1. Lubrizol Corporation
   29400 Lakeland Blvd.
   Wickliffe, OH 44092
   (216) 943-4200
   Lubrizol 8164

2. E.I. duPont de Nemours & Co., Inc.
   Specialty Chemicals Div.
   Wilmington, DE 19898
   (609) 540-2618
   DMA-4

3. Polar Molecular Corporation
   Vanguard Building
   Suite 303
   4901 Towne Centre Road
   Saginaw, MI 48604
   (517) 790-4764
   PMFC Fuel Compound

4. Phillips Petroleum Company
   Bartlesville, OK 74004
   (918) 661-3633
   Phillips EVAA 100

5. TK-7 Corporation
   1300 N.E., 4th Street
   Oklahoma City, OK 73117
   (405) 239-2212
   "S" Super Octane Booster

6. Reaction Laboratories, Inc.
   P.O. Box 343
   5335 River Road
   Tonawanda, NY 14150
   (716) 875-4105
   K-100-G

7. EPHCO, Inc.
   3432 West Juniper Ave.
   Phoenix, AZ 85023
   (602) 942-2442
   Fens 521

8. Fluoramics, Inc.
   103-105 Pleasant Ave.
   Upper Saddle River, NJ 07458
   (201) 825-8110
   TUFOIL

9. Sta-Safe Mfg., Inc.
   22102 Goldstone
   Katy, TX 77450
   (713) 392-0696
   Lead-Plus

10. Formula IV Corporation
    14415 N. 73rd Street
    Suite 107
    Scottsdale, AZ 85260
    (602) 951-2409
    Magna IV F-34 Gas Fuel Blending Agent

11. Mr. Gasket
    8700 Brookpark Road
    Cleveland, OH 44129
    (216) 398-8300
    Performance Lab Octane Fuel Lead

12. Lubri-Gas
    P.O. Box 429
    Fraser, MI 48026
    (313) 823-3700
    Lubri-Gas

13. Restoration Products
    P.O. Box 50046
    Tucson, AZ 85703
    (602) 624-8786
    EVA-A, EVA-L

14. B-T Energy Corporation
15700 Dixie Highway
Louisville, KY 40272
(502) 937-1700
Power LUB 4001, 4002, 4003, 4004
Power LUB 1001, 1002, 1003, 1004

15. GNC Energy Corporation
15700 Dixie Highway
Louisville, KY 40272
(502) 937-1700
Power LUB 2001, 2002, 2003, 2004, 4006, 2007, 4008, 4009

16. Sta-Lube, Inc.
3039 Ana Street
P.O. Box 5746
Rancho Dominguez, CA 90224-5746
(213) 537-5605
SIM-U-LEAD

17. A.I.M.S. Manufacturing
P.O. Box 23700
Ft. Lauderdale, FL 33307-3700
(305) 493-9492
Pro-Lead

18. Texas Refinery Corporation
P.O. Box 711
Ft. Worth, TX 76101
(817) 332-1161
TRC Valve Cushion Fuel Stabilizer

19. Primrose Oil Company, Inc.
P.O. Box 29665
Dallas, TX 75229
(214) 241-1100
Valve Gard

20. Gold Eagle Company
4400 South Kildare
Chicago, IL 60632
(312) 376-4400
Quantum lead
Quantum Valve Saver Formula

21. Marine Development and Research Corp.
116 Church Street
Freeport, NY 11520
(516) 546-1162
MDR Relead

22. Castle Products, Inc.
235 Surrey Run
Williamsville, NY 14221
(716) 631-5216
LS + (Lead Substitute Plus)

23. Royal Lubricants, Inc.
1304 Argentine Blvd.
Kansas City, KS 66105
(913) 321-9022
Royal's "No Lead"

24. Red Line Synthetic Oil Corp.
3450 Pacheco Blvd.
Martinez, CA 94553
(415) 228-7576
SI-2 Fuel Conditioner
Red Line Lead Substitute

25. Bell Fuels, Inc.
4116 W. Peterson Ave.
Chicago, IL 60646
(312) 286-0200
VALV-TECH Gasoline Additive

26. A.R. Industries
7118 Canby Unit D
Reseda, CA 91335
(818) 344-1739
Valvmax

27. Cartel Products, Inc.
3133 Madison, S.E.
Grand Rapids, MI 49508
(616) 243-0457
Cartel L.E.D.

28. B.G. Products, Inc.
701 S. Wichita
Wichita, KS 67213
(316) 265-2686
Val Save PN 205

29. Farmers Union Central
Exchange, Inc.
P.O. Box 64087
St. Paul, MN 55164-0089
(612) 451-5151
X-10

30. Archer Petroleum,
Witco Corporation
6196 North 16th Street
Omaha, NB 68110
GTA

31. Gromark, Inc.
1701 Towanda Avenue
Bloomington, IL
61702-2500
(309) 557-2410
FS Valve-Save Gasoline
Additive

32. Lubrimatic Division of
Witco Corp.
P.O. Box 1974
Olathe, KS 66061
Valve Care

33. Kendall/Amalie Division
of Witco Corp.
77 North Kendall Avenue
Bradford, PA 16701
(814) 368-6111
SD 854 1070
SD 854 1080
SD 854 1090

34. Moroso Performance Products
80 Carter Drive
Guilford, CT 06437
(203) 453-6571
Octane Booster II

35. FPPF Chemical Co., Inc.
117 W. Tupper Street
Buffalo, NY 14201
(716) 856-9607
BVP

36. Materials and Process
Research
Post Office Box 527
Canoga Park, CA 91305
(818) 709-4222
MPR-5

37. Sullivan Chemical Co., Inc.
P.O. Box 20177
Long Beach, CA 90801
(213) 435-2332
Preserve

38. Wynn Oil Company
P.O. Box 4370
Fullerton, CA 92634
(818) 334-0231
Wynn's Valve-Guard Anti-
Valve Recession Additive
X-Tend Concentrated Lead
Substitute

39. Unocal Refining and
Marketing Division
Union Oil Company of Calif.
1201 W. 5th Street
Los Angeles, CA 90017
(213) 977-7831
Unocal Valve Saver

40. K & W Products
P.O. Box 231
Whittier, CA 90608
(213) 693-8228
K & W Equa-Lead

41. B & M Specialty, Inc.
Rt. 13, Box 1095
Hattiesburg, MS 39401
(601) 264-6145
Octane Booster

42. Philco International, Inc.
8931 Gulf Freeway
Houston, TX 77017
(713) 946-1500
Engine Life Extender

43. Octane Boost Corporation
222 Town East Blvd., South
Mesquite, TX 75149
(214) 289-0632
104 + Real Lead

44. Berryman Products, Inc.
3800 E. Randol Mill Road
Arlington, TX 76011
(817) 640-2376
Valve Shield

45. Nationwide Industries
501 S. Basinger Road
Pandora, OH 45877
(419) 384-3241
Snap Plus Lead Substitute

46. Radiator Specialty Company
P.O. Box 34689
Charlotte, NC 28234
(704) 377-6555
Lead Substitute

47. Motor Chemical, Inc.
100 Sixth Ave.
Paterson, NJ 07524
(201) 278-0200
Jetgo Lead Substitute
"Likelead"

48. South Bay Oil Company
7734 Alondra Blvd.
Paramount, CA 90723
(213) 633-3224
Best Octane Plus, PJ
Octane Booster

49. Bell Chemical Company
411 North Wolcott Ave.
Chicago, IL 60622
(312) 733-5960
Flare Power Shield Gas
Additive

50. Universal Cooperatives, Incorporated
111 Glamorgan Street
Alliance, OH 44601
(619) 854-0800
Co-op Power Shield Gas Additive

51. USA-1 Products, Inc.
1410 - 7th Avenue, S.E.
Decatur, AL 35601
(205) 350-7724
USA-1 106 + Marine Booster

52. McKay Manufacturing
1920 Randolf Street
Los Angeles, CA 90001
(213) 582-7477
#112 McKay's Lead Substitute
#112 Mechanics Lead Substitute

53. Barden, Inc.
P.O. Box 629, Ford and Washington Streets
Norristown, PA 19404
(215) 278-2400
"No. 7" Valve Protector and Lubricant

54. Atlas Supply Company
11 Diamond Road
Springfield, NJ 07081
(201) 379-6550
Atlas Power Shield Gas Additive Product 264

55. Intercontinental Lubricants Corp.
Rt. 7, P.O. Box 208
Brookfield, CT 06804
(203) 775-1291
Valve Guard

56. Petro Blend
4334 E. Washington Blvd.
Los Angeles, CA 90023
(818) 365-9824
Petroblend Valve Guard

57. Chemical Fuels Corporation
1954 Airport Road
Suite 251
Chamblee, GA 30341
(404) 451-0411
Leaded Lyte
Leaded Lyte 2
Leaded Lyte 3

58. Mac's Division, Ashland Oil, Inc.
P.O. Box 391
Ashland, Kentucky 41114
(606) 329-5601
Mac's Lead Additive Substitute #5900

59. Brooklake Products
8900 Huff Ave. N.E.
Brooks, Oregon 97303
(503) 390-2150
Plus 2 Lead Substitute

60. X-Laboratories, Inc.
440 Denniston Ct.
Wheeling, IL 60090
(312) 459-5020
Super-X 305 Lead Replacement Additive

61. Penray Company
440 Denniston Court
Wheeling, IL 60090
(312) 459-5000
Penray 2512 Super Tech Lead Substitute

62. E-Zoil Products, Inc.
2355 Bailey Avenue
Buffalo, NY 14215
(716) 895-8494
Safe-T-Valve

63. Hydrotex, Inc.
P.O. Box 560707
Dallas, TX 75356-0707
(214) 638-7400
HTX-200 Valve Saver
Gasoline Lead Substitute

64. CRC Chemicals
885 Louis Dr.
Warminster PA 18974
(215) 674-4300
Siloo Valve Protector

65. Midwest Polychem, Ltd.
1502 N. 25th Ave.
Melrose Park, IL 60160
(312) 450-0100
Polyguard No Lead Substitute

66. Bagan Enterprises, Inc.
3500 Galt Ocean Drive
Suite 2403
Ft. Lauderdale, FL 33308
(305) 537-7910
SECUR - PAS/OB-2

67. Leadfoot
North American Oil Company
1806 Marietta Blvd N.W.
Atlanta, GA 30318

68. E.I. DuPont de Nemours & Co., Inc.
C&P Department
1007 Market Street
Wilmington, DE 19898
Valve Master

69. AMREP, Inc.
945 E. Pleasant Run Road
Lancaster, Texas 75146
(214) 227-3304
RLG - 999-419

70. Correlated Products, Inc.
5616 Progress Road
Indianapolis, Indiana 46241
Pro-Tec 95

71. PME, Inc.
P.O. Box 658
Cabot, AR 72023
(501) 843-3573
Valve Gard

72. Gulf Oil Division of Cumberland Farms
165 Flanders Road
Westboro, MA 01581-5006
(617) 366-4445
Cruisemaster/Gulf D.O.L.

73. Sun Products Company, Inc.
6831 N.W. 20th Ave.
Ft. Lauderdale, FL 33309
(305) 977-0468
Fire Power

74. Country Mark, Inc.
4565 Columbus Pike
P.O. Box 1206
Deleware, Ohio 43015
(614) 584-8200
RAMGUARD

75. Pyroil Company, Division of
Champion Labs.
P.O. Box 40
Albion, IL 62806
(618) 445-6011
Lead Substitute

76. Unifide Universal, Inc.
70 Hawthorne Ave.
Newark, NJ 07112
(201) 824-5615
Unifide Lead Substitute

77. Lilyblad Petroleum, Inc.
2244 Port of Tocama Rd.
P.O. Box 1556
Tocoma, WA 98401
(206) 572-4402

78. The American Lubricants Co.
1227 Deeds Ave.
Dayton, OH 45404
(513) 222-2851
Valve-eze

79. GRC Company
P.O. Box 626
Memphis, TN 38101
(501) 735-1442
GRC Instead of Lead

80. U.S. Aviex Company
1800 Terminal Road
P.O. Box 340
Niles, MI 49102
(616) 683-6767
Aviex Nu Lead

81. Valvetect Petroleum Products Corp.
3400 Dundee Road
Northbrook, IL 60062
(312) 272-2278
VALVTECT Lead Substitute - (c)oncentrate
VALVTECT Lead Substitute - (d)ilute

82. Index Industries
835 Chicago Dr. S.W.
Grand Rapids, MI 49509
(616) 245-6665
VSP

83. Protech Oil and Chemical
412 W. 700 South
Orem, Utah 84058
(801) 225-2214
Tom McCanns' Lead Octane Booster
Tom McCanns' Lead

84. Mohawk Labs
2730 Carl Road
Irving, TX 75062
(214) 438-0486
MILE HI LG

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