ETHYL CORPORATION
RESEARCH AND ENGINEERING DEPARTMENT
RESEARCH LABORATORIES • 1600 WEST EIGHT MILE ROAD
FERNDALE 20, DETROIT, MICHIGAN

May 18, 1955

Dr. R. A. Kehoe
University of Cincinnati
College of Medicine
Eden Avenue
Cincinnati 19, Ohio

Dear Bob:

I am looking forward to seeing you in Cincinnati early Tuesday morning, May 23.

One of the things I would like to talk about would be a four page report, RM-143, on the social significance of higher TEL concentrations which is an abstract of a much more comprehensive report now under preparation.

Enclosed is a copy of the report. If you could find time to glance over it before I see you, maybe we could talk more constructively.

Best regards,

Very truly yours,

W. G. Lovell

WGL:deb

Encl.

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Project 8U5-M
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Research Memorandum 143

ETHYL CORPORATION, RESEARCH LABORATORIES

Automotive Products Research

NATIONAL ECONOMIC ADVANTAGES IN THE USE OF HIGHER CONCENTRATIONS OF TEL

Report by: D. A. Hirschler

Date: May 18, 1955

Summary

Trends over the past twenty-five years indicate that the refining industry will continue to increase the octane number of marketed gasolines, and that these increases will be utilized quickly by car manufacturers in raising engine compression ratios to improve engine efficiency.

An increase in the maximum allowable TEL concentration from 3 to 4 ml/gallon, with a corresponding increase in average actual TEL concentrations from 2.23 ml/gallon at present to 3.23 ml/gallon, would lead to an increase of about 1.9 in the Research octane number of average gasoline. If this increase were to be accomplished by refinery operation rather than by the use of additional TEL, the production of the same amount of gasoline would require about 2% more crude oil.

An increase of 1.9 octane number in the rating of commercially-available gasolines would be expected to lead to an average increase in engine compression ratio of 0.3 ratio. This in turn would be expected to reduce by from 3 to 5 percent the amount of gasoline now required to do the same work at the lower compression ratio.

If the possible gains in car efficiency are combined with reduced refinery losses, an increase in maximum allowable TEL concentration from 3 to 4 ml/gallon could be expected to reduce by 5 to 7% the amount of crude petroleum required to produce the same work as that now being done by present gasolines at prevailing octane numbers and TEL concentrations.

Introduction

Several factors are important to consider in the possible use of TEL at a maximum concentration of 4 ml per gallon rather than at the present 3 ml level. One of these factors is the problem of whether such a change would be of economic advantage of the nation as a whole. This memo presents some preliminary calculations which have been made in this connection. First, the effect of using refinery processes rather than increased concentrations of TEL to produce an equivalent octane number increase has been considered from the standpoint of the amount of gasoline obtainable from a barrel of crude oil. Secondly, an estimate has been made of the effect of higher octane number fuel (achieved either by refining methods or by additional TEL) on the amount of fuel required to produce the same amount of useful work as is now provided by gasolines of the present octane number level.

Present Use of TEL

Over the past twenty-five years the octane number of commercial gasolines has increased at quite a uniform rate. Since 1930 the Research octane number of average regular-grade gasoline has increased from 63 to 87. During the same time TEL has been used in greater concentrations, and at the present time is used in 99% of motor gasoline at an average concentration of 2.23 ml/gallon. TEL is used in all aviation gasoline, and during the war was used at a concentration of 4.6 ml/gallon as an emergency measure to increase the available supply of aviation gasoline. Many refiners now are using TEL concentrations near the 3.0 ml level and in 1954, 23% of all U.S. gasoline contained 2.75 ml or more TEL. Other refiners, however, who are able to meet octane number competition with somewhat lower TEL concentrations prefer to do so, in order to leave a cushion below the 3.0 ml level to take care of variations in refinery operation. Because of this, the average concentration of TEL which is used will always be somewhat below the upper regulatory limit.

The use of TEL in increasing amounts has come about because it provides increased antiknock quality cheaper (or with less total labor) than can be done by more extensive refinery cracking processes. Furthermore, the more severe refinery processes which are now used to increase antiknock quality above present levels also suffer from loss of product and produce less gasoline per barrel of crude oil. Because of this, the use of TEL results fundamentally in a conservation of our national petroleum resources.

Another factor in the conservation of petroleum is antiknock quality. This is because higher antiknock quality permits the use of higher compression ratios in engines, and this in turn results in an improvement in engine thermodynamic efficiency which is greater than the decrease in yield per barrel of crude which accompanies refining to higher octane number levels. The use of TEL in raising antiknock quality obviously has its place also in this aspect of the efficient utilization of petroleum.

Higher TEL Concentrations as a Means of Preventing Loss in Refinery Yields

In 1954 the average commercial gasoline produced in the United States contained 2.23 ml TEL/gallon and had a research octane number of 89.3. Had 3.23 ml TEL been used in this fuel the octane number would have been increased to 91.2, and at a 4.0 ml TEL level the octane number would have reached 92.2. Therefore an increase in allowable TEL concentration from 3 to 4 ml and in increase in actual average usage from 2.23 ml to 3.23 ml represents a potential gain of 1.9 octane numbers. The trend in gasoline octane numbers over the last twenty-five years, shown in Figure 1, indicates that an octane number increase of this size over present levels can be expected to occur within the next two years.

This 1.9 octane number increase could be accomplished either by additional TEL with the same yield of gasoline, or by more severe refining methods at reduced yield. An estimate of the magnitude of this loss in yield with more severe refining methods can be obtained from Figure 2, which illustrates the relationship between yields and octane number for optimum refinery design as developed by W. M. Holaday of Socony Vacuum (Reference 1). This figure shows that in refining for a 91.2 research octane number fuel, 56.8% of the crude oil might be expected to be converted to gasoline, but that in refining for fuel 1.9 octane numbers lower, a yield of 58% might be expected. In other words, 2.1% more crude oil, equivalent to one week of production each year, would be required to produce the same amount of gasoline at the higher octane number level, and this loss would be eliminated if the octane number increase were accomplished by the use of 1.0 ml of additional TEL instead. The magnitude of the loss calculated in this way is quite conservative, since actual refineries are now less efficient than the ideal refineries used to develop the relationship in Figure 2. This is shown by the actual average yield of gasoline from crude oil, which in 1953 was 44.2% rather than the 58% value shown in Figure 2. If this actual value of yield is used for this comparison, the increase in crude oil required to produce the higher octane number fuel would be raised to nearly 2.8%.

The relative cost comparison between the use of higher TEL concentrations and additional refining operations for increased octane number is quite complex and varies considerably among different refiners depending on their installed equipment and their available capital for refinery improvements. However, Mr. T. W. Warren, Head of our Refinery Technology Group, has estimated that a large part of the industry would find the use of TEL cheaper and would achieve a saving in costs as well as in higher gasoline yields.

Higher Octane Numbers as a Means of Increasing the Usable Energy from Gasoline

Higher octane numbers by themselves do not increase the available energy in gasoline. Their desirability lies in the fact that they permit the use of more efficient engines which can convert more of the heat energy in gasoline to useful work. This is possible because the elimination of knock permits the use of higher compression ratios and allows the thermodynamic gains which result from greater compression and greater expansion of the gas in the engine cylinder to be realized.

An examination of the trends in octane numbers and engine compression ratios over the past twenty-five years, plotted in Figures 1 and 3, shows that engine manufacturers have been quick to build more efficient engines as better fuels became available. Similarly, the efficiency of cars as measured by the number of miles one ton can be moved by one gallon of gasoline, has increased correspondingly. Current competition among car manufacturers implies that they would be even more rapid to take advantage of better fuels today.

The data plotted in Figure 3 show that the octane number requirement of a laboratory engine operated at different compression ratios can be used to predict the change in average car compression ratio which will accompany the availability of better fuels. Both these laboratory engine data and an estimate based on past trends would predict that the 1.9 octane number increase obtainable from 1.0 ml of additional TEL would increase average compression ratios by 0.3 ratio, which would raise the average from the 8.0:1 of today to 8.3:1.

There are several ways to approximate the increase in car efficiency which would accompany this change in compression ratio. If we consider the engine alone, laboratory data have shown that 28.2% of the fuel heat can be converted to available work by an engine at 8.0:1, but 28.5% of the fuel heat can be converted to work at 8.3:1. This would result in a 1.0% increase in fuel economy at the same power output. If we go further and consider the work available at the rear wheels, this value would represent only a minimum figure, since under many conditions much of the engine work goes into overcoming friction in the tires and the driving mechanisms, and this portion is constant regardless of engine performance. Because of this, it follows that a small percentage change at the engine can represent a much larger percentage in terms of the work which finally arrives at the rear wheels and drives the car. Because of this it might be more accurate to look at the changes in the average efficiency of automobiles which have taken place since 1930 and accompanied the progressive increases in compression ratio. These data, in Figures 1 and 4, were compiled by C. L. McCuen of General Motors (Reference 2). Figure 4 shows the number of tons which could be moved one mile by one gallon of gasoline when used in cars of various years at their prevailing compression ratios governed by the fuels available at the time. In addition to the average data from 15 different makes of production cars, the curve also shows two other points which represent the results obtained with 1951 model cars having experimental engines of higher compression ratios. From the curve it can be seen that an increase in compression ratio from 8.0:1 to 8.3:1 (permitted by a 1.9 octane number increase) would be expected to increase the amount of useful work from a gallon of gasoline by 5%. This value is in reasonable agreement with a different analysis made by Holaday (Reference 1), based on laboratory engine data rather than past trends, which showed a corresponding increase of 3.2%. If we accept this lower value in the interests of being conservative and combine it with the 2% saving in petroleum made possible by the use of TEL instead of more severe refinery operations for production of this higher octane number fuel, the sum indicates that the use of 1 ml additional TEL would lower by about 5% the amount of crude oil required to produce the same energy in automobiles as we are now getting from lower octane number fuel at the present TEL concentration level.

To increase fuel octane number either by refinery processing or by the use of TEL increases the cost. One additional ml of TEL would increase gasoline cost by 0.217¢ per gallon, which compared to the national average retail gasoline price of 28.69¢ (in 1953) represents a 0.76% increase. If this cost increase is compared with the efficiency increases of 3 to 5% which may be obtained by use of the more costly fuel, it is clearly apparent why higher octane number fuels costing more per gallon allow the motorist to obtain more miles per dollar.

It is believed that the economic saving due to TEL which this study indicates has been borne out by the progressive increase in compression ratio and use of more TEL over the last twenty-five years. It would appear that the use of even higher concentrations of TEL would still represent an economic advantage to the nation, particularly in respect to the conservation of our petroleum resources.

In recent years the public has been demanding, in passenger cars, both more power and performance as well as more miles per gallon. The public demand for more power could not be met, except at much lower miles per gallon, were it not for increased compression ratio and higher antiknock quality.

References

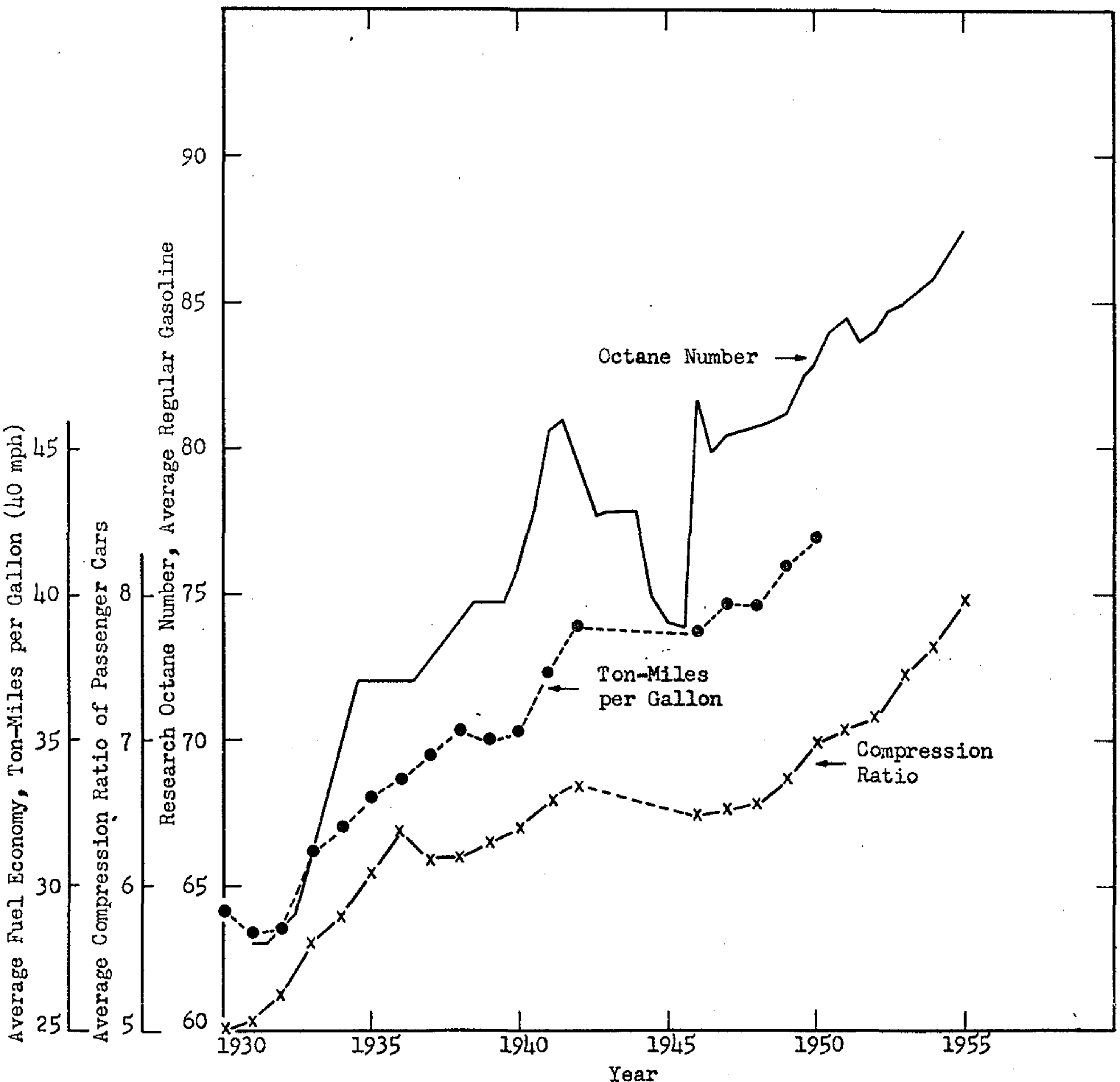
1. Holaday, W. M., Socony-Vacuum Laboratories; "What Can We Get From Higher Octane Number Fuels"; SAE Preprint No. 225, Presented at SAE Annual Meeting, Detroit, Michigan, January 11, 1954.

2. McCuen, C. L., Research Laboratories Division, General Motors Corporation; "Economic Relationship of Engine-Fuel Research"; SAE Quarterly Transactions, Vol. 6, No. 4, 290 (1952).

Figure 1

Trends in Fuel Octane Number and Average Passenger Car Compression Ratio and Fuel Economy

(Fuel economy data from C. L. McCuen, Reference 2)



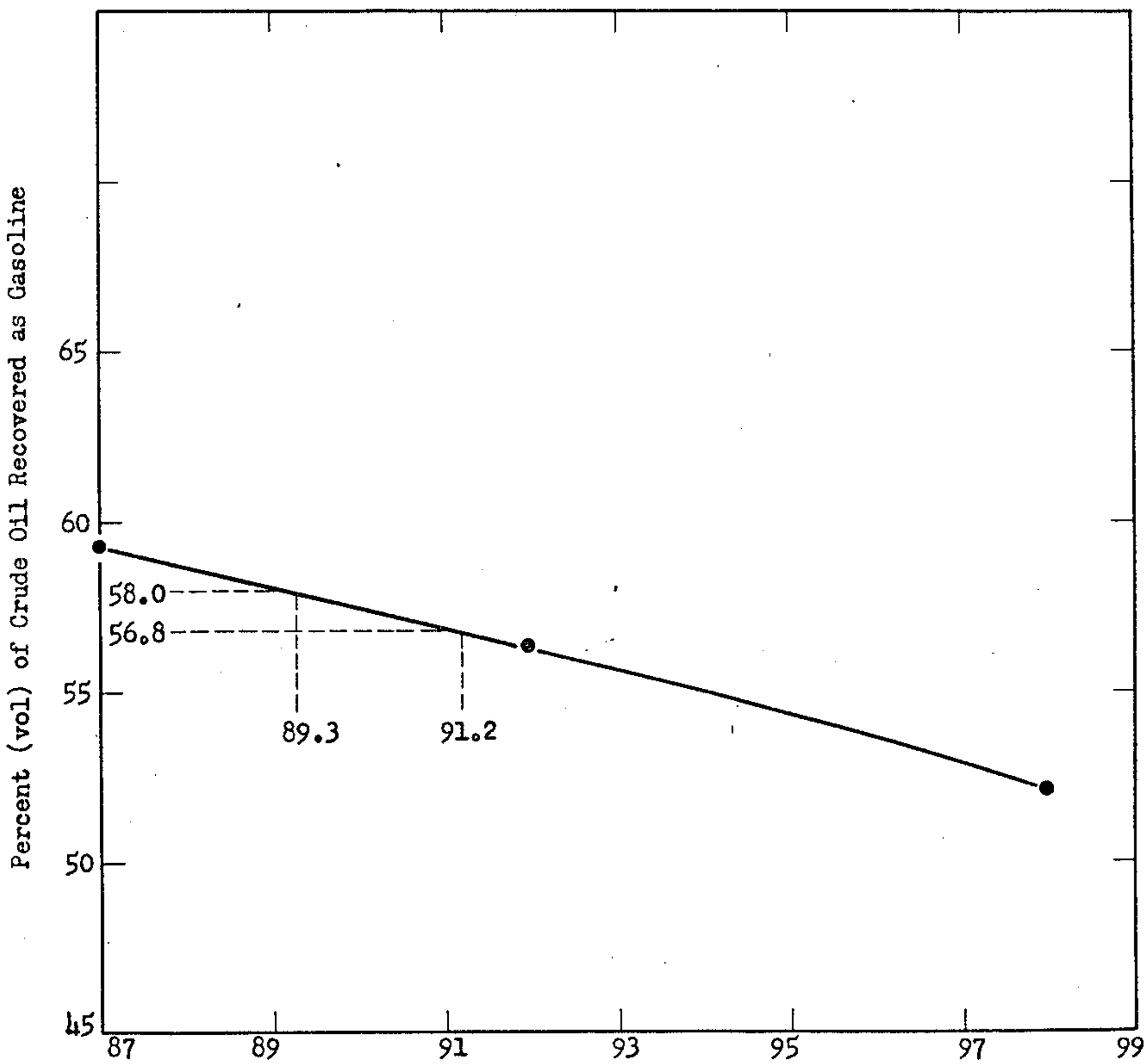
Curve Ref. No. 12350

Prepared by: D. A. Hirschler
Date: 5/12/55

Figure 2

Effect of Octane Number on Gasoline Yield
With Optimum Refining Methods

(Data from W. M. Holaday, Reference 2)



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Prepared by: D. A. Hirsc
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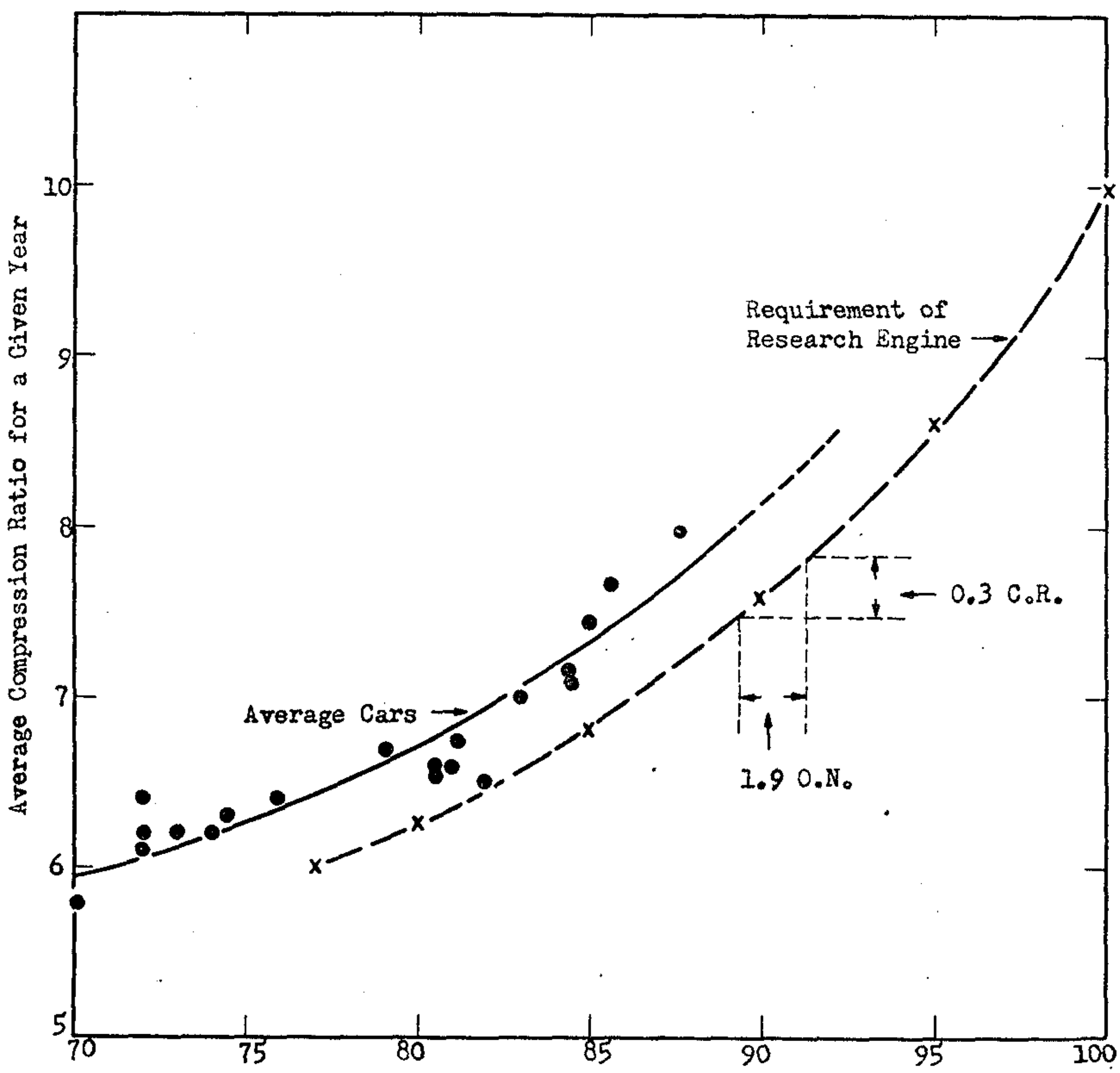
Figure 3

Relationship Between the Average Octane Number
of Prevailing Gasoline and Average Compression
Ratio of Production Cars Between 1930 and 1955



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Prepared by: D. A. Hirschler
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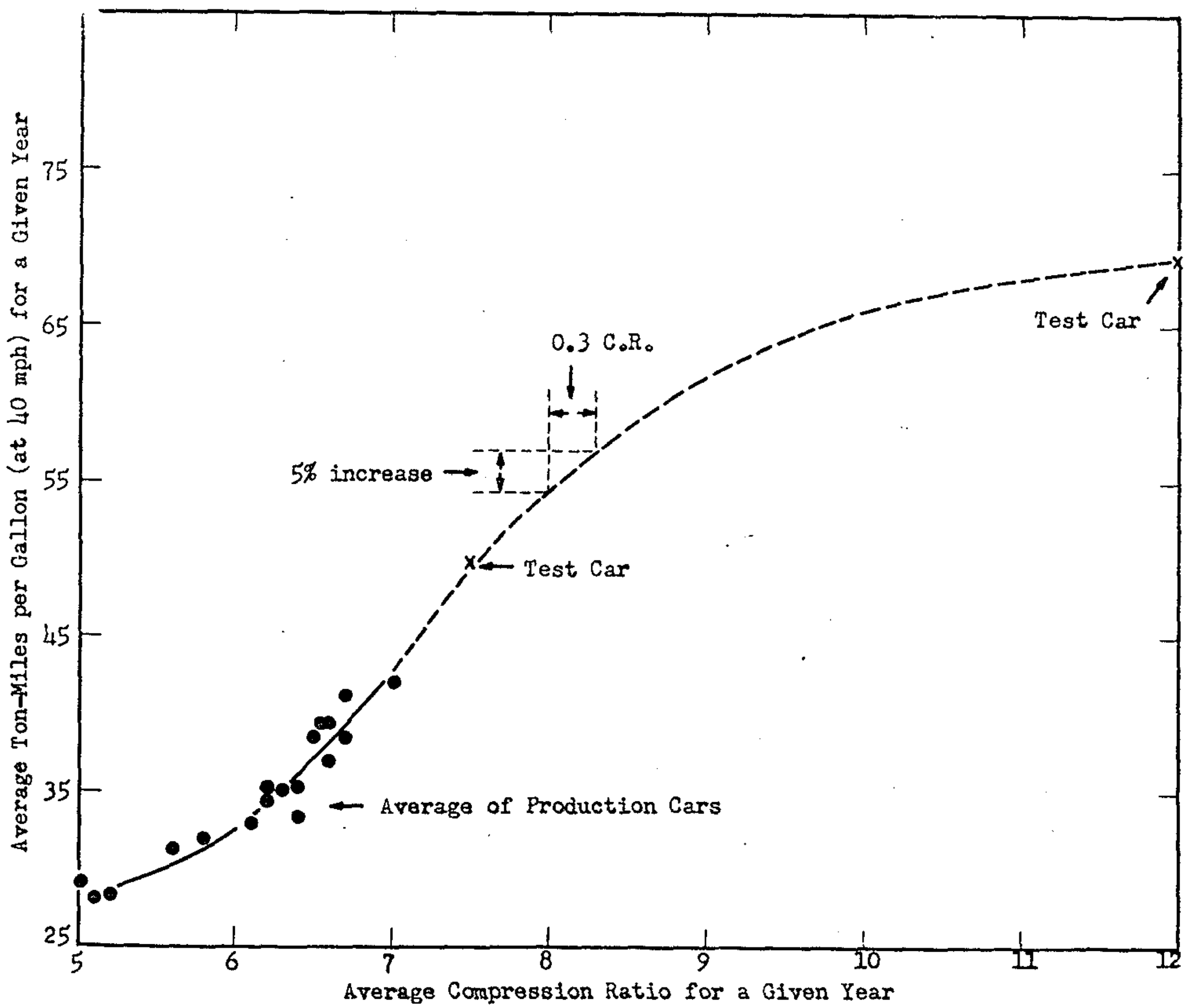
Figure 4

Relationship Between Prevailing Average Compression Ratio and Average Efficiency of Fuel Utilization in Passenger Cars for the Years 1930 to 1950



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