The word "Isomerate" is a Trademark registered by The Pure Oil Company. Through an oversight this term was incorrectly applied to stocks manufactured by isomerization processes in general.

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For: EJ Otto Jr.

From: H. W. KELLOGG

Refining, in the Sheraton Hotel, Philadelphia, Pa., May 14, 1957.

ROAD OCTANE NUMBERS OF TOMORROW'S GASOLINES IN TOMORROW'S CARS †

J. J. GREYTAK,* J. S. BELLAH,* AND W. E. MORRIS *

ABSTRACT

Planning the production of gasolines for tomorrow's high-compression-ratio cars requires information on the road octane quality which can be expected from possible future gasoline compositions. To provide such information, more than 5,000 road octane numbers were obtained in four 11:1- and 12:1-compression-ratio cars for 73 blends made from 28 components. Research and Motor octane values were also measured.

Catalytic reformates generally had higher road octane numbers than catalytically cracked components of the same Research octane number. Light alkylates, 2,3-dimethylbutane, and *iso*pentane had the highest road octane blending values of the components tested. Light catalytically cracked naphthas, polymer trimer, and mixed pentane-hexane isomerates did not raise the road ratings of base fuels having road octane ratings above 100. Many of the blends had road ratings of 102 to over 105.

An average of Research and Motor octane values was found to be most useful for predicting Modified Uniontown road ratings and low-speed Modified Borderline ratings, with little improvement as a result of including such factors as hydrocarbon-type analysis or distillation properties. High-speed Modified Borderline ratings were best for those fuels having high Motor octane number and high aromatic content.

The determination of surface-ignition tendencies showed that the high-octane-number fuels were similar to current superpremium gasolines; tomorrow's gasolines should not increase the prevalence of surface ignition.

Introduction

Petroleum industry management is confronted with complex problems in planning the plants to produce fuels for tomorrow's cars. This group must provide gasolines of adequate quality at minimum cost. The answers to the two following questions will help in making the necessary decisions:

1. What road octane quality can be expected from possible future gasoline compositions in tomorrow's high-compression-ratio cars?
2. Which of the gasolines of comparable road octane quality will be most economical to make?

This paper provides some answers to the first question in terms of more than 5,000 road octane numbers obtained in four cars of 11:1 and 12:1 compression ratios (CR) with 73 fuel blends made from 28 components which will probably be considered for use in tomorrow's gasolines. Using the data provided, cost comparisons can be made between blends of comparable octane quality to answer the second question. Because it may be necessary to design tomorrow's fuels to minimize surface ignition, data are included showing the relative surface-ignition tendency of representative fuel components.

Fuels, Cars, and Procedures

Selection of Fuel Components

Many refinery gasoline components meet the general requirement of high Research octane value. Consequently, in order to hold the fuels tested to some reasonable number, the components evaluated were limited to representative products from the processes likely to be used for producing future high-octane commercial gasolines. The applicable processes are catalytic cracking, catalytic polymerization, catalytic reforming, alkylation, and isomerization. All of these processes involve a chemical change; thus future gasolines, in general, are expected to be 100 per cent synthetic.

The specific components used were as follows:

Components	Number of Samples
Catalytically cracked:	5
3 Light	
2 Full-boiling	
Catalytic polymer:	1
1 Propylene trimer	
Catalytic reformates:	13
6 Debutanized reformates (C_5+)	
3 Dehexanized reformates (C_7+)	
2 Thermally cracked	
2 Aromatic extracts	
Alkylates:	3
3 Aviation quality	
Isomerates:	6
3 Mixed pentane-hexane (C_5/C_6) products	
3 Hydrocarbons (95+ per cent purity)	

The five catalytically cracked components represented products from both foreign and domestic crude oils in both fluid- and solid-bed units. The samples varied in 90-per-cent points from 143 F to 345 F, and in leaded Research octane number from 97 to 102.

The single polymerized gasoline was a narrow-boiling trimer compound with an initial boiling point of 232 F and a final boiling point of 320 F. The feed was essentially a 100-per-cent mixture of propane and propylene.

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Of the thirteen aromatic constituents from catalytic reforming operations, six were debutanized, full-boiling-range reformates (C_5+) from mixed Mid-Continent, mixed Texas, and mixed foreign-crude naphthas. Three were dehexanized fractions (C_7+) from three of the C_5+ reformates. Two samples represented products from thermally cracked, depentanized mild catalytic reformates, and two samples represented wide-boiling-range gasoline-component aromatic extracts. One of the aromatic extracts was synthesized from the analysis of a small laboratory run, and the other was from a commercial unit. The reformates varied in leaded Research octane number from 95 to 110.

The three alkylates were all of aviation quality from butane-butylene feed. Two were from hydrofluoric acid units, and one was from a sulfuric acid unit.

Three of the isomerates were representative of the products from mixed C_5/C_6 charges. One of these three was synthesized from a small-batch laboratory analysis; the other two were products of small pre-pilot units. The three remaining isomerates were essentially pure hydrocarbons: 2,3-dimethylbutane, mixed 2- and 3-methylpentanes, and *iso*pentane.

Detailed laboratory inspection data of both the charge materials and the process products are shown in Table 1 (a, b) of Appendix A, along with some process data.

To simplify blending, as well as to eliminate one possible variable, all components of less than 10 lb Reid vapor pressure (RVP) were first butanized to the desired 10-lb level. In order to eliminate the effect of varying tetraethyllead (TEL) content on road octane quality, all blends contained 3 ml TEL per gal (Motor Mix). Blend compositions, together with laboratory and road octane numbers, are given in Table 2 (a, b, c, d) of Appendix A. Laboratory inspection data on the 73 * finished blends are given in Table 3 (a, b, c, d, e, f, g) of Appendix A.

The finished blends varied considerably in their distillation characteristics. However, with few exceptions, the blends were within the maximum and minimum ranges of commercial gasolines. Those blends boiling above maximum temperatures reported by the Bureau of Mines contained abnormally high volumes of the heavy C_7+ reformates and heavy aromatic extracts. Those boiling below the commercial minimums were the light catalytically cracked and alkylate combinations.

Of the blends tested in this phase of the program, the number containing each of the primary components was as follows:

Component	Number of Blends
Catalytically cracked	38
Polymer	2
Catalytic reformate	63
Alkylate	22
Mixed isomerates	7

* Seventy-four blend numbers are tabulated. No. 8 and No. 54 are the same sample, tabulated in two places in the composition table to illustrate better the effects of two series of variables.

The greatest emphasis was placed on the catalytically reformed, catalytically cracked, and alkylate products, with secondary emphasis on isomerates and polymer products.

Fig. 1 shows the Research octane numbers of all fuels used in the program plotted against their Motor octane values, indicating the range of octane numbers and sensitivities covered. Research octane numbers varied from 95.2 to 108.6, and Motor octane numbers varied from 86.1 to 99.5, with one sample, a pure alkylate, having a Motor number of 104.6 and a negative sensitivity of 1.7 numbers.

Fig. 2 shows the percentages of aromatics and olefins in the experimental fuels. The aromatic content varied from 0 to 79 per cent, and the olefin content varied from 0 to 61 per cent. These limits are believed to bracket any foreseeable finished motor fuels. The range of aromatics and olefins found in present-day commercial premium fuels is indicated by the enclosed area of Fig. 2.

Fuel-Rating Cars

Four test cars were selected to form a representative cross section of combustion-chamber designs, induction systems, and transmission characteristics. The higher octane requirements of tomorrow's cars are expected to come, primarily, from increases in compression ratio and, secondarily, from volumetric-efficiency improvements. Therefore, all of the cars were modified to a higher compression ratio, and one was equipped with a special high-efficiency induction system. The higher compression ratios were achieved through the installa-

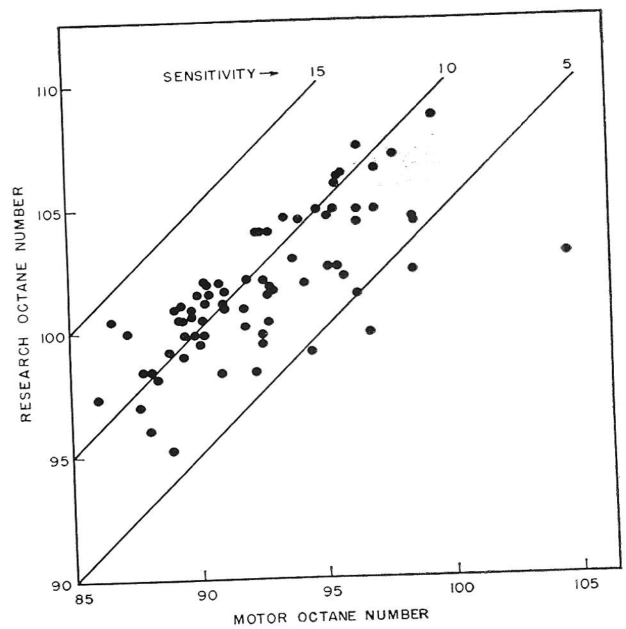

FIG. 1—Laboratory Octane Numbers of Test Fuels.

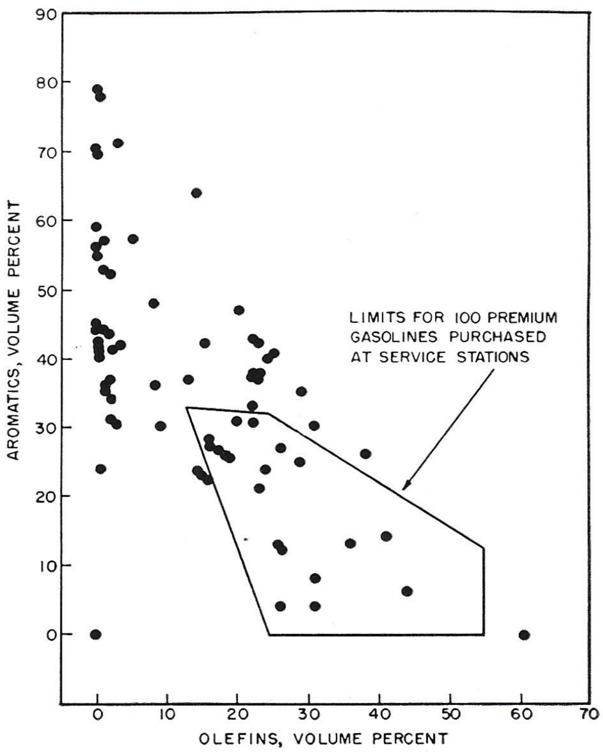

FIG. 2—Aromatic and Olefin Contents of Test Fuels.

tion of special domed pistons. All cars were equipped with automatic transmissions and dual exhaust systems. The following cars were used:

1. Car G, modified to 11.0:1 CR.
2. Car S, modified to 11.0:1 CR.
3. Car D, modified to 12.0:1 CR, and equipped with a high-volumetric-efficiency induction system.
4. Car L, modified to 12.0:1 CR.

The compression ratio of each cylinder was corrected to ±0.1 of a ratio, and factory-flow-tested carburetors were used in all cars. Details of engine modifications are given in Appendix B. All of the cars had a mixed-duty deposit accumulation before the program started, and used a 10W-30 motor oil throughout the entire program.

Road Rating Procedures

The Modified Borderline technique was used in determining the road octane numbers of all the fuels tested in this program. All road ratings were obtained on a chassis dynamometer under level-road conditions. Surface-ignition noises were never noticed while the road ratings were being obtained. A description of the Modified Borderline procedure is given in Appendix C. The detailed road octane results are given in Table 4 (a, b, c, d, e, f) of Appendix A.

Modified Uniontown octane numbers were derived from the Modified Borderline data in order to compare fuels on the basis of a single road octane number. The method used to convert Modified Borderline data to Modified Uniontown octane numbers is described in Appendix D.

All of the road octane data discussed in this paper were obtained under wide-open-throttle conditions. However, the tendency for some engines and some fuels to develop maximum knock under part-throttle conditions is recognized, and data obtained under these conditions will be reported at a later date.

Comparisons of Gasoline Components and Blends

A large number of comparisons of the individual components and fuel blends can be made with the use of the road octane ratings. Certain specific comparisons have been chosen to illustrate the important points.

Primary Components

The four-car-average Modified Uniontown octane ratings of the individual 10-lb RVP components are plotted against their respective Research octane numbers in Fig. 3. It is evident that the catalytically cracked components tested did not have as good a road rating in relation to their Research octane numbers as the other components. These catalytically cracked components varied in leaded Research octane number from 97.4 to 100.3, and their road ratings varied only from 97.2 to 98.4. On the other hand, the road ratings of the reformates and extracts were approximately the same

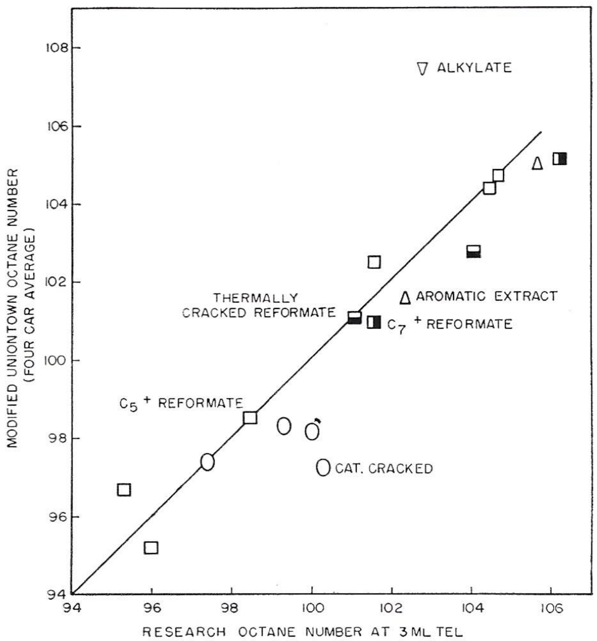

FIG. 3—Road and Research Octane Numbers.

as their Research octane numbers. The alkylate stood out for its superior road octane quality in comparison with all of the other components.

Average Octane Numbers of Primary Component Groups

Arithmetic averages of the Research, Motor, and Modified Uniontown octane numbers of the samples in each component group are shown in Fig. 4. With the exception of alkylate, the components fell in the same relative position on all three scales. Alkylate, with its very superior Motor octane number, also showed a several-number road superiority over both aromatic extract and C_7+ reformate, although both of these had higher Research ratings.

Comparison of Alkylates

Thirty per cent of three different alkylates, two made by the hydrofluoric acid process and one made by the sulfuric acid process, were added to the same base fuel blend consisting of an equal mixture of light catalytically cracked material and a full-boiling-range aromatic extract. The results are shown in Table 1.

Although the individual alkylates varied somewhat in octane quality, their effect in the blends was the same in each of the tests.

The Effect of Alkylate Addition in Various Base Fuels

Generally, the addition of alkylate increased the road octane number of a base fuel more than it increased the Research octane number, as indicated in Fig. 5. The alkylate had a decreasing road effect in the C_5+ Reformates as these base materials increased in Research and road octane level. Thirty per cent of alkylate increased the road octane number approximately two units for catalytically cracked components and the lower-octane reformates, and increased road octane number approximately one unit for the higher-octane reformates.

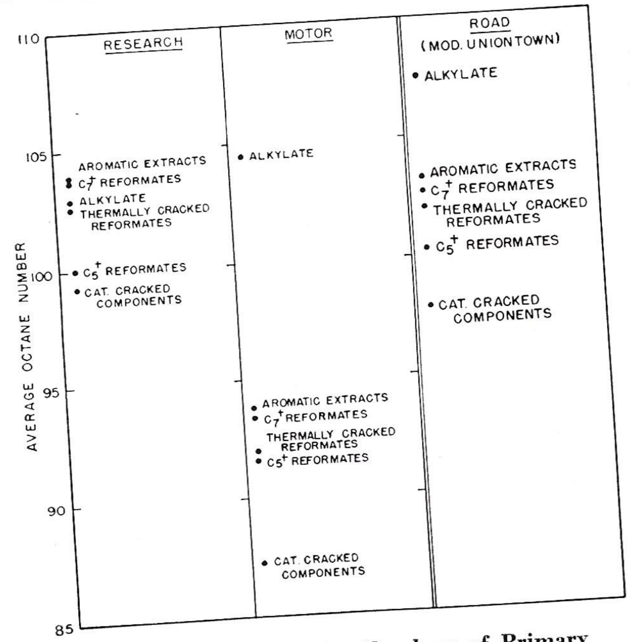

FIG. 4—Average Octane Numbers of Primary Component Groups.

Comparison of *Iso*paraffins

The effects of mixed 2- and 3-methylpentanes, alkylate, and 2,3-dimethylbutane at 30-per-cent concentra-

TABLE 1—Comparison of Alkylates

	Octane Number				
			Modified Borderline		
	Research	Motor	2,000 Rpm	3,500 Rpm	Modified Uniontown
Components:					
Base blend (50 per cent of light catalytically cracked, 50 per cent of extract)	100.6	89.8	100.5	96.8	99.5
Alkylate A (hydrofluoric acid)	102.9	104.6	108.2	106.2	107.5
Alkylate B (hydrofluoric acid)	103.8	105.7	....	....	....
Alkylate C (sulfuric acid)	106.8	105.8	....	....	....
30 Per cent of alkylates in base blend:					
Alkylate A	101.7	92.9	102.4	98.9	101.7
Alkylate B	101.8	92.9	102.4	98.9	101.6
Alkylate C	102.1	92.7	102.5	99.2	101.7

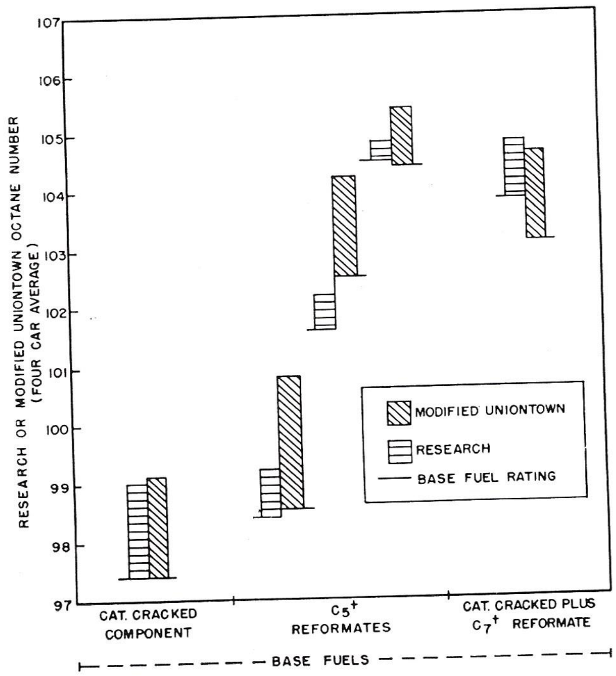

FIG. 5—Effect of 30 Per Cent of Alkylate on Octane Numbers.

tion in two different C_5+ reformates and a full-boiling-range catalytically cracked component are shown in Fig. 6. The change in the Modified Uniontown rating of the base fuels by the addition of these materials

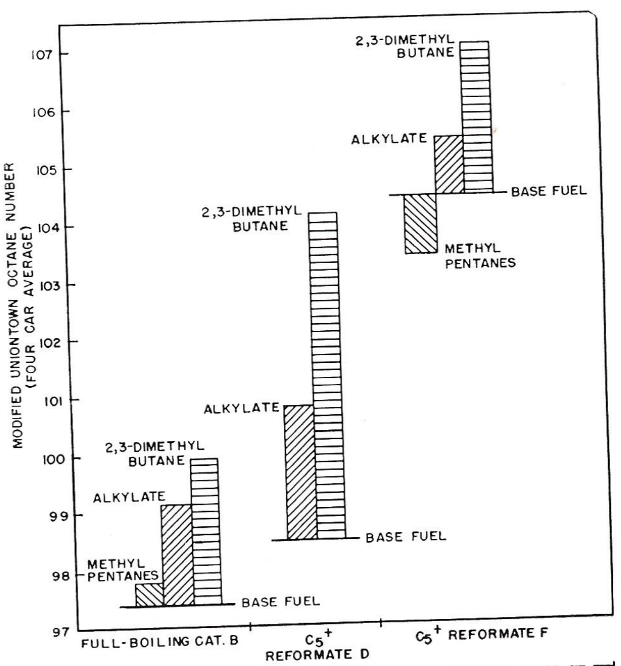

FIG. 6—Effect of 30 Per Cent of *Iso*paraffins on Road Octane Numbers.

is shown. Thirty per cent of mixed methylpentanes increased the road octane rating of the base fuel by only one half of one number. Alkylate was less effective than 2,3-dimethylbutane at any of the three base-fuel road octane levels.

Comparison of Isomerate, Alkylate, and Trimer

Fig. 7 compares three C_5/C_6 isomerates with alkylate and a trimer component. The three mixed isomerates lowered the rating of 101.6-road-octane-number aromatic-extract base fuel when added at a concentration of 30 per cent. Thirty per cent of alkylate raised the rating of the base fuel only one number, indicating an increase of only 0.3 octane number for each 10 per cent of alkylate present at this base-fuel road octane level. At 20-per-cent concentration in a 99.5-road-octane-level base-fuel blend of light catalytically cracked and aromatic extract, the three isomerates raised the base-fuel octane number approximately one unit. The same concentration of trimer, however, lowered the road rating more than one number below that of the base fuel, indicating that trimer is not desirable in gasolines at the 100 road octane level or higher.

High-Level Reforming Compared to Lower-Severity Reforming Combined with Isomerization

The increasing volume loss with increasing severity of reforming operations suggests that a comparison of high-level operations with a lower-level condition, isomerizing the reformate C_5/C_6 fraction and recombining, would be of interest. The results of such a comparison are shown in Table 2.

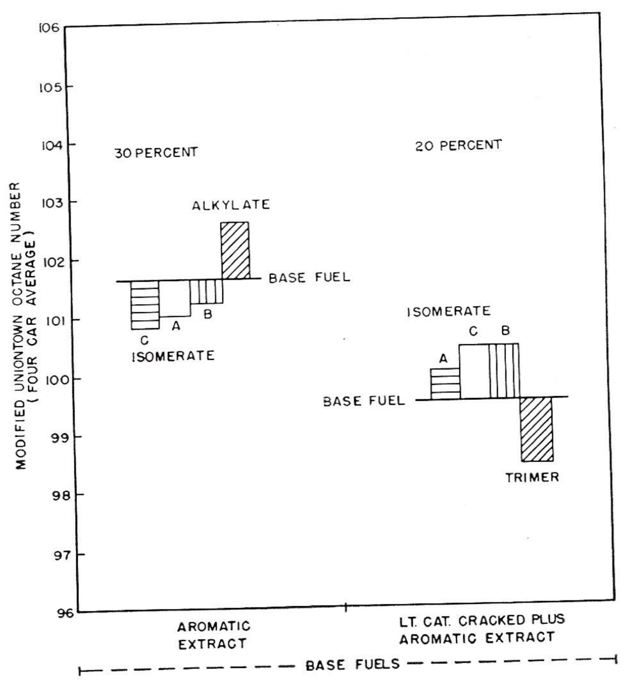

FIG. 7—Relative Effects of Isomerate, Alkylate, and Trimer on Road Octane Numbers.

TABLE 2—Comparison of High-Severity Reforming with Lower-Severity Reforming Combined with Isomerization of the C_5/C_6 Fraction

Blend No.	Component	Per Cent by Volume	Laboratory Octane Number: Research	Laboratory Octane Number: Motor	Modified Uniontown Octane Number
58	C_5+ reformate F	100	104.5	94.2	104.4
54	C_5+ reformate E	100	101.7	93.1	102.5
10	C_7+ reformate B	100	106.0	95.7	104.6
38	C_7+ reformate B Isomerate A	70 30	102.8	93.8	102.8

C_5+ reformate F, obtained by severe reforming, had a leaded Research octane number of 104.5. Removal of a C_5/C_6 fraction from reformate E, obtained by less severe reforming, gave reformate B, raising its Research octane number from 101.7 to 106.0. Replacement of the C_5/C_6 fraction with a synthesized C_5/C_6 isomerate, representing a typical product from a Mid-Continent virgin naphtha, raised the octane number only to 102.8, considerably lower than the 104.5 octane number obtained by more severe reforming. While it is realized that this may not be a true comparison in that the isomerate used is not necessarily the same as that which would be obtained from the front end of the C_5+ reformate, the results indicate that such an operation would be definitely questionable.

On the other hand, the use of C_5 isomerate (*iso*pentane) rather than mixed C_5/C_6 isomerate gave more encouraging results, as shown in Table 3. It is apparent from Table 3 that the yield advantage of lower-severity reforming and pentane isomerization might very well be deserving of a serious economic evaluation in that the latter blend is better than the high-severity reformate on the road. A fuel equivalent in quality to the high-severity reformate could be made with less *iso*pentane or a lower level of reforming severity.

Relative Effect of Light Olefins and *Iso*paraffins

A C_5/C_6 catalytically cracked fraction was compared to *iso*pentane and 2,3-dimethylbutane at equal concentrations in two different base fuels. Fig. 8 shows the increase in Modified Uniontown road octane numbers obtained by substituting *iso*paraffins for olefins. In the first fuels, *iso*pentane replaced the catalytically cracked material. This gave an increase of approximately 0.5 octane number for each 10-per-cent replacement. In the other base fuel, 2,3-dimethylbutane was substituted for the C_5/C_6 catalytically cracked material. An increase of approximately one road octane number resulted from each 10-per-cent replacement. This high road blending effect of 2,3-dimethylbutane was evident in all blends in which it was used.

Blending Values

Fig. 9 shows the arithmetic average Research, Motor, and Modified Uniontown octane-number blending values of the several minor components used. The road blending values are in the same order as the Motor octane blending values. A point of interest is the effect of different base fuels on the alkylate blending values. The base fuels did not affect Research blending values, but alkylate had appreciably lower Motor and road values in a straight catalytically cracked fuel than in aromatic or mixed aromatic and catalytically cracked fuels. A comparison of Fig. 9 with Fig. 4 shows that the average blending values of the catalytically cracked components are essentially the same as the basic octane numbers of these components. Fig. 9 also makes it apparent that trimer would not ordinarily be a suitable component in gasolines with octane numbers above 100.

The average blending values of the components used in this program are tabulated in detail in Appendix A, Table 5 (a, b, c, d).

TABLE 3—Comparison of High-Severity Reforming with C_7+ Lower-Severity Product Combined with *Iso*pentane

Blend No.	Component	Per Cent by volume	Laboratory Octane Number: Research	Laboratory Octane Number: Motor	Modified Uniontown Octane Number
58	C_5+ reformate F	100	104.5	94.2	104.4
67	C_7+ reformate B *Iso*pentane	60 40	104.9	96.4	105.3

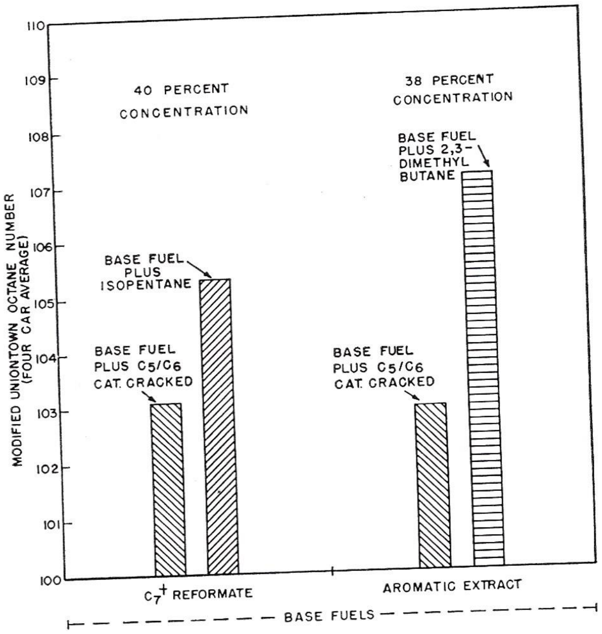

FIG. 8—Effect of Substituting *Iso*paraffins for a C_5/C_6 Catalytically Cracked Component.

Processes for Making Tomorrow's Gasolines

The road blending data have shown that relatively heavy aromatic constituents may well be the principal components in the back-end fractions of tomorrow's high-octane gasolines. The primary process for making such aromatic components will be catalytic reforming, which can be followed by redistillation, aromatic extraction, or thermal cracking. In the middle-volatility range, alkylate is far superior in road quality to polymerized trimer. Thus alkylation would seem to be an increasingly important process of the future. Alkylation may also be economically important in that it provides a ready means of absorbing large volumes of butane fractions which might otherwise present an economic disposal problem. Of course, a portion of the *n*butane would have to be isomerized and the remainder dehydrogenated prior to alkylation.

For the front-end components, paraffinic isomers would seem to offer the greatest possibility for both volatility and octane distribution balance, with *iso*pentane appearing to be the most feasible in the light of today's process developments. Other isomers, particularly 2,3-dimethylbutane, offer interesting possibilities. The data thus indicate that future high-octane gasoline components will come from various operating combinations of catalytic reforming, alkylation, and isomerization.

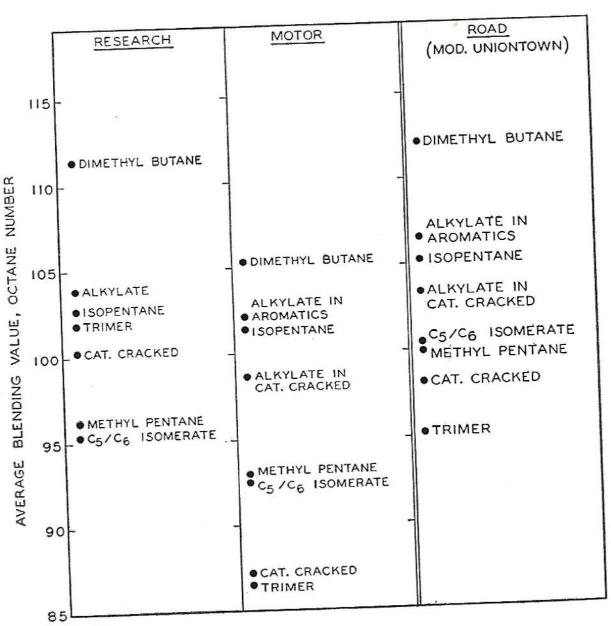

FIG. 9—Average Blending Values.

Relationships Between Laboratory and Road Octane Numbers

Road octane numbers of tomorrow's fuels in tomorrow's cars cannot be predicted accurately from Research octane number, as illustrated by Fig. 10. A road octane number of approximately 100 can be obtained with fuels having Research octane numbers ranging from 99 to 102, and fuels having a Research octane number of 102 can have road octane numbers from 100 to 104.

In order to permit predictions of road octane numbers for fuels not tested in this program, the general relationships between road octane numbers and laboratory data were studied in detail. Statistical analyses were made, with the use of the UNIVAC electronic computer, to determine whether road octane numbers

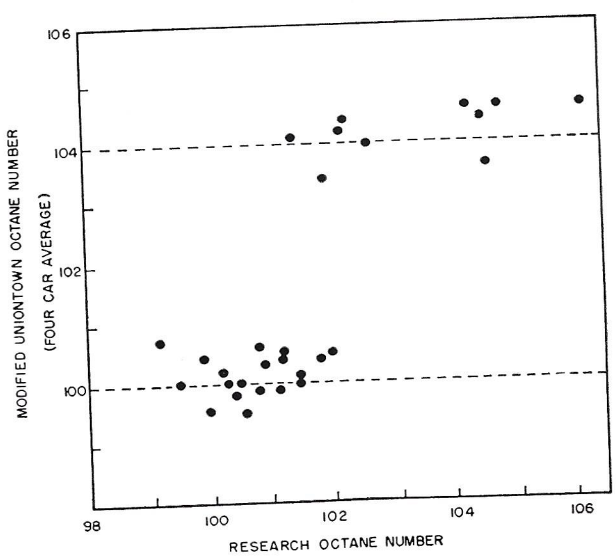

FIG. 10—Research Octane Number Does Not Determine Road Octane Number.

had any significant relationship to the following factors:

- Research octane number
- Motor octane number
- Olefins, per cent by volume
- Aromatics, per cent by volume
- Sulfur, per cent by weight
- Gravity, deg API
- ASTM 10-per-cent point
- ASTM 50-per-cent point
- ASTM 90-per-cent point

The UNIVAC results showed that the Modified Uniontown road octane number in each of the four test cars could be predicted from a combination of Research and Motor octane numbers, without regard to any of the other factors studied.

The average Modified Uniontown octane number in the four test cars is considered the best indication of overall road antiknock performance, and can be predicted from the average of Research and Motor octane numbers. The relationship shown in Fig. 11 indicates the following:

Road octane number = 0.5 Research + 0.5 Motor + 4.5

The superiority of the average over either Research or Motor octane number alone as a measure of road octane is illustrated by a comparison of Fig. 12 with Fig. 11. This relationship is meant to supplement, but not to replace, road octane testing. It gives a good approximation of average Modified Uniontown ratings, but an occasional fuel will deviate significantly. Furthermore, specific cars other than those tested may give quite a different correlation.

The average of Motor and Research octane numbers

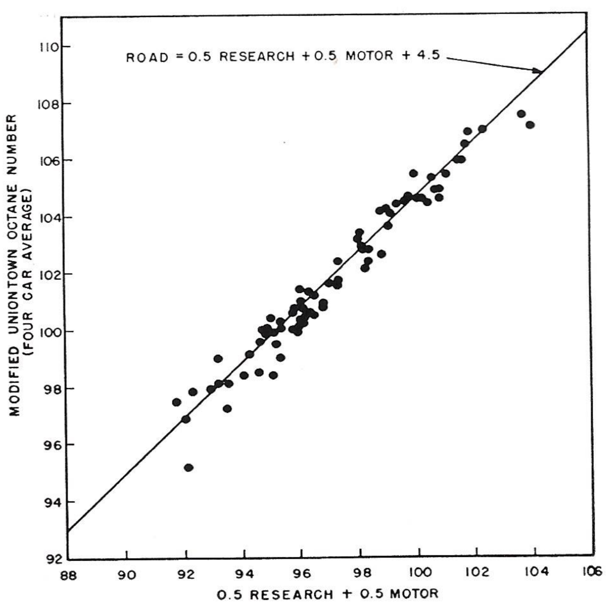

FIG. 11—Road Octane Number Can Be Predicted from Average of Research and Motor Octane Numbers.

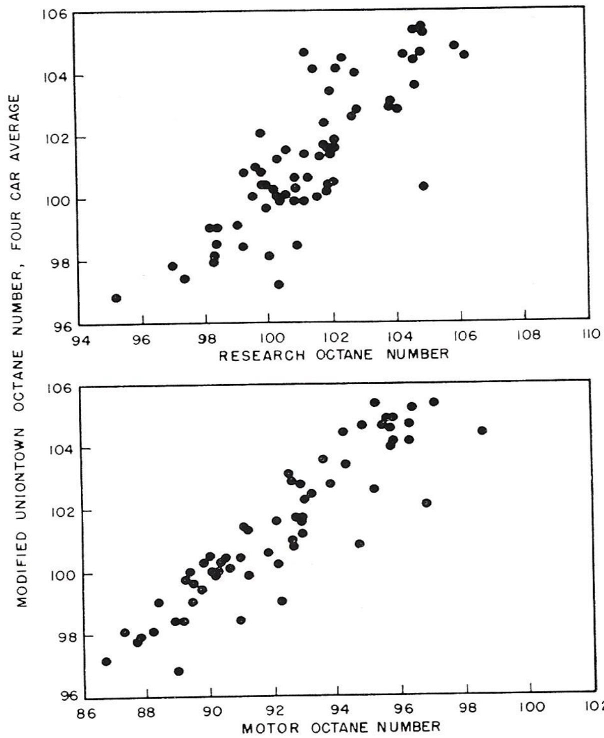

FIG. 12—Road Octane Number Is Not Related Closely to Research or Motor Octane Number Alone.

is also a good measure of road octane number for present-day gasolines in present-day cars. This relationship is shown in Fig. 13 for 50 premium gasolines purchased at service stations and tested in January 1957 in a 1957 Chrysler, a 1957 Oldsmobile, and a 1956 Buick.

The method by which the Modified Uniontown road octane numbers were obtained in this program is based upon the assumption that future automobile engines will be adjusted to the gasolines available, so that some gasolines will knock at low speed and some will knock at high speed, depending upon their composition. That assumption is considered valid for most of tomorrow's cars, but there will always be some car models and individual cars which will knock only within certain speed ranges, regardless of the gasoline composition. Modified Borderline road octane numbers can be used best for predicting antiknock performance in these cars.

The lowest speed at which octane numbers were obtained in all four test cars was 2,000 rpm. The UNIVAC results indicated that Research and Motor octane numbers were the only factors among those examined which had a significant relationship to Modified Borderline octane number at 2,000 rpm. In each of the test cars Research and Motor octane numbers were of approximately equal importance. Fig. 14 shows the relationship between the low-speed ratings and the average of the Research and Motor octane numbers.

Consideration of hydrocarbon composition of the fuels

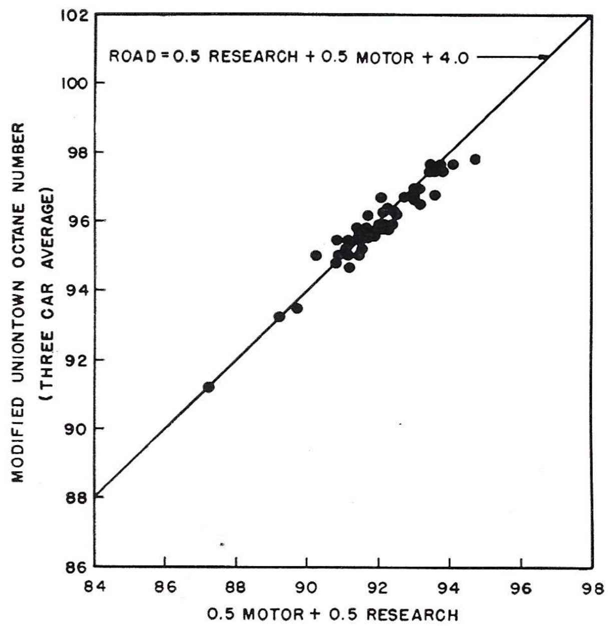

FIG. 13—Road Octane Number Can Be Predicted from Average of Research and Motor Octane Numbers for Present-Day Premium Gasolines in Present-Day Cars.

gave very little improvement in the correlation of Modified Uniontown or low-speed Modified Borderline road octane numbers with laboratory data. At high speed, however, the road rating was found to be related to Motor octane number, Research octane number, and olefin content. At 3,500 rpm, Modified Borderline road octane number is related to the following expression:

0.5 Research + 0.5 Motor − 0.1 (per cent of olefins)

This relationship, shown in Fig. 15, indicates that reducing the olefin content improves the high-speed road octane number.

The correlation of a 3,500-rpm road rating with a combination of Research and Motor octane numbers may seem a departure from past data which showed that high-speed road octane number was more closely related to Motor octane number than to Research octane number. However, when hydrocarbon composition is disregarded, Fig. 16 shows that, as in the past, Motor octane number will be a better measure of the high-speed road rating of tomorrow's fuels than will Research octane number.

Correlation of the high-speed road ratings with Research octane number, Motor octane number, and hydrocarbon type is complicated by the relationships between these factors. Sensitivity (Research minus Motor octane number) is increased by the addition of aromatics or olefins. Aromatics contribute about half as much to sensitivity as do olefins. For the fuels used in this program, a good relationship exists between sensitivity and the expression:

[Per cent of olefins + 0.5 (per cent of aromatics)],

as shown in Fig. 17.

The relationships in Fig. 15 and 17 can be used to show that, at a given Motor octane number, increasing aromatic content will increase high-speed road rating. Details are given in Appendix E. Fig. 18 shows the re-

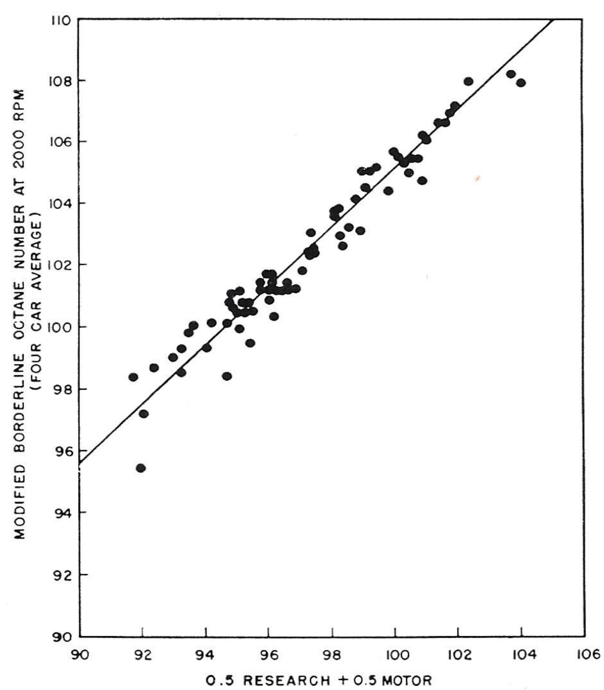

FIG. 14—Low-Speed Road Octane Number Is Related to Average of Research and Motor Octane Numbers.

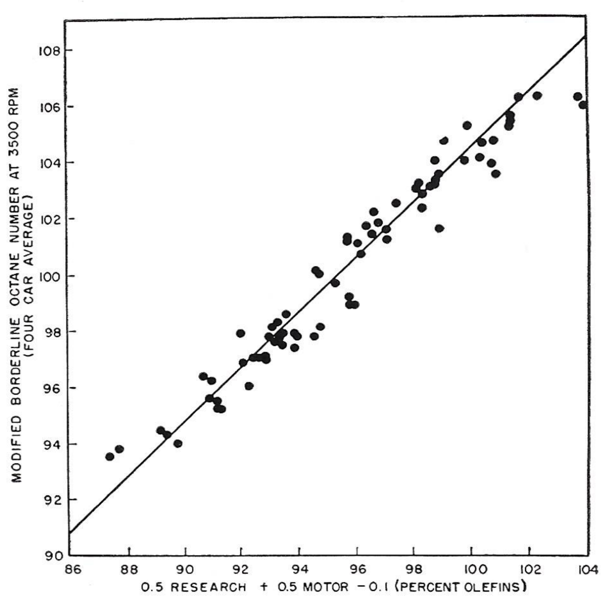

FIG. 15—High-Speed Road Octane Number Is Related to Laboratory Octane Number and Olefin Content.

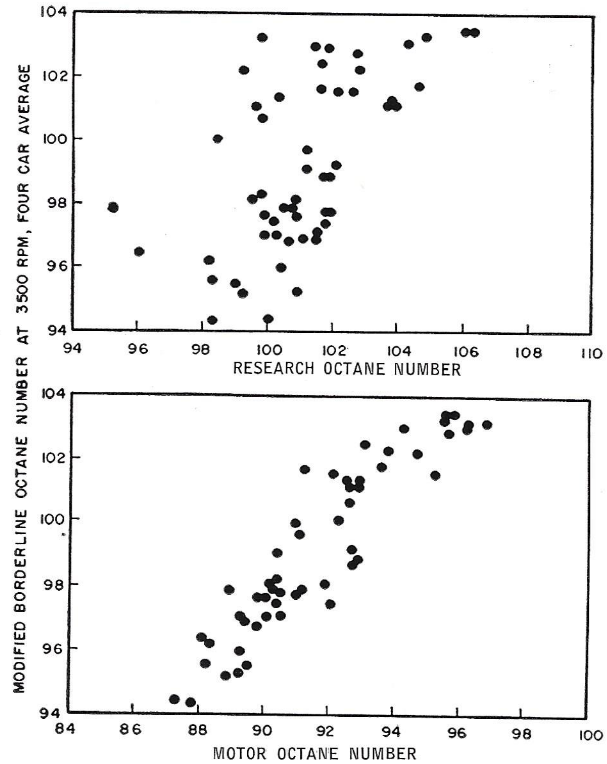

FIG. 16—High-Speed Road Rating Is More Closely Related to Motor Than to Research Octane Number.

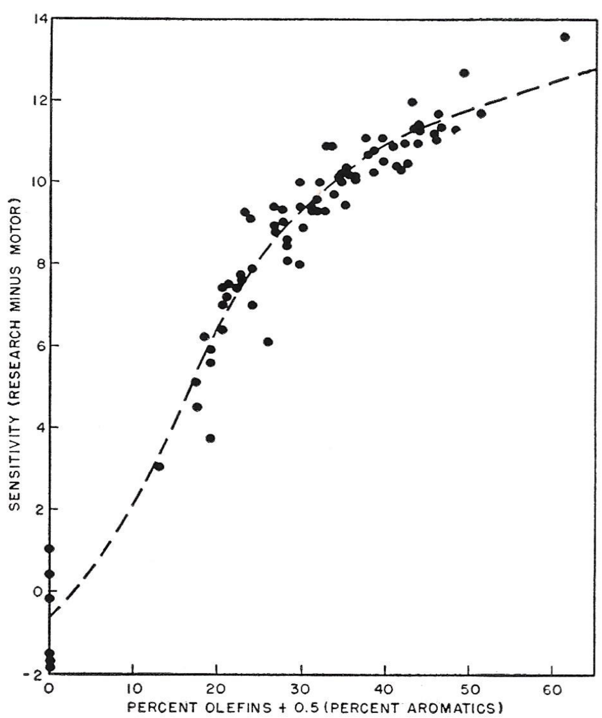

FIG. 17—Relationship Between Hydrocarbon Type and Sensitivity.

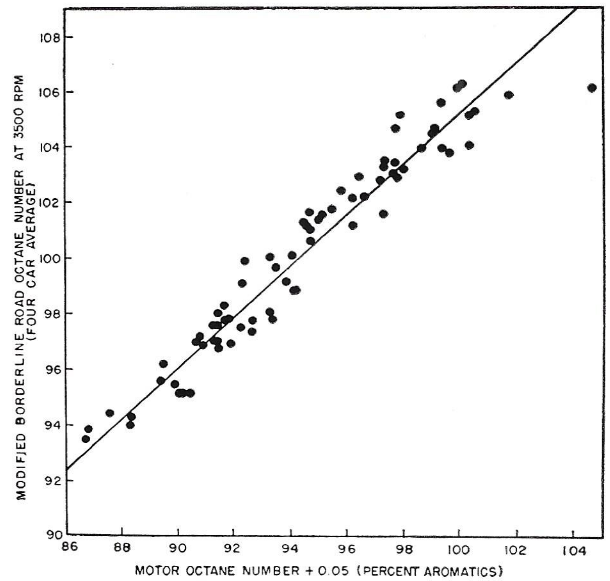

FIG. 18—High-Speed Octane Number Is Related to Motor Octane Number and Aromatic Content.

lationship between high-speed road rating and Motor octane number+0.05 (per cent of aromatics). The correlations in Fig. 15 and 18 are approximately equal in accuracy, and both are superior to the use of Motor octane number alone for predicting high-speed rating. Thus high-speed road rating can be predicted from a combination of Research and Motor octane number with a debit for olefins, or from Motor octane number alone with a credit for aromatics.

Based upon an examination of the relationships between road octane numbers and laboratory data, the best overall road antiknock performance will depend upon the average of Motor and Research octane number. Such relationships are useful as a guide in the blending of fuels, but are not intended as a replacement for road octane testing. Those cars having maximum knock at high speeds will be best satisfied by fuels having high Motor octane number and high aromatic content. The effect of aromatics is noteworthy.

A detailed analysis of the relationships between road octane numbers and laboratory data is being continued, and will be published at a later date.

Surface Ignition

The occurrence of surface ignition may become more frequent as the compression ratios of engines are increased. Consequently, it may become necessary to design tomorrow's gasolines to minimize surface ignition. As an aid for determining the gasoline blends with the best overall engine performance, relative surface-ignition tendency information was developed for representative types of the high-octane components and blends employed in this program.

Surface-ignition tendencies were determined by counting the number of surface ignitions occurring in a modern V-8 passenger-car engine operated on a laboratory test stand. The engine was modified to operate on a single cylinder. A domed piston was installed to raise the compression ratio to 11:1. Engine deposits were accumulated under part-throttle conditions using a standard fuel and oil combination. The test fuels were rated during periodic wide-open-throttle operation of the engine. The occurrence of surface ignition was detected and counted with an ionization gap and special electronic equipment. At least 10 ratings were obtained on each fuel blend, the ratings being made in random order. The data were treated statistically; they are reported as the range of surface-ignition counts obtained with each of the fuels during the rating periods.

These tests showed wide differences in the surface-ignition tendencies of the various types of refinery stocks, as shown in Fig. 19. Highly aromatic fuels, such as reformates and benzene, had the highest tendency to surface-ignite. Alkylates, catalytic naphthas, and *iso*-octane had very low tendencies toward surface ignition. Blends of the two classes were intermediate in this tendency. The type of refinery process used in producing fuel components is, therefore, of primary importance in determining the surface-ignition tendency of the final fuel blend.

Three commercially available superpremium fuels were also tested for comparison. These commercial fuels had surface-ignition tendencies which were intermediate to the fuels with high aromatic content and the fuels with low aromatic content, and were similar in behavior to blends of the two classes. The latter blends fall within the expected range of tomorrow's gasolines with respect to hydrocarbon type, distillation, and octane numbers.

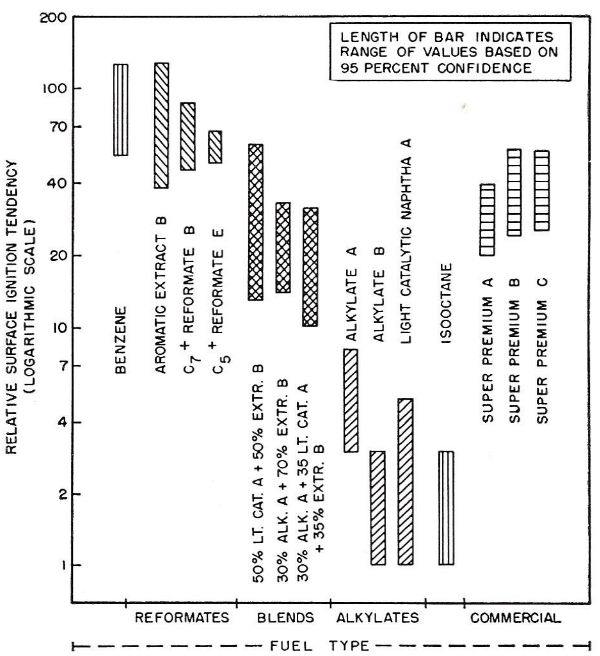

FIG. 19—Relative Surface-Ignition Tendencies of Fuels.

On the basis of these data, and on the assumption that present-day engines are not in serious trouble from surface ignition with the superpremium fuels, it seems reasonable to expect that tomorrow's gasolines will not significantly increase the prevalence of surface ignition. However, these results do show ways to reduce the surface-ignition tendency of fuels if and when this should become necessary.

Possible 102- and 105-Road-Octane-Number Gasolines

Many ways to make fuels having Modified Uniontown road octane numbers in the range of 98 to 106 can be determined from the data obtained in this program. Thus a refiner can operate with a reasonable amount of flexibility insofar as road octane quality is concerned. To illustrate some of the possibilities, those blends which were found to have road octanes at either of two arbitrarily chosen levels have been tabulated. Many more can be determined from the data. The two road octane levels selected were 102, as representative of the near future, and 105, as representative of the more distant future. Compositions giving approximately 102 road octane number are listed in Table 4. Table 5 shows possibilities for blending 105-road-octane-number gasolines.

TABLE 4—Possible Fuel Blends Having 102 Modified Uniontown Road Octane Number

Blend No.	Composition: Per Cent by Volume	Composition: Component and Research Octane Number	Modified Uniontown Road Rating of Blend
8....	100	C_5+ reformate E (101.7)	102.4
20....	100	Aromatic extract B (102.1)	101.6
29....	35	Aromatic extract B (102.1)	101.7
	35	Light catalytically cracked A	
	30	Alkylate A	
53....	55	C_5+ reformate D (98.4)	102.1
	45	Alkylate A	

TABLE 5—Possible Fuel Blends Having 105 Modified Uniontown Road Octane Number

Blend No.	Composition: Per Cent by Volume	Composition: Component and Research Octane Number	Modified Uniontown Road Rating of Blend
59....	85	C_5+ reformate F (104.5)	105.4
	15	Alkylate A	
64....	56	C_5+ reformate F (104.5)	104.6
	30.5	Alkylate A	
	13.5	Light catalytically cracked C	
67....	60	C_7+ reformate B (106.2)	105.3
	40	*Iso*pentane	
68....	47.5	C_7+ reformate B (106.2)	104.6
	29.5	Alkylate A	
	23	Light catalytically cracked C	
71....	47.5	C_7+ reformate C (109.7)	104.9
	29.5	Alkylate A	
	23	Light catalytically cracked C	

It is obvious that many other blends could be made of combinations of those listed, as well as from other components studied in this program. Volatilities of the compositions shown would fall well within the range of present practice, but some of them may be considered too heavy for winter gasoline. Those compositions having the highest aromatic contents would be most prone to give surface ignition from combustion-chamber deposits, according to results shown in Fig. 19. Whether this will be a serious enough problem to limit fuel composition is not presently known.

The data presented in this paper help to answer the question: "What road octane quality can be expected from possible future gasoline compositions in tomorrow's high-compression-ratio cars?" The analysis is based primarily on road-octane-number results, with little regard for other factors.

Conclusions

Based on road octane data obtained in 11:1-CR and 12:1-CR cars for a wide variety of refinery components which are expected to be used in tomorrow's gasolines, the following major conclusions have been reached:

1. Catalytic reformates generally have higher road octane numbers than catalytically cracked components of the same Research octane number.
2. Light catalytically cracked naphthas cannot be used to improve fuels which have road octane numbers above 100.
3. Light butane-butylene alkylates from different processes do not differ in road blending octane numbers.
4. Polymers do not appear to be desirable components in fuels having road octane numbers above 100.
5. 2,3-Dimethylbutane, light alkylate, and *iso*pentane, in the order stated, have the highest road octane blending values of the blending components tested.
6. Total isomerate product from mixed pentane-hexane feed probably will not be used to raise the road ratings of base fuels above the 100 octane level.
7. Catalytic reforming, alkylation, and isomerization will be major processes for making tomorrow's high-octane-number gasolines.
8. Research and Motor octane numbers will have approximately equal importance in predicting overall road antiknock performance of future fuels.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of the many oil companies whose contributions of advice and fuel samples made this program possible. Acknowledgment is made also to the authors' associates at the Petroleum Laboratory, E. I. du Pont de Nemours and Company, Inc., for their assistance in carrying out this program and in the preparation of the paper. In particular, we wish to thank Messrs. R. O. Bender, M. W. Corzilius, J. A. Lamb, and D. L. Pastell.

Appendix A

TABLE 1a—Process Information and Properties of Blending Components

Hydrocarbon type:	Paraffin									Olefin					
Product type:	Alkylate			Isomerate			Pure Hydrocarbon			Light Catalytically Cracked			Full-Range Catalytically Cracked		Polymer
Product sample:	A	B	C	A	B	C	2,3-Dimethylbutane (95+ per cent)	Methylpentane (commercial)	*Iso*pentane (98+ per cent)	A	B	C	A	B	Trimer
Process unit:	...	...	...	...	...	...	...	..	...	Fluid	Fluid	Solid bed	Solid bed	Solid bed	Catalytic polymer
Catalyst type:	Hydrofluoric acid		Sulfuric acid	...	...	...	...	..	...	Synthetic	Synthetic and natural	Synthetic	Synthetic	Synthetic	Phosphoric acid
Feed															
Crude-oil source	...	...	...	Mid-Continent	...	...	...	..	...	...	Texas, Louisiana, Arkansas	Mixed	Mixed domestic	Mixed	...
Composition	Butane plus butylenes			Note 1	...	...	...	..	...	...	...	...	Virgin gas oils	...	Propane, propylene
Gravity, deg API at 60 F	...	...	...	...	...	...	...	..	...	26.5	28.6	...	...	...	...
ASTM distillation, deg F:															
Initial boiling point	...	...	...	...	...	...	...	..	...	...	490	400	...	400	...
5-per-cent point	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...
10-per-cent point	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...
50-per-cent point	...	...	...	...	...	...	...	..	...	700	660	...	...	...	...
70-per-cent point	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...
90-per-cent point	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...
End point	...	...	...	...	...	...	...	..	...	...	...	850	...	850	...
Product															
Gravity, deg API at 60 F	74.8	70.6	74.1	83.1	83.0	78.9	...	..	...	72.9	74.1	81.5	57.3	...	59.2
Reid vapor pressure, psi	10.0	4.4	4.6	11.5	12.7	10.1	...	..	...	10.4	8.9	14.7	6.4	...	0.6
ASTM distillation, deg F:															
Initial boiling point	79	118	116	98	96	102	...	..	...	102	106	88	106	...	232
5-per-cent point	104	160	160	113	106	116	...	..	...	114	118	96	128	...	254
10-per-cent point	124	178	175	116	109	121	...	..	...	119	122	99	137	...	258
50-per-cent point	217	220	219	128	122	140	...	..	...	147	142	112	213	...	270
70-per-cent point	226	228	221	138	131	153	...	..	...	179	160	123	280	...	274
90-per-cent point	239	242	242	148	145	170	...	..	...	253	192	143	336	...	280
End point	293	306	310	158	158	190	...	..	...	339	243	164	402	...	320
Analysis of hydrocarbon type, per cent by volume:															
Paraffins	100	100	100	90	...	...	100	98	100	...	...	...	...	...	0
Olefins	0	0	0	0	...	...	0	0	0	44	62	37	31	...	100
Naphthenes	0	0	0	10	...	...	0	2	0	...	...	...	...	...	0
Aromatics	0	0	0	0	...	...	0	0	0	6	0	12	26	...	0
Blend with Reid vapor pressure of 10 psi: Butane* added, per cent by volume	None	10.5	10.0	None	None	None	7.4	6.0	None	None	2.0	None	5.0	6.0	16.5
ASTM octane number (D 908, Research Method), with addition of 3 ml TEL per gal	102.9	103.8	106.8	95.6	96.4	95.8	118	94.5	106	100.0	100.3	102.1	99.2	97.4	99.5
ASTM octane number (D 357, Motor Method), with addition of 3 ml TEL per gal	104.6	105.7	105.8	95.8	98.0	95.4	110	95.1	107	87.3	86.7	90.1	88.9	86.1	86.9

* More than 95 per cent of *n*butane.

Note 1: Feed stock and product contained the following percentages by volume: *iso*pentane—12.6, 34.5; *n*pentane—21.9, 1.5; cyclopentane—0.5, 1.0; 2,2-dimethylbutane—0.3, 4.5; 2,3-dimethylbutane—0.3, 3.5; 2-methylpentane—16.9, 21.0; 3-methylpentane—9.4, 11.5; *n*hexane—27.2, 13.5; methylcyclopentane—9.1, 9.0; cyclohexane—1.4, none; benzene—0.4, none.

TABLE 1b—Process Information and Properties of Blending Components

Hydrocarbon type:	Aromatic												
Product type:	C_5+ Reformate						C_7+ Reformate			Thermally Cracked Reformate		Extract	
Product sample:	A	B	C	D	E	F	A	B	C	A	B	A	B
Process unit:	Cat-former	Houdri-former	Ultra-former	Sova-former	Sova-former	Sova-former	Cat-former	Sova-former	Sova-former	Thermal reformer	Thermal reformer	...	...
Catalyst type:	Atlantic	Houdry	Indiana	Sinclair	Sinclair	Sinclair	Atlantic	Sinclair	Sinclair	...	...	...	...
Feed													
Crude-oil source	...	...	Mixed Texas	Mixed	...	Mid-Continent	...	Mixed	Mid-Continent	...	...	...	Mid-Continent and Wyoming
Composition	...	...	...	Note 2	Blend of 42 per cent D and 58 per cent F	Note 2	Redistilled C_5+ reformate A	Redistilled C_5+ reformate E	Redistilled C_5+ reformate F	...	Note 3	Note 4	...
Gravity, deg API at 60 F	...	...	50.0	...	...	...	...	...	...	...	...	...	...
ASTM distillation, deg F:													
Initial boiling point	140	240	180	116	...	200	...	...	...	240	178	...	200
5-per-cent point	...	...	...	...	...	...	...	...	...	...	...	...	...
10-per-cent point	200	254	...	...	...	...	...	...	...	...	228	...	...
50-per-cent point	245	297	...	...	...	...	...	...	...	...	280	...	...
70-per-cent point	...	...	319	...	...	...	...	...	...	...	...	...	...
90-per-cent point	300	...	352	...	...	...	...	...	...	...	332	...	...
End point	340	380	392	375	...	380	...	...	...	380	380	...	380
Product													
Gravity, deg API at 60 F	54.2	48.4	42.4	...	...	...	38.2	35.3	33.1	41.4	47.3	34.9	41.6
Reid vapor pressure, psi	5.8	4.4	6.2	...	...	...	0.7	0.8	0.8	5.6	3.2	1.1	1.2
ASTM distillation, deg F:													
Initial boiling point	119	126	112	...	...	...	260	230	212	114	129	190	164
5-per-cent point	152	172	...	...	...	...	276	251	240	150	...	242	200
10-per-cent point	171	204	156	...	...	...	279	262	248	182	178	253	214
50-per-cent point	234	270	285	...	...	...	296	292	288	276	260	295	280
70-per-cent point	262	292	312	...	...	...	307	312	308	296	...	311	311
90-per-cent point	302	320	346	...	...	...	332	347	346	322	328	344	350
End point	358	382	396	...	...	...	391	428	434	390	360	427	366
Analysis of hydrocarbon type, per cent by volume:													
Paraffins	...	43	28	...	...	...	...	...	...	...	...	...	30
Olefins	1	3	0	...	...	...	0	0	2	15	9	0	...
Naphthenes	...	7	2	...	...	...	...	...	...	...	...	...	2
Aromatics	38	47	70	...	...	...	62	77	89	69	54	82	68
Blend with Reid vapor pressure of 10 psi:													
Butane* added, per cent by volume	7.5	10.0	7.0	7.8	7.9	8.0	14.5	14.5	14.0	7.0	10.5	13.5	13.5
ASTM octane number (D 908, Research Method), with addition of 3 ml TEL per gal	95.2	96.0	104.8	98.4	101.7	104.5	101.6	106.2	109.7	104.0	101.1	105.8	102.1
ASTM octane number (D 357, Motor Method), with addition of 3 ml TEL per gal	89.0	88.1	94.8	91.0	93.1	94.2	91.2	95.7	99.2	92.9	91.1	95.6	92.1

* More than 95 per cent of *n*butane.

Note 2: The feed stock for C_5+ reformate D contained some thermal naphtha and was hydrogenated. The feed stocks for C_5+ reformates D and F contained the following percentages by volume; paraffins—55, 51; olefins—1, 1; naphthenes—36, 40; aromatics—8, 8.
Note 3: Contained 45 per cent of paraffins, 41 per cent of naphthenes, 14 per cent of aromatics.
Note 4: Product synthesized from pilot-plant data.

TABLE 2a—Blend Compositions and Octane Data

(All blends contain 3 ml TEL, Motor Mix, per gal)

Component / Blend No.:	1	2	3	4	5	6	7	8*	9	10	11	12	13	14	15	16	17	18	19
	Per Cent by Volume of 10-Lb RVP Component																		
Component																			
Light catalytically cracked:																			
A	100	....	50	....	50	....	50	....	50	....	50	....	50	....	50	....	50	....	50
C_5+ reformate:																			
A	....	100	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
B	....	....	....	100	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....
C	....	....	....	....	....	100	50	....	....	....	....	....	....	....	....	....	....	....	....
E	....	....	....	....	....	....	....	100	50	....	....	....	....	....	....	....	....	....	....
C_7+ reformate:																			
A	....	....	....	....	....	....	....	....	....	100	50	....	....	....	....	....	....	....	....
B	....	....	....	....	....	....	....	....	....	....	....	100	50	....	....	....	....	....	....
Thermally cracked reformate:																			
A	....	....	....	....	....	....	....	....	....	....	....	....	....	100	50	....	....	....	....
B	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	100	50	....	....
Aromatic extract:																			
A	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	100	50
Laboratory octane number:																			
ASTM D 908, Research Method	100.0	95.2	98.1	96.0	98.3	104.8	101.2	101.7	100.9	101.6	99.9	106.2	101.8	104.0	101.5	101.1	100.4	105.8	101.8
ASTM D 357, Motor Method	87.3	89.0	88.4	88.1	88.2	94.8	90.4	93.1	89.8	91.2	89.5	95.7	90.5	92.9	90.1	91.1	89.3	95.6	90.4
Sensitivity	12.7	6.2	9.7	7.9	10.1	10.0	10.8	8.6	11.1	10.4	10.4	10.5	11.3	11.1	11.4	10.0	11.1	10.2	11.4
Road octane number (four-car average):																			
Modified Borderline, 2,000 rpm	100.0	97.2	99.2	95.4	98.5	104.4	101.5	103.1	100.8	101.2	100.1	104.7	101.3	103.2	101.3	101.7	101.1	105.5	101.4
Modified Borderline, 3,500 rpm	94.4	97.9	96.2	96.4	95.6	104.0	98.6	102.5	97.6	101.7	97.0	103.5	97.8	101.2	97.0	99.7	96.0	103.9	97.4
Modified Uniontown	98.1	96.8	99.0	95.1	98.1	104.7	100.6	102.4	100.3	101.3	99.6	104.6	100.4	102.8	100.0	101.4	99.8	104.9	100.3

* Same as No. 54.

TABLE 2b—Blend Compositions and Octane Data

(All blends contain 3 ml TEL, Motor Mix, per gal)

Component Blend No.:	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
	Per Cent by Volume of 10-Lb RVP Component																		
Light catalytically cracked:																			
A	....	50	....	....	....	....	....	70	....	35	35	35	40	....	40	....	40	....	....
B	....	....	100	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Full-range catalytically cracked:																			
A	....	....	....	....	100	50	....	....	....	....	....	....	....	....	....	....	....	....	....
C_7+ reformate:																			
B	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	70
Aromatic extract:																			
B	100	50	....	50	....	50	....	....	70	35	35	35	40	70	40	70	40	70	....
Alkylate:																			
A	....	....	....	....	....	....	100	30	30	30	....	....	....	....	....	....	....	....	....
B	....	....	....	....	....	....	....	....	....	....	30	....	....	....	....	....	....	....	....
C	....	....	....	....	....	....	....	....	....	....	....	30	....	....	....	....	....	....	....
Isomerate:																			
A	....	....	....	....	....	....	....	....	....	....	....	....	20	30	....	....	....	....	30
B	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20	30	....	....	....
C	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20	30	....
Laboratory octane number:																			
ASTM D 908, Research Method	102.1	100.6	100.3	101.1	99.2	100.5	102.9	101.5	102.6	101.7	101.8	102.1	99.5	99.6	99.8	100.3	99.9	99.8	102.8
ASTM D 357, Motor Method	92.1	89.8	86.7	89.4	88.9	90.3	104.6	90.6	95.2	92.9	92.9	92.7	90.2	92.6	90.4	92.9	90.0	92.6	93.8
Sensitivity	10.0	10.8	13.6	11.7	10.3	10.2	—1.7	10.9	7.4	8.8	8.9	9.4	9.3	7.0	9.4	7.4	9.9	7.2	9.0
Road octane number (four-car average):																			
Modified Borderline, 2,000 rpm	101.9	100.5	99.8	100.8	99.3	100.5	108.2	101.7	103.1	102.4	102.4	102.5	100.6	101.3	101.2	101.5	100.5	100.4	102.9
Modified Borderline, 3,500 rpm	101.6	96.8	93.5	96.9	95.2	97.9	106.2	97.1	101.6	98.9	98.9	99.2	98.1	101.1	98.3	101.4	97.6	100.7	102.3
Modified Uniontown	101.6	99.7	97.2	99.9	98.4	100.0	107.5	100.1	102.7	101.7	101.6	101.7	100.0	101.0	100.4	101.2	100.4	100.8	102.8

TABLE 2c—Blend Compositions and Octane Data

(All blends contain 3 ml TEL, Motor Mix, per gal)

Component Blend No.:	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54 *	55	56	57
	Per Cent by Volume of 10-Lb RVP Component																		
Light catalytically cracked:																			
A	37.5	40	....	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
C	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	13.5	....
Full-range catalytically cracked:																			
B	....	....	....	....	100	84.5	69.5	69.5	70	54.5	....	....	....	....	....	....	....	....	....
Polymer:																			
Trimer	....	20	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
C_5+ reformate:																			
D	....	....	....	....	....	....	....	....	....	....	100	85	70	70	55	....	....	....	....
E	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	100	70	56.0	55.5
Aromatic extract:																			
B	37.5†	40	80	50†	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Alkylate:																			
A	....	....	....	....	....	15.5	30.5	....	....	45.5	....	15	30	....	45	....	30	30.5	30.0
Pure hydrocarbon:																			
2,3-Dimethylbutane	....	....	....	....	....	....	....	30.5	....	....	....	....	....	30	....	....	....	....	....
Mixed methylpentanes	....	....	....	....	....	....	....	....	30	....	....	....	....	....	....	....	....	....	....
*Iso*pentane	25.0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	14.5
Laboratory octane number:																			
ASTM D 908, Research Method	100.8	100.9	102.0	100.3	97.4	98.3	99.0	100.8	97.0	100.2	98.4	98.4	99.2	101.4	99.8	101.7	102.2	102.7	102.3
ASTM D 357, Motor Method	91.9	89.2	91.0	89.4	86.1	87.8	89.5	91.2	87.7	92.1	91.0	92.3	94.7	96.3	96.8	93.1	95.8	95.7	98.6
Sensitivity	8.9	11.7	11.0	10.9	11.3	10.5	9.5	9.6	9.3	8.1	7.4	6.1	4.5	5.1	3.0	8.6	6.4	7.0	3.7
Road octane number (four-car average):																			
Modified Borderline, 2,000 rpm	101.2	99.9	101.2	100.8	98.4	99.0	100.1	100.9	98.7	101.2	98.4	99.5	100.2	104.1	102.7	103.1	105.0	105.0	105.0
Modified Borderline, 3,500 rpm	98.1	95.2	97.8	97.0	93.8	94.3	95.5	97.9	94.0	97.5	100.0	100.1	102.2	103.0	103.2	102.5	104.0	102.8	104.1
Modified Uniontown	100.6	98.4	100.5	100.0	97.4	97.9	99.1	99.9	97.8	100.2	98.5	99.0	100.8	104.1	102.1	102.4	104.2	104.0	104.4

* Same as No. 8.
† Not pressurized.

TABLE 2d—Blend Compositions and Octane Data

(All blends contain 3 ml TEL, Motor Mix, per gal)

Component								Per Cent by Volume of 10-Lb RVP Component									
Blend No.:	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
Light catalytically cracked:																	
C	....	....	....	....	....	....	13.5	....	37.5	....	23.0	37	....	23.0	37.5	....	....
C_5+ reformate:																	
F	100	85	70	70	70.5	55	56.0	55.5	....	....	....	....	....	....	....	....	....
C_7+ reformate:																	
B	....	....	....	....	....	....	....	....	62.5	60	47.5	....	....	....	....	....	....
C	....	....	....	....	....	....	....	....	....	....	....	63	60	47.5	....	....	....
Aromatic extract:																	
A	....	....	....	....	....	....	....	....	....	....	....	....	....	....	62.5	62	81
Alkylate:																	
A	....	15	30	....	....	45	30.5	30.0	....	....	29.5	....	....	29.5	....	....	....
Pure hydrocarbon:																	
2,3-Dimethylbutane	....	....	....	30	....	....	....	....	....	....	....	....	....	....	....	38	19
Mixed methylpentanes	....	....	....	....	29.5	....	....	....	....	....	....	....	....	....	....	....	....
*Iso*pentane	....	....	....	....	....	....	....	14.5	....	40	....	....	40	....	....	....	....
Laboratory octane number:																	
ASTM D 908, Research Method	104.5	104.6	104.8	107.1	101.9	104.5	104.3	104.3	103.8	104.9	104.8	104.6	106.5	106.0	103.8	108.6	107.4
ASTM D 357, Motor Method	94.2	95.3	97.1	97.8	94.3	98.6	96.3	98.7	92.5	96.4	95.5	93.6	97.1	95.8	92.6	99.5	96.5
Sensitivity	10.3	9.3	7.7	9.3	7.6	5.9	8.0	5.6	11.3	8.5	9.3	11.0	9.4	10.2	11.2	9.1	10.9
Road octane number (four-car average):																	
Modified Borderline, 2,000 rpm	105.1	105.7	106.1	108.0	103.8	106.6	105.4	106.6	103.6	105.5	105.6	104.5	107.0	106.2	103.8	107.9	107.2
Modified Borderline, 3,500 rpm	104.7	105.2	104.7	106.3	103.0	105.2	103.1	105.3	101.3	104.6	103.3	101.8	106.2	103.5	101.2	105.9	105.6
Modified Uniontown	104.4	105.4	105.4	107.0	103.4	105.9	104.6	105.9	103.1	105.3	104.6	103.6	106.5	104.9	102.9	107.1	106.9

TABLE 3a—Inspection Data on Experimental Blends

Inspection / Blend No.:	1	2	3	4	5	6	7	8*	9	10	11	12
Gravity, deg API at 60 F	72.4	57.6	64.8	52.5	62.0	45.1	57.6	49.9	61.1	43.2	56.6	40.8
Reid vapor pressure, psi	10.1	9.6	9.9	9.9	10.0	9.6	9.9	9.9	10.0	10.1	10.1	9.5
ASTM distillation, deg F:												
Initial boiling point	97	90	90	86	87	84	92	82	92	90	88	91
5 per cent evaporated	110	105	106	90	99	98	108	110	106	...	103	...
10 per cent evaporated	116	126	117	124	113	120	117	129	117	...	117	140
20 per cent evaporated	122	158	132	194	131	159	130	165	131	280	137	253
50 per cent evaporated	143	225	184	273	203	279	193	250	183	300	240	289
70 per cent evaporated	174	253	226	291	261	309	268	289	240	309	291	308
90 per cent evaporated	248	289	281	323	305	348	330	334	309	330	322	338
End point	312	347	344	391	378	399	384	398	381	396	379	420
Recovery, per cent by volume	98.0	97.0	98.0	94.5	97.0	96.5	98.0	98.0	98.0	88.0	97.5	90.5
Residue, per cent by volume	1.0	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0
Loss, per cent by volume	1.0	2.0	1.0	4.5	2.0	2.0	1.0	1.0	1.0	11.0	1.5	8.5
Analysis of hydrocarbon type, per cent by volume:												
Aromatics	6	35	21	42	24	69	38	56	31	70	38	79
Olefins	44	1	23	3	24	0	22	0	22	0	22	0
Sulfur, per cent by weight	0.029	0.010	0.020	0.000	0.015	0.000	0.015	0.001	0.015	0.006	0.018	0.005
ASTM octane numbers:												
D 908, Research Method	100.0	95.2	98.1	96.0	98.3	104.8	101.2	101.7	100.9	101.6	99.9	106.2
D 357, Motor Method	87.3	89.0	88.4	88.1	88.2	94.8	90.4	93.1	89.8	91.2	89.5	95.7
Sensitivity	12.7	6.2	9.7	7.9	10.1	10.0	10.8	8.6	11.1	10.4	10.4	10.5
Tetraethyllead content, ml per gal as Motor Mix	3.14	2.99	3.07	3.03	3.09	3.04	3.09	3.02	3.08	3.02	3.08	3.03

* Same as No. 54.

TABLE 3b—Inspection Data on Experimental Blends

Inspection / Blend No.:	13	14	15	16	17	18	19	20	21	22	23	24
Gravity, deg API at 60 F	55.2	45.0	57.5	51.4	61.3	41.3	55.5	47.9	59.3	74.1	59.9	64.2
Reid vapor pressure, psi	9.8	10.2	10.2	9.5	9.8	10.4	10.3	10.4	10.3	9.5	10.0	9.3
ASTM distillation, deg F:												
Initial boiling point	88	91	94	91	94	93	88	88	91	103	90	92
5 per cent evaporated	103	...	106	100	105	...	102	...	101	114	106	106
10 per cent evaporated	113	109	116	119	117	...	116	102	114	121	116	121
20 per cent evaporated	133	188	133	154	133	247	135	169	122	126	133	138
50 per cent evaporated	220	272	203	246	183	287	221	267	194	141	185	201
70 per cent evaporated	278	294	262	284	241	306	275	301	256	159	241	270
90 per cent evaporated	323	336	318	321	304	338	321	343	323	192	317	336
End point	397	400	387	357	353	407	389	397	385	260	384	381
Recovery, per cent by volume	97.5	92.0	97.0	96.0	97.0	88.5	97.0	91.0	97.0	98.0	97.5	97.5
Residue, per cent by volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0
Loss, per cent by volume	1.5	7.0	2.0	3.0	2.0	10.5	2.0	8.0	2.0	1.5	1.5	1.5
Analysis of hydrocarbon type, per cent by volume:												
Aromatics	43	64	35	48	27	79	43	59	33	0	30	25
Olefins	22	14	29	8	26	0	22	0	22	61	31	29
Sulfur, per cent by weight	0.015	0.006	0.018	0.007	0.018	0.003	0.016	0.000	0.015	0.011	0.006	0.016
ASTM octane numbers:												
D 908, Research Method	101.8	104.0	101.5	101.1	100.4	105.8	101.8	102.1	100.6	100.3	101.1	99.2
D 357, Motor Method	90.5	92.9	90.1	91.1	89.3	95.6	90.4	92.1	89.8	86.7	89.4	88.9
Sensitivity	11.3	11.1	11.4	10.0	11.1	10.2	11.4	10.0	10.8	13.6	11.7	10.3
Tetraethyllead content, ml per gal as Motor Mix	3.09	3.02	3.08	2.92	3.03	3.01	3.08	3.01	3.08	2.96	2.99	3.00

TABLE 3c—Inspection Data on Experimental Blends

Inspection Blend No.:	25	26	27	28	29	30	31	32	33	34	35	36
Gravity, deg API at 60 F	53.9	74.1	72.9	55.0	63.5	63.5	62.6	62.9	56.2	63.2	56.0	61.1
Reid vapor pressure, psi	9.9	10.0	10.1	10.3	10.2	10.2	10.1	10.5	10.7	10.5	11.1	10.2
ASTM distillation, deg F:												
Initial boiling point	90	89	93	88	93	87	87	94	92	94	92	100
5 per cent evaporated	102	102	109	96	102	98	104	105	108	104	105	111
10 per cent evaporated	119	123	115	120	115	111	115	115	121	114	117	125
20 per cent evaporated	148	157	126	170	137	132	134	128	142	127	136	137
50 per cent evaporated	240	214	162	242	204	205	205	175	217	171	216	184
70 per cent evaporated	292	226	200	272	244	239	246	230	283	234	277	241
90 per cent evaporated	342	244	244	330	309	300	308	319	335	319	336	323
End point	390	298	323	391	374	373	379	382	395	382	392	382
Recovery, per cent by volume	97.0	96.5	98.0	95.0	97.0	97.0	97.0	98.0	98.0	98.0	98.0	98.0
Residue, per cent by volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Loss, per cent by volume	2.0	2.5	1.0	4.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0
Analysis of hydrocarbon type, per cent by volume:												
Aromatics	42	0	4	41	23	23	23	26	41	26	41	26
Olefins	15	0	31	0	15	15	15	18	0	18	0	18
Sulfur, per cent by weight	0.008	0.004	0.022	0.001	0.012	0.011	0.013	0.012	0.000	0.012	0.000	0.012
ASTM octane numbers:												
D 908, Research Method	100.5	102.9	101.5	102.6	101.7	101.8	102.1	99.5	99.6	99.8	100.3	99.9
D 357, Motor Method	90.3	104.6	90.6	95.2	92.9	92.9	92.7	90.2	92.6	90.4	92.9	90.0
Sensitivity	10.2	−1.7	10.9	7.4	8.8	8.9	9.4	9.3	7.0	9.4	7.4	9.9
Tetraethyllead content, ml per gal as Motor Mix	3.01	3.02	3.11	3.01	3.06	3.04	3.06	3.07	3.02	3.04	3.01	3.06

TABLE 3d—Inspection Data on Experimental Blends

Inspection Blend No.:	37	38	39	40	41	42	43	44	45	46	47	48
Gravity, deg API at 60 F	54.4	51.1	65.0	61.0	51.0	55.4	59.3	59.7	62.8	65.0	64.3	64.5
Reid vapor pressure, psi	10.3	10.1	10.5	10.1	10.3	6.1	9.7	9.8	9.8	9.7	9.6	9.8
ASTM distillation, deg F:												
Initial boiling point	100	92	91	88	87	105	88	91	86	98	83	74
5 per cent evaporated	120	106	101	100	...	125	107	112	107	112	102	99
10 per cent evaporated	133	120	109	112	121	135	122	126	120	122	113	117
20 per cent evaporated	157	145	117	132	193	149	145	145	143	134	122	140
50 per cent evaporated	227	252	150	215	265	212	213	222	217	169	152	215
70 per cent evaporated	285	297	228	267	293	269	253	275	258	230	208	248
90 per cent evaporated	340	331	312	307	337	330	345	358	341	346	332	331
End point	402	402	379	373	396	386	385	389	389	389	383	396
Recovery, per cent by volume	98.0	97.0	97.0	97.0	92.5	98.0	96.5	98.0	98.0	97.0	96.0	96.5
Residue, per cent by volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5
Loss, per cent by volume	1.0	2.0	2.0	2.0	6.5	1.0	2.5	1.0	1.0	2.0	3.0	2.0
Analysis of hydrocarbon type, per cent by volume:												
Aromatics	41	55	28	26	47	37	14	13	8	13	13	4
Olefins	0	0	16	38	20	22	41	36	31	25	26	26
Sulfur, per cent by weight	0.000	0.004	0.011	0.012	0.000	0.015	0.054	0.045	0.031	0.037	0.043	0.034
ASTM octane numbers:												
D 908, Research Method	99.8	102.8	100.8	100.9	102.0	100.3	97.4	98.3	99.0	100.8	97.0	[illegible]
D 357, Motor Method	92.6	93.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sensitivity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Tetraethyllead content, ml per gal as Motor Mix..... 3.01 3.03 2.75 3.05 3.01 2.98 2.90 2.97 2.94 3.04 3.10 3.06

TABLE 3e—Inspection Data on Experimental Blends

Inspection Blend No.:	49	50	51	52	53	54 *	55	56	57	58	59	60
Gravity, deg API at 60 F	56.8	57.4	62.5	62.1	66.4	49.9	56.4	60.7	60.8	49.7	50.9	54.6
Reid vapor pressure, psi	10.0	10.0	9.7	9.7	9.9	9.9	9.8	10.7	10.4	10.2	9.6	10.0
ASTM distillation, deg F:												
Initial boiling point	90	102	88	93	86	82	90	85	85	73	83	92
5 per cent evaporated	111	120	107	98	108	110	111	100	104	107	108	113
10 per cent evaporated	125	135	125	112	128	129	128	116	119	130	128	134
20 per cent evaporated	152	163	155	138	157	165	162	139	138	165	167	170
50 per cent evaporated	243	239	226	180	223	250	229	213	222	252	242	233
70 per cent evaporated	287	275	248	243	251	289	261	248	256	292	279	262
90 per cent evaporated	334	328	306	317	303	334	320	310	312	336	330	321
End point	389	384	366	378	368	398	388	384	390	419	412	400
Recovery, per cent by volume	96.0	98.0	96.0	96.0	97.0	98.0	97.0	98.0	97.5	97.0	97.0	98.0
Residue, per cent by volume	2.0	1.0	2.0	1.0	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0
Loss, per cent by volume	2.0	1.0	2.0	3.0	2.0	1.0	1.5	1.0	1.5	2.0	2.0	1.0
Analysis of hydrocarbon type, per cent by volume:												
Aromatics	44	36	31	31	24	56	37	30	34	71	53	41
Olefins	0	8	2	2	1	0	2	9	2	3	1	2
Sulfur, per cent by weight	0.000	0.001	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.000
ASTM octane numbers:												
D 908, Research Method	98.4	98.4	99.2	101.4	99.8	101.7	102.2	102.7	102.3	104.5	104.6	104.8
D 357, Motor Method	91.0	92.3	94.7	96.3	96.8	93.1	95.8	95.7	98.6	94.2	95.3	97.1
Sensitivity	7.4	6.1	4.5	5.1	3.0	8.6	6.4	7.0	3.7	10.3	9.3	7.7
Tetraethyllead content, ml per gal as Motor Mix	2.94	2.94	3.00	2.97	3.00	3.02	3.05	2.99	3.11	3.00	3.05	3.13

* Same as No. 8.

TABLE 3f—Inspection Data on Experimental Blends

Inspection Blend No.:	61	62	63	64	65	66	67	68	69	70	71
Gravity, deg API at 60 F	56.3	56.6	58.3	59.3	59.0	53.1	53.4	56.3	50.8	51.3	56.6
Reid vapor pressure, psi	9.6	9.5	9.8	10.4	10.5	9.8	10.2	10.0	10.1	10.3	9.7
ASTM distillation, deg F:											
Initial boiling point	98	87	89	95	82	80	82	92	85	78	91
5 per cent evaporated	111	110	111	108	104	95	91	110	90	99	101
10 per cent evaporated	122	123	131	119	118	106	100	126	104	110	114
20 per cent evaporated	141	141	168	142	139	126	113	155	128	122	140
50 per cent evaporated	193	190	228	216	220	238	248	238	228	253	222
70 per cent evaporated	260	257	251	252	250	290	291	270	283	288	258
90 per cent evaporated	318	313	311	314	311	334	325	322	330	330	312
End point	408	402	398	389	394	404	398	400	408	410	395
Recovery, per cent by volume	97.0	97.0	97.0	98.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Residue, per cent by volume	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Loss, per cent by volume	2.0	2.0	1.5	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Analysis of hydrocarbon type, per cent by volume:											
Aromatics	44	45	34	27	36	40	52	37	38	57	31
Olefins	1	0	2	16	1	24	2	13	23	1	20
Sulfur, per cent by weight	0.000	0.006	0.001	0.001	0.001	0.002	0.001	0.002	0.002	0.000	0.002
ASTM octane numbers:											
D 908, Research Method	107.1	101.9	104.5	104.3	104.3	103.8	104.9	104.8	104.6	106.5	106.0
D 357, Motor Method	97.8	94.3	98.6	96.3	98.7	92.5	96.4	95.5	93.6	97.1	95.8
Sensitivity	9.3	7.6	5.9	8.0	5.6	11.3	8.5	9.3	11.0	9.4	10.2
Tetraethyllead content, ml per gal as Motor Mix	3.00	2.98	2.90	2.89	3.09	3.09	2.98	2.99	3.06	3.10	3.08

TABLE 3g—Inspection Data on Experimental Blends

Inspection Blend No.:	72	73	74
Gravity, deg API at 60 F	52.0	55.6	48.5
Reid vapor pressure, psi	9.9	10.7	10.3
ASTM distillation, deg F:			
Initial boiling point	89	78	81
5 per cent evaporated	100	101	112
10 per cent evaporated	112	116	138
20 per cent evaporated	132	141	225
50 per cent evaporated	241	220	294
70 per cent evaporated	290	294	322
90 per cent evaporated	333	333	371
End point	402	402	407
Recovery, per cent by volume	96.0	97.5	97.0
Residue, per cent by volume	1.0	1.0	1.0
Loss, per cent by volume	3.0	1.5	3.0
Analysis of hydrocarbon type, per cent by volume:			
Aromatics	41	45	57
Olefins	25	1	5
Sulfur, per cent by weight	0.002	0.000	0.001
ASTM octane numbers:			
D 908, Research Method	103.8	108.6	107.4
D 357, Motor Method	92.6	99.5	96.5
Sensitivity	11.2	9.1	10.9
Tetraethyllead content, ml per gal as Motor Mix	2.95	3.01	3.04

TABLE 4a—Detailed Road-Octane-Number Results

Fuel No.:	1	2	3	4	5	6	7	8*	9	10	11	12	13
Laboratory Octane Numbers													
ASTM D 908, Research Method	100.0	95.2	98.1	96.0	98.3	104.8	101.2	101.7	100.9	101.6	99.9	106.2	101.8
ASTM D 357, Motor Method	87.3	89.0	88.4	88.1	88.2	94.8	90.4	93.1	89.8	91.2	89.5	95.7	90.5
Sensitivity	12.7	6.2	9.7	7.9	10.1	10.0	10.8	8.6	11.1	10.4	10.4	10.5	11.3
Road Octane Numbers													
Four-Car Average													
Modified Borderline:													
2,000 rpm	100.0	97.2	99.2	95.4	98.5	104.4	101.5	103.1	100.8	101.2	100.1	104.7	101.3
2,500 rpm	98.1	97.2	98.5	95.9	97.7	104.4	100.5	102.5	100.1	101.1	99.4	104.2	100.1
3,000 rpm	96.4	97.8	97.7	97.2	96.8	105.0	100.3	103.0	99.0	102.2	98.3	104.5	99.1
3,500 rpm	94.4	97.9	96.2	96.4	95.6	104.0	98.6	102.5	97.6	101.7	97.0	103.5	97.8
Modified Uniontown	98.1	96.8	99.0	95.1	98.1	104.7	100.6	102.4	100.3	101.3	99.6	104.6	100.4
11:1 CR, Car G													
Modified Borderline:													
1,500 rpm	102.0	94.0	98.6	93.3	97.1	102.9	101.5	99.9	101.0	101.4	100.3	103.8	102.4
2,000 rpm	100.6	95.7	99.1	95.0	97.9	103.5	100.8	102.1	100.5	100.5	99.9	104.0	101.6
2,500 rpm	98.9	97.0	98.9	95.2	97.5	104.0	100.2	102.4	100.1	101.3	99.4	103.9	100.0
3,000 rpm	96.8	97.5	98.3	96.5	96.8	103.8	99.5	102.1	98.9	101.2	98.2	103.9	99.5
3,500 rpm	94.4	98.4	95.7	95.1	95.0	102.7	97.7	102.3	97.1	100.3	96.5	103.3	97.1
Modified Uniontown	98.5	94.8	98.9	94.0	97.0	103.8	100.0	100.4	100.2	101.1	99.3	103.8	100.3
Knocking speed, rpm	3,500	1,500	1,500	1,500	1,500, 2,500	1,500	3,000	1,500	3,000	2,000	2,500, 3,000	2,500, 3,500	3,500
11:1 CR, Car S													
Modified Borderline:													
2,000 rpm	100.4	97.4	99.4	95.6	98.8	105.9	102.4	103.4	101.3	101.8	100.5	105.7	101.6
2,500 rpm	98.0	96.9	98.2	95.8	97.7	104.7	100.3	102.1	99.8	101.0	99.2	104.1	100.0
3,000 rpm	95.1	96.9	96.3	96.8	96.0	105.5	100.1	101.9	98.1	100.9	97.1	103.2	98.0
3,500 rpm	92.6	96.3	94.7	96.7	94.1	105.3	98.5	102.3	95.8	101.9	95.9	103.0	96.3
Modified Uniontown	98.3	97.3	99.2	95.6	98.5	106.0	101.1	103.6	100.7	101.7	99.8	105.1	100.5
Knocking speed, rpm	3,500	2,000	2,500	2,000	2,000	2,000, 2,500	3,500	2,000, 2,500	3,000	2,000	3,000	2,500	3,000
12:1 CR, Car L													
Modified Borderline:													
2,000 rpm	99.7	97.3	99.1	96.0	98.9	104.4	102.2	103.1	100.8	101.6	100.2	103.8	100.9
2,500 rpm	97.9	97.6	99.0	96.9	98.5	106.0	101.6	104.2	100.7	101.6	100.4	104.5	100.8
3,000 rpm	97.0	100.1	99.0	99.8	98.7	107.8	102.2	106.9	100.4	105.9	100.1	107.0	100.5
3,500 rpm	95.2	99.6	98.2	98.9	97.9	105.2	99.3	104.2	99.9	104.0	99.3	104.6	100.3
Modified Uniontown	97.6	97.3	99.1	96.0	98.8	105.2	101.2	103.4	100.5	101.6	99.9	104.1	100.6
Knocking speed, rpm	3,500	2,000	2,000, 3,000, 3,500	2,000	2,000	2,000	3,500	2,000	3,000, 3,500	2,500	3,500	2,000	3,000, 3,500
12:1 CR Car D													
Modified Borderline:													
2,000 rpm	99.3	98.4	99.2	94.9	98.5	103.8	100.5	104.0	100.8	100.9	100.0	105.3	101.0
2,500 rpm	97.7	97.3	97.9	95.7	97.1	103.0	99.9	101.3	99.7	100.6	98.8	104.3	99.6
3,000 rpm	96.9	96.9	97.1	95.7	95.8	103.0	99.4	101.1	98.7	100.7	98.0	103.8	98.5
3,500 rpm	95.3	97.5	96.2	95.0	95.3	102.7	98.9	104.2	97.6	100.5	96.5	103.0	97.4
4,000 rpm	93.8	97.7	95.2	94.3	93.6	102.0	97.2	101.2	96.2	98.6	95.5	103.0	96.4
Modified Uniontown	98.0	97.9	98.8	94.9	98.0	103.9	100.1	102.3	99.9	101.0	99.5	105.2	100.1
Knocking speed, rpm	2,500, 4,000	2,000, 2,500	2,500	2,000	2,000	2,000	2,000	2,500	4,000	2,000	4,000	2,000, 2,500	3,000, 4,000

* Same as No. 54.

TABLE 4b—Detailed Road-Octane-Number Results

Fuel No.:	14	15	16	17	18	19	20	21	22	23	24	25	26
Laboratory Octane Numbers													
ASTM D 908, Research Method	104.0	101.5	101.1	100.4	105.8	101.8	102.1	100.6	100.3	101.1	99.2	100.5	102.9
ASTM D 357, Motor Method	92.9	90.1	91.1	89.3	95.6	90.4	92.1	89.8	86.7	89.4	88.9	90.3	104.6
Sensitivity	11.1	11.4	10.0	11.1	10.2	11.4	10.0	10.8	13.6	11.7	10.3	10.2	—1.7
Road Octane Numbers													
Four-Car Average													
Modified Borderline:													
2,000 rpm	103.2	101.3	101.7	101.1	105.5	101.4	101.9	100.5	99.8	100.8	99.3	100.5	108.2
2,500 rpm	102.3	100.2	101.4	99.6	104.7	100.3	101.6	99.4	97.7	99.7	98.2	99.9	108.1
3,000 rpm	102.4	98.7	101.0	98.0	105.4	99.3	101.9	98.5	95.7	98.6	97.0	99.4	107.4
3,500 rpm	101.2	97.0	99.7	96.0	103.9	97.4	101.6	96.8	93.5	96.9	95.2	97.9	106.2
Modified Uniontown	102.8	100.0	101.4	99.8	104.9	100.3	101.6	99.7	97.2	99.9	98.4	100.0	107.5
11:1 CR, Car G													
Modified Borderline:													
1,500 rpm	102.7	102.0	99.8	101.2	104.9	102.5	100.0	100.4	102.2	101.6	98.7	99.8	108.4
2,000 rpm	102.9	101.4	101.0	100.7	104.9	102.0	101.3	100.7	100.3	101.3	98.9	99.8	109.5
2,500 rpm	102.5	100.7	100.9	99.8	104.8	101.1	101.3	100.1	98.3	100.4	98.5	99.6	109.0
3,000 rpm	101.5	99.1	100.4	98.0	104.4	100.0	101.1	99.1	95.9	99.1	97.5	98.9	107.4
3,500 rpm	100.2	96.6	99.2	95.3	103.3	97.2	100.6	96.5	93.2	96.6	95.1	96.8	106.3
Modified Uniontown	102.3	100.0	99.9	99.0	103.0	100.2	100.2	99.8	97.2	99.8	98.3	99.3	107.5
Knocking speed, rpm	3,500	3,500	1,500	3,500	3,500	3,500	1,500	3,500	3,500	3,500	1,500, 2,500, 3,000, 3,500	2,500	3,500
11:1 CR, Car S													
Modified Borderline:													
2,000 rpm	103.6	101.2	101.4	101.4	106.1	101.4	102.3	100.8	100.0	101.2	100.5	101.4	106.8
2,500 rpm	101.7	99.4	100.1	99.7	104.0	99.6	101.0	99.3	97.5	99.2	98.5	100.0	107.3
3,000 rpm	100.9	96.8	99.2	96.9	104.7	97.9	100.9	97.2	94.8	97.2	96.7	98.7	107.0
3,500 rpm	100.2	94.5	97.4	95.1	103.5	95.8	99.8	95.6	92.0	95.0	93.9	97.5	105.7
Modified Uniontown	103.1	99.7	101.4	100.1	105.7	100.3	101.8	100.0	97.7	100.0	99.4	100.7	107.2
Knocking speed, rpm	2,500	3,500	2,000	3,000, 3,500	2,500	3,500	2,500	3,000	3,500	3,000	3,500	2,000, 2,500, 3,000	3,500
12:1 CR, Car L													
Modified Borderline:													
2,000 rpm	104.3	101.9	103.2	101.3	105.4	101.3	102.2	100.7	99.5	100.5	99.4	100.5	108.0
2,500 rpm	103.4	101.5	103.8	99.7	106.4	100.5	103.3	99.6	97.4	100.3	98.3	100.5	108.5
3,000 rpm	105.6	100.5	103.7	99.0	109.2	100.3	105.2	100.0	93.6	100.4	97.9	100.9	108.1
3,500 rpm	103.1	98.9	102.0	97.5	105.2	98.9	103.0	98.4	94.9	99.6	97.2	99.4	106.1
Modified Uniontown	103.7	100.5	103.2	100.2	106.1	100.4	102.6	99.8	97.3	100.3	98.7	100.1	107.2
Knocking speed, rpm	2,500	3,500	2,000	3,000, 3,500	2,000	3,000	2,000	2,500	3,000	3,500	2,500	2,000, 2,500, 3,500	3,500
12:1 CR, Car D													
Modified Borderline:													
2,000 rpm	101.9	100.8	101.1	101.1	105.5	101.0	101.9	99.9	99.4	100.1	98.6	100.4	108.5
2,500 rpm	101.8	99.3	100.9	99.4	103.8	100.0	101.0	98.8	97.6	98.8	97.5	99.7	107.7
3,000 rpm	101.5	98.4	100.6	98.1	103.5	98.9	100.4	97.6	95.7	97.7	95.8	99.1	107.3
3,500 rpm	101.2	97.9	100.3	96.1	103.5	97.9	103.0	96.6	94.0	96.3	94.8	98.0	106.6
4,000 rpm	100.7	96.7	99.9	95.3	103.6	96.4	99.8	95.3	92.4	95.1	92.8	96.9	106.9
Modified Uniontown	102.2	99.6	101.1	99.8	104.8	100.2	101.7	99.3	96.8	99.6	97.4	100.1	108.0
Knocking speed, rpm	2,000	4,000	2,000	4,000	2,500	4,000	2,000	4,000	4,000	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 4c—Detailed Road-Octane-Number Results

Fuel No.:	27	28	29	30	31	32	33	34	35	36	37	38	39
Laboratory Octane Numbers													
ASTM D 908, Research Method	101.5	102.6	101.7	101.8	102.1	99.5	99.6	99.8	100.3	99.9	99.8	102.8	100.8
ASTM D 357, Motor Method	90.6	95.2	92.9	92.9	92.7	90.2	92.6	90.4	92.9	90.0	92.6	93.8	91.9
Sensitivity	10.9	7.4	8.8	8.9	9.4	9.3	7.0	9.4	7.4	9.9	7.2	9.0	8.9
Road Octane Numbers													
Four-Car Average													
Modified Borderline:													
2,000 rpm	101.7	103.1	102.4	102.4	102.5	100.6	101.3	101.2	101.5	100.5	100.4	102.9	101.2
2,500 rpm	100.4	102.8	101.8	101.6	101.7	99.9	101.6	100.3	101.7	99.8	101.0	103.2	100.2
3,000 rpm	98.7	102.7	100.7	100.7	100.8	99.4	101.8	99.7	102.1	99.1	101.0	103.5	99.4
3,500 rpm	97.1	101.6	98.9	98.9	99.2	98.1	101.1	98.3	101.4	97.6	100.7	102.3	98.1
Modified Uniontown	100.1	102.7	101.7	101.6	101.7	100.0	101.0	100.4	101.2	100.4	100.8	102.8	100.6
11:1 CR, Car G													
Modified Borderline:													
1,500 rpm	103.5	101.3	102.8	102.5	101.9	100.6	98.8	101.2	99.3	100.9	98.6	100.9	100.6
2,000 rpm	102.3	102.2	102.6	102.5	102.6	99.6	100.6	100.7	100.9	100.5	100.3	102.3	100.9
2,500 rpm	101.5	102.6	102.0	101.9	102.1	99.3	101.5	100.3	101.7	100.1	100.9	102.9	100.6
3,000 rpm	99.6	102.3	100.9	101.1	101.2	98.9	102.0	99.4	101.6	98.7	100.7	102.9	99.5
3,500 rpm	96.5	101.4	99.0	99.0	99.4	98.6	101.2	98.2	101.0	96.3	100.4	102.3	98.3
Modified Uniontown	99.8	101.4	101.6	101.7	101.5	99.6	99.1	100.2	99.3	101.6	101.2	101.9	100.5
Knocking speed, rpm	3,500	1,500	3,000, 3,500	3,500	1,500, 2,500, 3,000, 3,500	2,500	1,500	2,500, 3,000	1,500	3,000	1,500	1,500, 2,000	1,500, 2,500, 3,000
11:1 CR, Car S													
Modified Borderline:													
2,000 rpm	100.5	103.8	102.2	102.3	102.5	101.0	101.6	101.7	102.6	101.0	101.0	103.5	101.3
2,500 rpm	99.0	102.2	100.7	100.6	100.9	99.8	100.9	100.5	101.7	99.3	100.2	102.4	99.8
3,000 rpm	96.4	101.1	99.2	98.6	99.3	98.5	100.3	99.4	101.8	97.9	100.1	102.8	97.7
3,500 rpm	94.4	99.4	96.1	96.1	96.6	97.0	100.7	98.0	102.8	96.3	100.2	102.1	95.7
Modified Uniontown	99.6	102.8	101.4	101.3	101.7	99.8	101.4	100.5	102.4	100.5	101.3	103.3	100.3
Knocking speed, rpm	3,000, 3,500	2,500	3,500	3,500	3,500	3,000	2,000	3,000, 3,500	2,000	3,000, 3,500	2,000	2,000	3,000
12:1 CR, Car L													
Modified Borderline:													
2,000 rpm	101.4	104.1	103.1	102.5	103.2	102.1	102.7	101.7	102.2	101.4	101.8	103.5	102.0
2,500 rpm	99.9	104.2	103.5	102.7	103.0	101.2	103.9	100.9	103.2	100.7	103.3	105.3	101.2
3,000 rpm	99.1	105.4	102.6	102.4	102.9	101.3	104.6	101.3	104.7	100.6	103.5	106.3	101.5
3,500 rpm	97.8	103.8	100.7	100.5	101.1	98.9	102.1	98.8	101.9	99.0	102.5	103.3	100.1
Modified Uniontown	100.1	104.2	102.8	102.0	102.8	100.9	103.4	100.8	102.7	100.1	102.3	104.2	101.4
Knocking speed, rpm	3,000	2,500, 3,500	3,500	3,500	3,500	2,500, 3,500	2,000	3,500	2,500	3,500	2,000	3,500	2,000, 2,500, 3,000
12:1 CR, Car D													
Modified Borderline:													
2,000 rpm	102.5	102.4	101.9	102.3	101.9	99.7	100.4	100.7	100.4	99.3	98.6	102.4	100.8
2,500 rpm	101.2	102.2	100.9	101.3	100.7	99.2	100.0	99.7	100.3	99.3	99.7	102.2	99.1
3,000 rpm	99.7	102.0	100.0	100.7	100.0	98.9	100.2	98.9	100.2	99.1	99.7	102.2	99.1
3,500 rpm	99.7	102.0	99.7	100.1	99.6	98.0	100.6	98.2	100.0	98.8	99.8	101.5	98.2
4,000 rpm	98.2	101.9	99.7	99.4	98.4	96.8	99.8	96.9	99.7	97.6	100.4	101.0	96.6
Modified Uniontown	100.9	102.4	101.1	101.5	100.9	99.6	100.1	100.3	100.4	99.3	98.4	101.9	100.1
Knocking speed, rpm	3,000	2,000	3,000	2,000, 3,000	2,000, 4,000	2,000	2,000	2,000, 3,000	2,000	2,000	2,000	2,000	2,500

TABLE 4d—Detailed Road-Octane-Number Results

Fuel No.:	40	41	42	43	44	45	46	47	48	49	50	51	52
Laboratory Octane Numbers													
ASTM D 908, Research Method	100.9	102.0	100.3	97.4	98.3	99.0	100.8	97.0	100.2	98.4	98.4	99.2	101.4
ASTM D 357, Motor Method	89.2	91.0	89.4	86.1	87.8	89.5	91.2	87.7	92.1	91.0	92.3	94.7	96.3
Sensitivity	11.7	11.0	10.9	11.3	10.5	9.5	9.6	9.3	8.1	7.4	6.1	4.5	5.1
Road Octane Numbers													
Four-Car Average													
Modified Borderline:													
2,000 rpm	99.9	101.2	100.8	98.4	99.0	100.1	100.9	98.7	101.2	98.4	99.5	101.2	104.1
2,500 rpm	98.7	100.3	99.6	97.0	97.8	99.0	100.4	97.7	100.1	98.9	99.8	101.7	104.3
3,000 rpm	97.0	99.7	98.9	95.4	96.3	97.5	99.5	96.1	99.2	99.5	100.1	101.9	104.0
3,500 rpm	95.2	97.8	97.0	93.8	94.3	95.5	97.9	94.0	97.5	100.0	100.1	102.2	103.0
Modified Uniontown	98.4	100.5	100.0	97.4	97.9	99.1	99.9	97.8	100.2	98.5	99.0	100.8	104.1
11:1 CR, Car G													
Modified Borderline:													
1,500 rpm	100.1	101.3	100.3	97.2	97.9	99.3	103.1	98.1	102.2	94.5	96.2	98.4	101.9
2,000 rpm	99.4	101.7	100.1	97.9	98.4	99.6	102.1	98.0	102.2	95.3	99.1	99.9	103.9
2,500 rpm	98.8	101.0	99.6	96.7	97.5	99.0	100.9	97.4	101.2	97.0	100.1	101.3	104.2
3,000 rpm	96.9	100.6	98.8	94.5	95.2	97.1	97.5	95.3	100.1	97.7	99.6	102.0	103.9
3,500 rpm	94.2	97.8	96.2	92.2	93.1	95.3	95.3	93.1	97.8	100.5	101.2	102.5	103.1
Modified Uniontown	97.4	100.5	99.2	96.3	96.7	98.8	99.6	96.8	100.7	95.5	96.6	99.0	103.2
Knocking speed, rpm	3,500	3,500	2,500, 3,500	3,000, 3,500	3,000	3,000	3,500	3,500	3,500	1,500	1,500	1,500	1,500
11:1 CR, Car S													
Modified Borderline:													
2,000 rpm	100.0	101.3	102.3	99.0	99.8	100.6	102.3	99.7	102.0	100.1	99.9	101.6	104.8
2,500 rpm	98.1	99.7	100.1	96.6	98.0	98.9	100.0	97.7	100.1	99.2	99.6	101.5	103.8
3,000 rpm	95.9	97.7	98.6	94.3	96.1	96.4	97.9	95.4	98.2	98.9	99.3	100.7	102.3
3,500 rpm	93.6	95.7	95.8	92.0	93.3	93.2	94.5	92.4	95.2	99.9	99.0	101.5	101.3
Modified Uniontown	98.8	100.5	100.9	97.8	98.9	99.1	99.7	98.3	100.5	100.1	100.0	101.6	104.3
Knocking speed, rpm	3,000, 3,500	3,000	3,500	3,500	3,500	3,500	3,500	3,500	3,500	2,000	2,000	2,000	2,000
12:1 CR, Car L													
Modified Borderline:													
2,000 rpm	100.5	101.7	100.9	98.5	98.6	100.3	99.8	98.2	100.4	99.7	99.7	102.4	104.5
2,500 rpm	99.4	101.5	100.4	97.5	97.5	99.2	101.7	97.9	99.8	101.7	101.7	103.7	106.2
3,000 rpm	97.9	101.6	100.4	96.8	96.8	98.7	103.2	96.9	99.6	103.2	102.8	104.5	106.2
3,500 rpm	96.9	99.7	99.2	95.7	94.7	96.9	102.0	94.9	98.9	101.7	101.6	103.9	104.6
Modified Uniontown	98.7	101.3	100.4	97.5	97.2	99.2	101.3	97.6	99.6	100.4	100.4	102.4	105.6
Knocking speed, rpm	3,000	2,500, 3,500	3,000	2,500, 3,500	3,000	2,500, 3,000	2,000	3,000	2,500	2,000	2,000	2,000	3,500
12:1 CR, Car D													
Modified Borderline:													
2,000 rpm	99.7	100.2	100.1	98.1	99.4	100.0	99.4	99.1	100.4	98.5	99.2	101.0	103.4
2,500 rpm	98.5	99.1	98.5	97.3	98.4	98.8	99.2	98.0	99.5	97.9	98.7	100.2	103.0
3,000 rpm	97.5	98.9	97.9	95.9	97.1	97.8	99.5	96.7	99.0	98.1	98.6	100.5	103.6
3,500 rpm	96.1	98.1	97.0	95.5	96.1	96.6	99.7	95.8	98.2	97.9	98.6	100.9	103.0
4,000 rpm	93.9	96.5	95.7	93.3	95.3	95.5	99.1	95.3	97.3	98.0	98.8	101.0	102.0
Modified Uniontown	98.5	99.8	99.4	97.9	98.7	99.3	99.0	98.5	100.0	98.2	98.9	100.2	103.2
Knocking speed, rpm	4,000	2,000, 2,500	2,500, 3,000, 4,000	2,000	3,000	3,000, 4,000	2,000	2,000, 3,000	2,000, 3,000	2,000	2,000	4,000	2,000

TABLE 4e—Detailed Road-Octane-Number Results

Fuel No.:	53	54 *	55	56	57	58	59	60	61	62	63	64	65
Laboratory Octane Numbers													
ASTM D 908, Research Method	99.8	101.7	102.2	102.7	102.3	104.5	104.6	104.8	107.1	101.9	104.5	104.3	104.3
ASTM D 357, Motor Method	96.8	93.1	95.8	95.7	98.6	94.2	95.3	97.1	97.8	94.3	98.6	96.3	98.7
Sensitivity	3.0	8.6	6.4	7.0	3.7	10.3	9.3	7.7	9.3	7.6	5.9	8.0	5.6
Road Octane Numbers													
Four-Car Average													
Modified Borderline:													
2,000 rpm	102.7	103.1	105.0	105.0	105.0	105.1	105.7	106.1	108.0	103.8	106.6	105.4	106.6
2,500 rpm	103.0	102.5	104.9	104.2	104.9	104.8	105.5	105.3	107.4	103.7	106.1	104.8	105.7
3,000 rpm	103.4	103.0	104.7	103.9	104.8	105.3	106.0	105.5	107.6	103.5	106.4	104.5	105.9
3,500 rpm	103.2	102.5	104.0	102.8	104.1	104.7	105.2	104.7	106.3	103.0	105.2	103.1	105.3
Modified Uniontown	102.1	102.4	104.2	104.0	104.4	104.4	105.4	105.4	107.0	103.4	105.9	104.6	105.9
11:1 CR, Car G													
Modified Borderline:													
1,500 rpm	98.7	99.9	102.2	103.7	103.0	104.2	104.5	104.8	108.1	101.6	104.5	105.5	105.0
2,000 rpm	101.6	102.1	105.1	105.1	105.5	105.6	106.0	105.8	107.9	103.5	105.8	106.1	105.6
2,500 rpm	102.5	102.4	105.3	105.0	105.5	105.6	106.5	105.6	107.2	103.6	105.8	105.7	105.2
3,000 rpm	102.4	102.1	104.4	104.1	105.0	105.0	106.7	105.7	106.6	103.4	105.4	105.1	104.7
3,500 rpm	103.4	102.3	103.9	103.0	103.7	104.4	106.8	104.6	106.2	103.2	104.8	103.1	104.5
Modified Uniontown	99.5	100.4	103.8	104.4	103.9	104.5	105.8	105.1	106.9	102.4	104.6	105.8	104.8
Knocking speed, rpm	1,500	1,500	1,500, 3,000	1,500	1,500	1,500	1,500	1,500	3,000	1,500	1,500	2,500, 3,500	3,000
11:1 CR, Car S													
Modified Borderline:													
2,000 rpm	103.9	103.4	105.2	104.8	105.4	105.5	106.7	106.5	108.9	105.2	107.8	105.2	107.7
2,500 rpm	103.1	102.1	104.4	103.8	104.6	104.7	105.7	105.5	107.4	104.0	106.2	104.2	106.1
3,000 rpm	102.5	101.9	103.7	102.7	104.1	103.7	104.5	104.5	106.6	102.9	105.3	103.3	104.7
3,500 rpm	103.3	102.3	104.0	101.9	104.1	104.9	104.9	104.9	105.4	102.7	105.0	102.8	104.4
Modified Uniontown	103.8	103.6	104.8	104.2	105.1	105.0	105.9	105.6	107.6	104.5	106.7	104.6	106.6
Knocking speed, rpm	2,000	2,000, 2,500	3,000	3,000, 3,500	3,000	3,000	3,000	3,000	3,500	3,500	3,000	3,000	3,000
12:1 CR, Car L													
Modified Borderline:													
2,000 rpm	102.4	103.1	105.8	104.9	105.5	104.6	104.7	106.8	107.8	103.7	106.6	105.5	106.6
2,500 rpm	104.3	104.2	107.0	105.2	106.8	106.2	106.0	107.0	109.5	104.8	107.9	105.9	107.4
3,000 rpm	106.3	106.9	107.8	105.8	107.3	110.0	109.3	109.1	112.1	105.3	109.8	106.6	110.0
3,500 rpm	104.0	104.2	105.0	103.8	105.6	107.0	105.8	106.1	108.3	103.8	106.9	103.9	107.7
Modified Uniontown	102.9	103.4	105.4	104.8	105.7	104.9	105.4	107.0	107.8	104.3	107.1	104.7	107.1
Knocking speed, rpm	2,000	2,000	2,000, 3,500	3,500	2,000	2,000	2,000	2,000, 3,500	2,000, 3,500	2,500, 3,500	2,000	2,000, 3,500	2,000
12:1 CR, Car D													
Modified Borderline:													
2,000 rpm	102.8	104.0	103.9	105.1	103.6	104.8	105.4	105.4	107.5	102.8	106.3	104.8	106.7
2,500 rpm	102.1	101.3	103.1	102.9	102.8	102.8	103.8	103.1	105.5	102.3	104.4	103.4	104.2
3,000 rpm	102.5	101.1	103.0	103.0	103.0	102.7	103.6	102.9	105.2	102.5	105.3	103.0	104.4
3,500 rpm	102.3	101.1	103.3	102.6	102.9	102.6	103.4	103.1	105.2	102.2	104.3	102.8	104.5
4,000 rpm	101.2	101.2	102.3	101.1	102.0	102.2	103.0	103.7	103.6	100.2	103.5	101.8	103.5
Modified Uniontown	102.4	102.3	102.9	102.6	102.8	103.4	104.6	104.0	105.9	102.6	105.2	103.2	105.2
Knocking speed, rpm	2,000, 2,500, 4,000	2,500	2,000, 4,000	4,000	4,000	2,000, 2,500	2,000, 2,500	2,500	4,000	2,000	2,000, 2,500	4,000	2,500

* Same as No. 8.

TABLE 4f—Detailed Road-Octane-Number Results

Fuel No.:	66	67	68	69	70	71	72	73	74
Laboratory Octane Numbers									
ASTM D 908, Research Method	103.8	104.9	104.8	104.6	106.5	106.0	103.8	108.6	107.4
ASTM D 357, Motor Method	92.5	96.4	95.5	93.6	97.1	95.8	92.6	99.5	96.5
Sensitivity	11.3	8.5	9.3	11.0	9.4	10.2	11.2	9.1	10.9
Road Octane Numbers									
Four-Car Average									
Modified Borderline:									
2,000 rpm	103.6	105.5	105.6	104.5	107.0	106.2	103.8	107.9	107.2
2,500 rpm	103.1	105.3	104.9	103.9	106.9	105.1	102.9	107.2	106.7
3,000 rpm	102.7	105.6	104.5	103.3	107.1	104.9	102.1	107.2	107.2
3,500 rpm	101.3	104.6	103.3	101.8	106.2	103.5	101.2	105.9	105.6
Modified Uniontown	103.1	105.3	104.6	103.6	106.5	104.9	102.9	107.1	106.9
11:1 CR, Car G									
Modified Borderline:									
1,500 rpm	104.8	105.0	107.4	107.2	107.2	106.8	105.1	108.7	108.1
2,000 rpm	104.8	105.5	106.6	105.8	106.8	106.6	104.3	108.5	107.3
2,500 rpm	104.2	106.0	106.4	105.5	107.2	106.0	103.1	107.9	107.5
3,000 rpm	102.7	106.3	105.0	104.2	107.2	104.7	100.9	107.3	107.0
3,500 rpm	101.3	105.6	103.7	102.5	107.4	103.2	100.1	107.4	105.9
Modified Uniontown	104.0	105.8	105.7	105.2	106.9	105.1	102.9	107.8	107.3
Knocking speed, rpm	3,000	1,500	3,000	3,000	3,000	3,000	3,000	3,000	3,000
11:1 CR, Car S									
Modified Borderline:									
2,000 rpm	103.9	106.3	105.7	104.6	108.3	105.8	104.4	107.9	108.1
2,500 rpm	102.5	104.9	104.3	103.4	106.7	104.3	102.9	106.2	106.2
3,000 rpm	101.8	104.1	103.3	102.2	105.7	103.3	101.7	105.0	105.1
3,500 rpm	100.9	104.4	102.2	101.4	106.0	102.8	101.2	103.8	104.8
Modified Uniontown	103.3	105.6	104.5	103.7	107.0	104.9	103.5	106.4	106.8
Knocking speed, rpm	2,500	3,000	3,500	3,000	3,000	3,000	3,000	3,500	3,000
12:1 CR, Car L									
Modified Borderline:									
2,000 rpm	103.3	105.9	105.0	103.5	106.2	106.7	103.4	107.4	106.4
2,500 rpm	103.9	107.5	105.5	104.2	108.8	106.2	103.5	108.4	107.3
3,000 rpm	105.1	108.9	106.6	105.5	111.2	108.2	104.1	110.6	111.7
3,500 rpm	102.6	106.0	104.8	102.7	107.6	105.4	102.7	106.5	107.2
Modified Uniontown	103.5	106.0	105.0	103.5	106.5	106.4	103.2	107.5	106.9
Knocking speed, rpm	2,000	2,000	2,000	2,000	2,000	2,000, 3,500	2,000	2,500, 3,500	2,000, 3,500
12:1 CR, Car D									
Modified Borderline:									
2,000 rpm	102.3	104.2	105.2	104.0	106.8	105.9	103.0	107.7	107.1
2,500 rpm	101.7	103.0	103.5	102.4	104.8	103.9	102.0	106.5	105.7
3,000 rpm	101.2	103.2	103.2	101.5	104.2	103.3	101.6	106.0	105.2
3,500 rpm	100.6	102.6	102.4	100.7	103.8	102.6	100.7	105.9	104.6
4,000 rpm	100.4	102.6	101.8	100.8	103.5	102.2	100.8	104.6	104.4
Modified Uniontown	101.6	104.0	103.1	102.1	105.8	103.3	101.9	106.8	106.7
Knocking speed, rpm	4,000	2,000, 2,500	4,000	4,000	2,000	4,000	4,000	2,000, 2,500, 4,000	2,500

TABLE 5a—Calculated Blending Values

Blend No.	Blending Component: Component	Blending Component: Per Cent by Volume	Base Fuel: Component	Base Fuel: Per Cent by Volume	Calculated Blending Value: Research Octane	Calculated Blending Value: Motor Octane	Calculated Blending Value: Modified Uniontown
3	Light catalytically cracked A	50	C_5+ reformate A	50	101	88	101
5	Light catalytically cracked A	50	C_5+ reformate B	50	101	88	101
7	Light catalytically cracked A	50	C_5+ reformate C	50	98	86	96
9	Light catalytically cracked A	50	C_5+ reformate E	50	100	86	98
11	Light catalytically cracked A	50	C_7+ reformate A	50	98	88	98
13	Light catalytically cracked A	50	C_7+ reformate B	50	97	85	96
15	Light catalytically cracked A	50	Thermally cracked reformate A	50	99	87	97
17	Light catalytically cracked A	50	Thermally cracked reformate B	50	100	87	98
19	Light catalytically cracked A	50	Extract A	50	98	85	96
21	Light catalytically cracked A	50	Extract B	50	99	87	97
23	Light catalytically cracked B	50	Extract B	50	100	87	98
25	Full-range catalytically cracked A	50	Extract B	50	99	88	98
56	Light catalytically cracked C	13.5	C_5+ reformate E Alkylate A	56 30.5	105	92	101
64	Light catalytically cracked C	13.5	C_5+ reformate F Alkylate A	56 30.5	101	88	98
72	Light catalytically cracked C	37.5	Extract A	62.5	100	87	99
27	Alkylate A	30	Light catalytically cracked A	70	105	98	105
28	Alkylate A	30	Extract B	70	104	102	105
29	Alkylate A	30	Light catalytically cracked A Extract B	35 35	104	100	107

TABLE 5b—Calculated Blending Values

Blend No.	Blending Component: Component	Blending Component: Per Cent by Volume	Base Fuel: Component	Base Fuel: Per Cent by Volume	Calculated Blending Value: Research Octane	Calculated Blending Value: Motor Octane	Calculated Blending Value: Modified Uniontown
44	Alkylate A	15.5	Full-range catalytically cracked B	84.5	103	97	101
45	Alkylate A	30.5	Full-range catalytically cracked B	69.5	103	97	103
48	Alkylate A	45.5	Full-range catalytically cracked B	54.5	104	99	104
50	Alkylate A	15	C_5+ reformate D	85	98	99	102
51	Alkylate A	30	C_5+ reformate D	70	101	103	106
53	Alkylate A	45	C_5+ reformate D	55	101	104	106
55	Alkylate A	30	C_5+ reformate E	70	103	102	108
59	Alkylate A	15	C_5+ reformate F	85	105	101	111
60	Alkylate A	30	C_5+ reformate F	70	105	104	108
63	Alkylate A	45	C_5+ reformate F	55	104	104	108
68	Alkylate A	29.5	C_7+ reformate B Light catalytically cracked C	47.5 23.0	106	102	108
30	Alkylate B	30	Light catalytically cracked A Extract B	35 35	105	101	105
31	Alkylate C	30	Light catalytically cracked A Extract B	35 35	106	100	106

TABLE 5c—Calculated Blending Values

Blend No.	Blending Component: Component	Blending Component: Per Cent by Volume	Base Fuel: Component	Base Fuel: Per Cent by Volume	Calculated Blending Value: Research Octane	Calculated Blending Value: Motor Octane	Calculated Blending Value: Modified Uniontown
32	Isomerate A	20	Light catalytically cracked A Extract B	40 40	95	93	100
33	Isomerate A	30	Extract B	70	94	94	100
38	Isomerate A	30	C_7+ reformate B	70	95	89	99
34	Isomerate B	20	Light catalytically cracked A Extract B	40 40	97	93	104
35	Isomerate B	30	Extract B	70	96	95	100
36	Isomerate C	20	Light catalytically cracked A Extract B	40 40	97	91	104
37	Isomerate C	30	Extract B	70	93	93	99
66	Light catalytically cracked C	37.5	C_7+ reformate B	62.5	99	87	101
67	*Iso*pentane	40	C_7+ reformate B	60	103	97	106

TABLE 5d—Calculated Blending Values

Blend No.	Blending Component: Component	Blending Component: Per Cent by Volume	Base Fuel: Component	Base Fuel: Per Cent by Volume	Calculated Blending Value: Research Octane	Calculated Blending Value: Motor Octane	Calculated Blending Value: Modified Uniontown
46	2,3-Dimethylbutane	30.5	Full-range catalytically cracked B	69.5	108	103	106
52	2,3-Dimethylbutane	30	C_5+ reformate D	70	108	109	117
61	2,3-Dimethylbutane	30	C_5+ reformate F	70	113	106	113
73	2,3-Dimethylbutane	39	Extract A	62	113	106	111
74	2,3-Dimethylbutane	19	Extract A	81	114	100	115
47	Mixed methylpentanes	30	Full-range catalytically cracked B	70	96	91	99
62	Mixed methylpentanes	29.5	C_5+ reformate F	70.5	96	94	101
39	*Iso*pentane	25	Light catalytically cracked A Extract B*	37.5 37.5	102	99	102
57	*Iso*pentane	14.5	C_5+ reformate E Alkylate A	55.5 30	102	112	104
65	*Iso*pentane	14.5	C_5+ reformate F Alkylate A	55.5 30	103	105	108
40	Trimer	20	Light catalytically cracked A Extract B	40 40	102	87	94
41	Trimer	20	Extract B	80	102	87	96

* Not pressurized.

APPENDIX B

ENGINE MODIFICATIONS

The compression ratio of each test car was increased by the use of special domed pistons. The ratio of each cylinder was corrected to within ±0.1 of the specified ratio by means of the following:

1. Exchanging pistons so as to locate the piston with the largest dome in the cylinder having the largest combustion chamber.
2. Milling the cylinder heads.
3. Installing new valves in some cylinders, and refacing and reseating the valves in other cylinders.
4. Enlarging the volume of the combustion chamber through light grinding.
5. Decreasing the volume of the piston dome by milling.
6. Selecting head gaskets to obtain the desired thickness.

Several modifications of the engines were made because of the severe operating conditions used in knock rating. Long slipper-type pistons with 0.003- to 0.004-in. clearance were designed for quiet, trouble-free operation.

Heavy-duty coils, dual-point distributor plates, and special extended-electrode spark plugs were used to provide additional ignition reserve. New secondary ignition harnesses were fabricated to hold the spark-plug wires apart in order to reduce inductive losses and avert cross firing.

Aluminum and copper-lead rod-insert bearings were used because of their high load-carrying capacity. The oil was changed each 500 miles and filters were changed at 1,000-mile intervals as a precautionary measure.

APPENDIX C

ROAD RATING TECHNIQUES

All of the road octane ratings were obtained by the Modified Borderline technique to enable an evaluation of the fuel blends throughout the speed range. The ratings were obtained under trace-knock conditions on the Petroleum Laboratory chassis dynamometer set for level-road operation, with the temperature controlled to 70 F.

In the development of Modified Borderline data, trace knock was obtained at a particular rating speed by manually varying the spark timing as the test car was accelerated. The throttle was depressed to as near wide-open as possible without causing the transmission to shift to a lower gear. The octane number of a fuel at a given speed was obtained by comparing its knock-limited spark advance with spark advances obtained on reference fuels at that particular speed. In this manner, octane numbers were obtained over the speed range.

Rating accelerations were made at minimum vacuum and in the highest gear in all cars except the 11:1-CR car G, which was accelerated at wide-open throttle in third gear to hold the car to a reasonable speed at 3,500 engine rpm. When the desired rating speed was reached, the rater quickly advanced the spark, calling out the timing at which trace knock was first encountered. This procedure was repeated for each succeeding rating speed. Care was taken never to get into knock too deeply, especially before the lowest speed rating, as this was found to depreciate the fuels greatly. Also, special care was taken to hold the spark slightly retarded from knock during acceleration at the higher speeds in cars D and L because many of the fuel blends required less spark advance for knock at higher speeds than they did at intermediate speeds. The fuel ratings were obtained in all cars to 3,500 rpm, and in one car to 4,000 rpm.

From three to eight accelerations were made for each single fuel rating. Each fuel was rated by at least three raters. Whenever the spread exceeded two octane numbers at any speed, additional ratings were made. A day-to-day check on the car's fuel-rating characteristics was made by use of a check fuel which was run during each testing period.

The cans containing the fuel blends were inserted into a pan of ice water, prior to and during the rating of the fuel, to prevent loss of light ends.

APPENDIX D

DERIVATION OF MODIFIED UNIONTOWN RATINGS

Modified Uniontown Technique

Modified Uniontown octane numbers are obtained by comparing test- and reference-fuel basic spark settings for trace knock, regardless of the speed at which the knock occurs.

In the Modified Uniontown road octane technique, the basic spark setting, as measured when the engine is idling, is adjusted until trace knock occurs during some portion of a wide-open-throttle acceleration. No spark adjustments are made during the acceleration, and the spark advance attributable to engine speed is controlled by the distributor. Thus distributor spark-advance characteristics are a significant factor in the Modified Uniontown determination, and are required in order to derive Modified Uniontown ratings from Modified Borderline ratings. The specification of a distributor spark-advance curve is, therefore, required.

"Specified" Spark Advance

The shape of the distributor curve for each car was set to approximate the average of the knock-limited spark-advance curves for all the fuel blends rated in that car. Horsepower data were developed on a chassis dynamometer, and the average knock-limited spark-advance curve was then displaced until it fell near the one-per-cent power-loss curve at some point in the speed range. Somewhat greater power losses were obtained at other speeds, as listed in the following:

Test Car	Per Cent of Power Loss: 1,500 Rpm	2,000 Rpm	2,500 Rpm	3,000 Rpm	3,500 Rpm	4,000 Rpm
11:1 car G	5.5	4.5	2.5	1.5	1.5	..
11:1 car S	..	3.0	2.5	1.5	1.0	..
12:1 car L	..	5.0	1.5	1.0	2.0	..
12:1 car D	..	3.0	2.0	1.5	2.0	2.5

In this manner, both the shape and advance of the car's wide-open-throttle distributor curve were defined. This curve will be referred to as the "specified" spark-advance curve.

Derivation of Modified Uniontown Ratings from Modified Borderline Data

In order to derive Modified Uniontown ratings from the Modified Borderline results in this program, the knock-limited spark advance at each speed was compared to the "specified" spark advance. For example, spark-advance data obtained by a rater in the 11:1-CR car S are compared with "specified" spark advances for this car, as follows:

Fuel	Spark Advance for Trace Knock (From Modified Borderline Tests) (Degrees): 2,000 Rpm	2,500 Rpm	3,000 Rpm	3,500 Rpm
102 Reference fuel	20	27	33	37
104 Reference fuel	24	31	36	39
Test fuel	27	29	32	34
"Specified" Spark Advance	18.5	22	25.5	29

Comparison of the spark positions for trace knock of 102 reference fuel at each speed with the "specified" spark advances shows that the least advance above "specified" occurs at 2,000 rpm and is 1.5 deg. By operating at "specified" plus 1.5 deg, 102 reference fuel would knock at 2,000 rpm. In the same manner, it is determined that the test fuel will knock at 3,500 rpm with a spark advance of "specified" plus 5 deg, and the

104 reference fuel will knock at 2,000 rpm with a spark advance of "specified" plus 5.5 deg. By interpolation, the test fuel would have a Modified Uniontown octane number of 103.7.

In the above manner, Modified Uniontown octane numbers were derived from the results of each individual set of Modified Borderline determinations. To determine the accuracy of the derived data, Modified Uniontown ratings were obtained experimentally on some of the fuel blends. The derived and experimental data checked well within the accuracy of the Modified Uniontown test method.

APPENDIX E

RELATIONSHIPS BETWEEN ROAD OCTANE NUMBERS, LABORATORY OCTANE NUMBERS, AND HYDROCARBON TYPE

Because sensitivity (Research minus Motor) is related to hydrocarbon type, specifying hydrocarbon type along with one of the laboratory octane numbers is approximately, but not exactly, the same as specifying the other laboratory octane number. These interrelationships complicate the problem of correlating road octane numbers with laboratory data.

In this program the UNIVAC electronic computer indicated that high-speed road octane numbers were related to the quantity:

$$0.5 \text{ Research} + 0.5 \text{ Motor} - 0.1 \text{ (per cent of olefins)} \quad (1)$$

Comparison of hydrocarbon-type data with sensitivity indicated that the following approximation can be made:

$$\text{Sensitivity} = \frac{\text{per cent of olefins} + 0.5 \text{ (per cent of aromatics)}}{5} \quad (2)$$

Rearranging (2):

$$\text{Per cent of olefins} = 5 \text{ (sensitivity)} - 0.5 \text{ (per cent of aromatics)} \quad (3)$$

Substituting (3) in (1):

$$0.5 \text{ Research} + 0.5 \text{ Motor} - 0.5 \text{ (sensitivity)} + 0.05 \text{ (per cent of aromatics)} \quad (4)$$

Rearranging (4):

$$0.5 \text{ Research} + 0.5 \text{ Motor} - 0.5 \text{ Research} + 0.5 \text{ Motor} + 0.05 \text{ (per cent of aromatics)} \quad (5)$$

Rearranging again, the quantity:

$$\text{Motor} + 0.05 \text{ (per cent of aromatics)} \quad (6)$$

is obtained. This is an expression related to high-speed road octane number, and is an approximation of the quantity (1). The relationship of (6) with high-speed road octane number appears to be about as close as the relationship of (1) with high-speed road octane number, and both are closer than the use of Motor octane number alone. Thus high-speed road octane number can be predicted equally well from a combination of Research and Motor octane number with a debit for olefins, or from Motor octane number alone with a credit for aromatics.